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Review of Efficacy Tests for Chlorination of Irrigation Systems

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Water treatment technologies are used in irrigation systems to control biological problems including algae, biofilm clogging of irrigation lines and pathogens. Chlorination is an important treatment option with low installation and operating costs. However, growers face the challenge of identifying the proper chlorine dose for the control of their specific target problem without resulting in phytotoxicity of crop plants. The objective of this project was to summarize literature on chlorine efficacy to control plant pathogens. The compilation of data included mortality efficacy data of 11 genera of plant pathogens (22 species). The efficacy of chlorine varied with pathogen species and life stage. The dose required to achieve 90% mortality ranged from 0.1 (*Erwinia carotovora*) to 50,000 mg·L^{-1} (*Melodoigyne javanica*) with a range in contact times from 0.25 min to 24 h. Given the high dose required to control certain pathogens, chlorination should be viewed as only one component of an overall sanitation and integrated pest management approach. This database can be used by growers as a reference guide for whether chlorine is likely to be an effective control for the target pathogen of interest.

Irrigation water is a source and distribution mechanism for plant pathogens (Rotem and Palti, 1969), which is a major concern for growers especially when using recycled and surface waters (Lane, 2004). The pathogens identified in irrigation water include 16 species of *Phytophthora*, 28 species of *Pythium*, 27 genera of true fungi, 10 species of bacteria, 10 viruses, and 13 genera of nematodes (Hong and Moorman, 2005).

In Florida, intensive use of the aquifers and low levels of rainfall have encouraged water districts to recommend that growers use recycled irrigation water, stormwater runoff, reclaimed municipal sewage water, and lakes for agricultural use (Norman et al., 2003). In addition, the Florida Department of Environmental Protection (FDEP) agency appointed by the Florida Water Restoration Act (FWRA) developed and applied the Total Maximum Daily Loads (TMDL) for impaired waters of the state (Boman and Obreza, 2010). These local regulations to control irrigation runoff to natural resources and the resulting increased risk of crop loss due to plant disease incidence have prompted growers toward the use of water treatment technologies for irrigation in their operations.

Several chemical, physical and biological alternatives are available for growers to treat irrigation water. Among the available chemical alternatives are chlorine, chlorine dioxide, bromine, chlorobromine, iodine, ozone, hydrogen peroxide, surfactants, acidic electrolyzed oxidizing water, ionization, peroxyacetic acid, CO_2, and fungicides (Stewart-Wade, 2010). Of the technologies mentioned above, chlorine is the most commonly used by nursery growers (Lane, 2004).

Nursery growers who recycle water identified the need for guidelines for water disinfestation with different treatment technologies as a top research priority (Lane, 2004). Reviews articles have consolidated information regarding pathogens in the irrigation water and water treatment technologies (Ehret et al., 2001; Hong and Moorman, 2005; Lane, 2004; Runia, 1995; Stewart-Wade, 2010; van Os, 2009). However, a grower-oriented summary of research on treatment efficacy has not been developed. The objective of this project was to carry out a literature review of the published efficacy studies on chlorination for control of plant pathogens in the water and organize them into a searchable database that is hosted at the Water Education Alliance for Horticulture website (www.watereducationalliance.org).

Efficacy of Chlorine

The concentration of hypochlorous acid (HOCl), which is the main disinfestant form of dissolved chlorine in solution, is highly dependent on pH (increasing as solution pH decreases), organic matter contaminants such as peat, and chemical contaminants such as ammonium fertilizer (Fisher et al., 2008; Huang et al., 2011). Irrigation water pH and contaminants reduce the active ingredient concentration available for pathogen control (Lang et al., 2008; Robbs et al., 1995). Secondary compounds such as chloramines, which result from reaction with ammonium, can also be phytotoxic to crop plants (Date et al., 2005). Water quality therefore has a large impact on the chlorine injection rate required to achieve a target residual concentration of hypochlorous acid.

The genotype and growth stage of the pathogen affect the contact time and dose required to control pathogens (Table 1). More than 2.5 mg·L^{-1} (ppm) was required to achieve high mortality (≥90%) of *Agrobacterium* (Poncet et al., 2001), cucumber leaf

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Table 1. Summary of published efficacy tests for chlorine as a control for waterborne pathogens.[z]

Target organism species (and life stage)	Effective dose (>90% control)	Practical implications	Citation
Agrobacterium tumefaciens	Very high dose. 4 ppm for 30 min	4 ppm of chlorine for 30 min was required to control *Agrobacterium tumefaciens.* This dose applied to irrigation water for rose culture (cultivar Anna) did not cause visual phytotoxicity symptoms.	Poncet et al. (2001)
Cucumber leaf spot virus (CLSV)	Very high dose. 4 ppm for 30 min	4 ppm completely controlled the virus inoculum in irrigation recycled water. Lower doses (3 ppm) had no effect on virus viability.	Rosner et al. (2006)
Erwinia carotovora f. *zeae*	0.1 ppm for 1 min	0.1 ppm residual chlorine at the spray emitter of the irrigation system resulted in complete mortality of *Erwinia carotovora* f. *zeae*	Thompson (1965)
Erwinia carotovora subsp. *carotovora*	0.5 ppm at pH 6.0 for 2 min or 0.75 ppm at pH 8.0 for 2 min	Lower doses of chlorine controlled *E. carotovora* at pH 6 compared with pH 8. At a given chlorine dose, the higher the pH the lower the mortality.	Robbs et al. (1995)
Fusarium oxysporum (conidia)	Very high dose. 8.0 ppm for 1.5 min or 10.0 ppm for 0.5 min	A very high dose of chlorine (8–10 ppm) was required to obtain high mortality of *F. oxysporum* in water. Doses as low as 4 ppm of chlorine for 0.5 min resulted in a mortality ≥50%.	Cayanan et al. (2009)
Geotrichum candidum (conidia)	Very high dose. 25 ppm at pH 6.0 for 2 min	Very high doses of chlorine (likely to cause phytotoxicity to crop plants) were required to achieve mortality of *Geotrichum candidum*, causal agent of sour rot.	Robbs et al. (1995)
Meloidogyne javanica (eggs)	Very high dose. 5% (50,000 ppm) for 5 min	The dose required (5%) to effectively prevent egg hatching of root knot juvenile nematodes was extremely high and was not recommended for grower use.	Stanton and O'Donnell (1994)
Meloidogyne javanica (juveniles)	Very high dose. 200 ppm for 24 h (mortality)	Very high dose was required to kill juvenile nematodes (200 ppm for 24 h) and was not recommended for grower use. However, a dose of 2 ppm for 24 h reduced the motility of juveniles. In addition, pre-plant irrigation of soil with 4 ppm for 4 weeks reduced the amount of root galls observed in tomato plants by >90%.	Stanton and O'Donnell (1994)
Phytophthora cactorum (zoospores)	0.3 ppm for 0.5 min	At any dose ≥0.3 ppm for ≥1.5 min resulted in 100% mortality.	Cayanan et al. (2009)
Phytophthora capsici (zoospores)	2 ppm for 10 min	2 ppm of chlorine reduced the motility of zoospores after 3 min and caused 100% mortality after 10 min	Granke and Hausbeck (2010)
Phytophthora capsici (zoospores)	2 ppm for 10 min	≥2 ppm of chlorine applied to *P. capsici* recovered from pond water resulted in 100% mortality	Roberts and Muchovej (2008)
Phytophthora capsici (zoospores)	1 ppm for 2 min	1 ppm resulted in ≥90% mortality, whereas 2 ppm of chlorine consistently resulted in 100% mortality of *P. capsici*	Hong et al. (2003)
Phytophthora infestans (sporangia)	0.3 ppm for 3 min or 0.4 ppm for 1.5 min. 100% mortality at ≥1 ppm at ≥0.5 min.	Sporangia mortality was ≥90% at 0.3 and 0.4 ppm. 100% of mortality was consistently achieved at chlorine applications ≥1 ppm for ≥0.5 min.	Cayanan et al. (2009)
Phytophthora nicotianae (mycelia)	2 ppm for 8 min or 4 ppm (very high dose) for 0.5 min	High mortality rates of mycelia required more time or higher chlorine concentration compared with zoospores.	Hong et al. (2003)
Phytophthora nicotianae (sporangium)	Very high dose. 4 ppm for 8 min or 8 ppm for 0.5 min	Sporangia were more resistant to chlorination compared w/zoospores and mycelia. Sporangia required higher chlorine rates of 4–8 ppm. 2 ppm of chlorine for ≥1 min resulted in sporangial mortality ≥60%.	Hong et al. (2003)
Phytophthora nicotianae (zoospores)	2 ppm for 0.25 min	2 ppm of of residual chlorine at sprinklers or risers provided control in irrigation water.	Hong et al. (2003)
Phytophthora spp.	N/A	Survival and yields (kg/m^2) of cherry tomato plants inoculated with *Phytophthora* and 3 isolates of *Pythium* were higher on plants that were irrigated with 5 ppm of chlorine than without chlorine.	Berenguer et al. (2001)
Phytophthora	0.1–3.5 ppm fluctuating over year, avg 0.6 ppm	A 2-year research project in a nursery measured an avg of 0.6 ppm of chlorine at the irrigation riser, which resulted in an avg ≥90% mortality compared with an untreated irrigation line.	Bush et al. (2003)
Phytophthora spp.	N/A	Survival and yields of cherry tomato plants inoculated with *Phytophthora* and 3 isolates of *Pythium* were higher on plants that were irrigated with 5 ppm of chlorine than without chlorine.	Berenguer et al. (2001)

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Table 1. Continued.

Target organism species (and life stage)	Effective dose (>90% control)	Practical implications	Citation
Phytopthora cinnamomi (zoosphores)	0.5 ppm for 2 min	0.5 ppm of chlorine for 2 min resulted in ≥90% mortality. Nonetheless, 100% mortality was consistently observed at ≥2 ppm.	Hong et al. (2003)
Phytopthora citricola P. citrophora, and *P. cryptogea* (zoospores)	0.25 ppm for 2 min	0.25 ppm of chlorine for 2 min resulted in ≥90% mortality. 100% mortality was consistently observed at 1 ppm or above.	Hong et al. (2003)
Phytopthora megasperma (zoospores)	1 ppm for 2 min	1 ppm of chlorine was sufficient to kill 100% of of *P. megasperma*	Hong et al. (2003)
Plasmodiophora brassicae		None of the doses (0.2, 2.0, 20, 200 ppm) evaluated resulted in 90% of mortality of spores. Mortality ranged from 5% to 56%, respectively. However, club root on cabbage incidence was of 80% for plants treated with 0.2 ppm of chlorine and 0% for all the other doses. Spore concentration was lower in suspensions exposed to ≥2 ppm of chlorine. Despite not having high mortality rates, the incidence of club root was reduced from 95% to 0% in cabbage plants treated with ≥2 ppm of chlorine.	Datnoff et al. (1987)
Pythium aphanidermatum (zoospores)	0.5 ppm at pH 6.3 for 0.25 min, 764 mV ORP	Chlorine doses ≥0.5 ppm resulted in mortality >90% when the pH was adjusted ≈6, with an ORP level of 764 mV. A given chlorine dose was less effective as pH increased, and ORP decreased.	Lang et al. (2008)
Pythium aphanidermatum	1 ppm for 3 min or 2 ppm for 1.5 min	At any dose ≥0.3 ppm for ≥3 min	Cayanan et al. (2009)
Pythium dissotocum (zoospores)	0.5 ppm at pH 6.3 for 4 min, 766 mV ORP or 2 ppm at pH 7.0 for 0.25 min, 790 mV ORP	Chlorine concentrations ≥ 0.5 ppm resulted in mortality >90% when the pH was adjusted ≈6, with an ORP level of 766 mV. A given dose concentration was less effective as pH increased, and ORP decreased.	Lang et al. (2008)
Pythium spp.	N/A	Survival and yields (kg/m^2) of cherry tomato plants inoculated with *Phytophthora* and 3 isolates of *Pythium* were higher on plants that were irrigated with 5 ppm of chlorine than without chlorine.	Berenguer et al. (2001)
Pythium spp.	2 ppm for 2 min	11 of 15 isolates did not survive at 2 ppm and those that survived were at very low levels. Doses ≤ 1 ppm resulted in low mortality (did not provide consistent control).	Hong and Richardson (2004)
Pythium spp.	2 ppm	Diverse *Pythium* sp. were controlled in water by using a free chlorine dose ≥2 ppm. Any dose <2 ppm represented a risk of survival by several isolates.	Kong et al. (2004)
Pythium spp.	2 ppm for 10 min	100% mortality of *Pythium* sp. recovered from pond water with chlorine treatments of 2 ppm or higher.	Roberts and Muchovej (2008)
Rhizoctonia solani (mycelia)	Very high dose. 10 ppm for 10 min	A very high dose of chlorine (10 ppm, likely to be phytotoxic) was required to obtain high mortality of *Rhizoctonia solani* in water. Rates as low as 4 ppm of chlorine for 0.5 min resulted in a mortality ≥50%.	Cayanan et al. (2009)
Xanthomonas campestris	2 ppm for 10 min	2 ppm of chlorine resulted in 100% mortality of *X. campestris* recovered from pond water.	Roberts and Muchovej (2008)

[z]This table summarizes published research that tested control of plant pathogens using chlorine and is not intended as a recommended dosage rate.

spot virus (Rosner et al., 2006), *Fusarium oxysporum* (Cayanan et al., 2009b), *Geotrichum candidum* (Robbs et al., 1995), *Meloidogyne javanica* (Stanton and O'Donnell, 1994), *Plasmodiophora brassicae* (Datnoff et al., 1987), and *Rhizoctonia solani* mycelia (Cayanan et al., 2009b). On the other hand, *Erwinia* spp. (Robbs et al., 1995; Thompson, 1965) and zoospores of *Phytophthora* spp. and *Pythium* spp. (Berenguer et al., 2001; Cayanan et al., 2009a, 2009b; Granke and Hausbeck, 2010; Hong and Richardson, 2004; Hong et al., 2003; Lang et al., 2008; Roberts and Muchovej, 2009) were controlled at ≤2 mg·L^{-1} (ppm). However, control of mycelia and sporangia of *P. nicotianae* required up to 4 and 8 mg·L^{-1} (ppm), respectively, which was higher than the required dose for the zoospore life stage (Hong et al., 2003).

Phytotoxicity from chlorine varies with plant species, with 2.5 mg·L^{-1} (ppm) reported to cause phytotoxicity of certain crops (Cayanan et al., 2008, 2009; Chase and Conover, 1993; Jenkins, 1981; Schuerger and Pategas, 1984). Because phytotoxicity is likely above the 2 mg/L (ppm) of free chlorine that is required to control certain pathogens, chlorination alone is not likely to be effective. An integrated approach to disease management, including clean plant material, growing media, and containers; and use of fungicides is recommended. In general, it is recommended to test different doses on a small group of plants for phytotoxicity and efficacy before applying to the entire crop.

A prototype searchable database including the literature review in Table 1 and the information of the other technologies has been developed as an online grower tool. The database can be searched based on pathogen and water treatment technology. This tool is available on an extension website at watereducationalliance.org under the "grower tools" section.

Literature Cited

Berenguer, J.J., I. Escobar, M. García, J. Gómez, and A. Alvarez. 2001. Methods to control *Pythium* and *Phytophthora* in cold plastic houses. Acta Hort. 559:759–763.

Boman, B.J. and T.A. Obreza. 2010. Water quality issues facing Florida growers. Proc. Fla. State Hort. Soc. 123:315–321.

Cayanan, D.F., Y. Zheng, P. Zhang, and T. Graham. 2008. Sensitivity of five container-grown nursery species to chlorine in overhead irrigation water. HortScience 43:1882–1887.

Cayanan, D.F., M. Dixon, Y. Zheng, and J. Llewellyn. 2009. Response of container-grown nursery plants to chlorine used to disinfest irrigation water. HortScience 44:164–167.

Cayanan, D.F., P. Zhang, L. Weizhong, M. Dixon, and Y. Zheng. 2009. Efficacy of chlorine in controlling five common plant pathogens. HortScience 44:157–163.

Chase, Anne R. and C.A. Conover. 1993. Algae control in an ebb and flow irrigation system. Proc. Fla. State Hort. Soc. 106:280 – 282.

Date, S., S. Terabayashi, Y. Kobayashi, and Y. Fujime. 2005. Effects of chloramines concentration in nutrient solution and exposure time on plant growth in hydroponically cultured lettuce. Scientia Hort. 103:257–265.

Datnoff, L.E., T.K. Kroll, and G.H. Lacy. 1987. Efficacy of chlorine for decontaminating water infested with resting spores of *Plasmodiophora brassicae*. Plant Dis. 71:734–736.

Ehret, D.L., B. Alsanius, W. Wohanka, J.G. Menzies, and R. Utkhede. 2001. Disinfestation of recirculation nutrient solutions in greenhouse horticulture. Agronomie 21:323–339.

Fisher, P.R., J. Huang, A. Looper, D. Minsk, W.R. Argo, R. Vetanovetz, and Y. Zheng. 2008. Water sanitation using chlorine. GMPro, July:15–22.

Granke, L.L. and M.K. Hausbeck. 2010. Effects of temperature, concentration, age, and algaecides on *Phytophthora capsici* zoospore infectivity. Plant Dis. 94:54–60.

Hong, C.X. and P.A. Richardson. 2004. Efficacy of chlorine on *Pythium* species in irrigation water. SNA Res. Conf. Proc. 49:265–267.

Hong, C.X., P.A. Richardson, P. Kong, and E.A. Bush. 2003. Efficacy of chlorine on multiple species of *Phytophthora* in recycled nursery irrigation water. Plant Dis. 87:1183–1189.

Hong, C.X. and G.W. Moorman. 2005. Plant pathogens in irrigation water: Challenges and opportunities. Crit. Rev. Plant Sci. 24:189–208.

Huang, J., D.P. Meador, D.B. Decio, and P.R. Fisher. 2011. Effect of peat-based substrate and irrigation cycles on the residual activity of sodium hypochlorite. Acta Hort. 891:241–248.

Jenkins, S.F. 1981. Use of chlorine to suppress root infecting pathogens of vegetables growing in recirculating hydroponic systems. Phytopathology 71:883.

Lane, V. 2004. Audit and gap analysis of nursery waste-water research and communication. Horticultural Australia Ltd., Sydney, Australia.

Lang, J.M., B. Rebits, S.E. Newman, and N. Tisserat. 2008. Monitoring mortality of *Pythium* zoospores in chlorinated water using oxidation reduction potential. Plant Health Progr. doi:10.1094/PHP-2008-0922-01-RS.

Norman, D.J., J.M. Yuen, and J. Boswell. 2003. Characterization of *Erwinia* populations from nursery retention ponds and lakes infecting ornamental plants in Florida. Plant Dis. 87:193–196.

Poncet, C., M. Offroy, G. Bonnet, and R. Brun. 2001. Disinfection of recycling water in rose cultures. Acta Hort. 547:121–127.

Robbs , P.G., J.A. Bartz, J.K. Brecht, and S.A. Sargent. 1995. Oxidation-reduction potential of chlorine solutions and their toxicity to *Erwinia carotovora* subsp. *carotovora* and *Geotrichum candidum*. Plant Dis. 79:158– 162.

Roberts, P.D. and R.M. Muchovej. 2009. Evaluation of tailwater from vegetable fields for recovery of phytopathogens and methods to reduce contamination. Southwest Florida Water Management District.

Rosner, A., O. Lachman, M. Pearlsman, L. Feigelson, L. Maslenin, and Y. Antignus. 2006. Characterization of *Cucumber leaf spot virus* isolated from recycled irrigation water of soil-less cucumber cultures. Ann. App. Biol. 149:313– 316.

Rotem, J. and J. Palti. 1969. Irrigation and plant diseases. Annu. Rev. Phytopathol. 7:267–288.

Runia, W.T. 1995. A Review of possibilities for disinfection of recirculation water from soilless cultures. Acta Hort. 221–229.

Schuerger, A.C. and K.G. Pategas. 1984. Management of two *Pythium* spp. in hydroponic lettuce production. Phytopathology 74:796.

Stanton, J.M. and W.E. O'Donnell. 1994. Hatching, motility, and infectivity of root-knot nematode (*Meloidogyne javanica*) following exposure to sodium hypochlorite. Austral. J. Expt. Agr. 34:105–108.

Stewart-Wade, Sally M. 2010. Plant pathogens in recycled irrigation water in commercial plant nurseries and greenhouses: Their detection and management. Irr. Sci. 1–31.

Thompson, D.L. 1965. Control of bacterial stalk rot of corn by chlorination of water in sprinkler irrigation. Crop Sci. 5:369–370.

Van Os, E.A. 2009. Comparison of some chemical and non-chemical treatments to disinfect a recirculation nutrient solution. Acta Hort. 229–234.

Van Os, E.A. 2010. Disease management in soilless culture systems. Acta Hort. 385–394.