Disinfecting Irrigation Water for Disease Management

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Introduction:

High quality water for agricultural use is becoming limited. Runoff and irrigation return flow from containerized nursery and greenhouse facilities may contain nitrogen, phosphorus, pathogens, certain pesticides, various salts, and trace metals (Alexander, 1993). This has stimulated many studies on water and nutrient management. Traditional greenhouse irrigation practices recommend watering to 10% excess, with application scheduled just prior to incipient wilting (Nelson, 2003). These practices prevent the build-up of soluble salts in the medium, guarantees complete wetting of the root-zone, and ensure that water stress occurs during each water cycle. However, these practices also produce to a sizeable volume of wastewater, particularly when overhead or sprinkler irrigation is used or if timing devices are not well maintained. The use of trickle tube irrigation can significantly reduce the volume of irrigation water consumed in a greenhouse; however, leaching levels of 30 to 50% have been measured in controlled studies designed to duplicate commercial practices (George et al., 1990).

Closed and subirrigation systems are widely used by European greenhouses to comply with government imposed regulations to limit environmental contamination from pesticides and fertilizers from greenhouses (Molitor, 1990). Ebb and flood irrigation, where pots are placed on watertight benches and periodically flooded and drained with nutrient solution (Dole, 1994; Dole et al., 1994; Nelson 2003), is one subirrigation system that is being adapted by U.S. growers to reduce fertilizer and water waste. Yet, this is not new to floriculture. Post (1949) illustrated several sub-irrigation strategies that were easily adapted to greenhouse culture. Closed recirculated irrigation systems can reduce the consumption of water by about 30% and fertilizer consumption by more than 50% (Vernooij, 1992).

Plant disease can potentially be introduced through irrigation water. This risk is even greater when the water is recirculated.. *Pythium dissotocum* and *P. rostratum* have been detected in irrigation water from holding ponds in Colorado (Pottorff and Panter, 1997). *Pythium* and *Olpidium brassicae*, the fungal vector of Lettuce Big Vein Virus and Lettuce Ring Necrosis Disease, both limit the development of recirculated nutrient film (NFT) production of lettuce (Vanachter, 1995). Fungicides are often considered to be the first line of defense and often applied to the substrate, but not the irrigation water. Irrigation systems are often used to apply fungicides, but this use of fungicides is in violation of most labels. Irrigation water contaminated with a fungicide is also a hazardous waste and with fresh "make-up" water, the fungicide will become diluted, possibly encouraging the development of pesticide resistant strains. Therefore alternative disease control

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strategies or integrated pest management (IPM) should be employed when using recirculated irrigation water.

Of nursery and floriculture enterprises surveyed in 2000, only 19% reported using beneficial organisms in an IPM program and only 52% reported that they deliberately scouted for pests on a scheduled basis (NASS, 2002). These practices led to a total of 5.36 million pounds of active ingredients applied to nursery and floriculture crops in California, Florida, Michigan, Oregon, Pennsylvania, and Texas alone for the year 2000 (NASS, 2002). Of that total, 39% or 2.1 million pounds of active ingredient were applied to floriculture crops. Recognizing that these six states represent 55% of the national reported value of the nursery and floriculture industry (NASS 2003), one can project on a national scale, 9.75 million pounds of active ingredients, are applied to floriculture and nursery crops annually. Of that total, 3.8 million pounds of active ingredient were applied to floriculture crops. Approximately 40% of Colorado greenhouse growers have adopted some form of IPM strategies (Pottorff, 2003). These growers are documented to use IPM practices such as resistant cultivars, pot spacing, relative humidity control strategies, sanitation or removal of debris, soil testing, alternative plant location and dates to reduce pest pressure, water management, and chemical rotations.

Many growers in The Netherlands using recirculated irrigation water employ several water disinfection methods to prevent the spread of soil borne disease organisms, including UV-C radiation, ozone, chlorination and iodination, heat treatment, membrane or slow sand filtration, and activated hydrogen peroxide (Runia, 1995). Low pressure UV-C radiation has been demonstrated disinfest contaminated irrigation water adequately for lettuce production (Vanachter, 1995); however, UV-C radiation efficacy is dose specific (Runia, 1994a). Slow sand filtration has been demonstrated to reduce Fusarium infection (Wohanka, 1995) and Pelargonium Flower Break Virus of geraniums (Berkelmann et al., 1995). Ozonation has been demonstrated to be effective in reducing Cucumber Mosaic Virus, but *Verticillium sclerotia* were resistant (Runia, 1994b).

Ultraviolet Radiation of Irrigation Water

Ultraviolet (UV) light is electromagnetic radiation with wavelengths between 200 and 700 nm. Visible light is from about 400 to 700 nm. UV-radiation is further subdivided into three wave length bands. UV-A is between 315 and 400 nm and generates photochemical smog as well as responsible for fading and damage to plastics, paints and fabrics . UV-B is between 290 and 315 nm and is about 1% of solar radiation. UV-B is responsible for detrimental health effects to animals and plants. UV-C is between 220 to 290 nm and is absorbed by ozone in the atmosphere.

UV disinfection water systems use UV-C radiation at 254 nm. Microorganisms absorb most of the energy at this wavelength resulting in a germicidal effect. The photochemical reaction alters essential molecular components (DNA and RNA). This process essentially eliminates most fungi, bacteria and viruses. Disinfection is dependent on duration and intensity. UV-C radiation intensity, or dose for recycled greenhouse irrigation water is typically 100 mJ/cm^2 (100,000 µwatt-sec/cm^2) selective disinfection or 250 mJ/cm^2 (250,000 µwatt-sec/cm^2) for total disinfection eliminating most plant pathogens and viruses. Virucidal activity has been reported for prawn aquaculture using UV-C radiation at 90 mJ/cm^2 for 60 minutes (Chang, et al., 1998), but no bactericidal activity for greenhouse rose recycled irrigation water at 71.44 mJ/cm^2 with several passes across the lamp (Poncet et al., 2001). The United States Department of Health and Human Services has established a minimum exposure of 16,000 µwatt-sec/cm^2 (16 mJ/cm^2) for UV disinfectant systems used for drinking water, whereas, UV water sterilization systems designed for greenhouse irrigation water are designed for exposures from 80-250 mJ/cm^2 (Fig. 1). This is primarily in relationship to the clarity of the recycled water, which is typically about 25%.

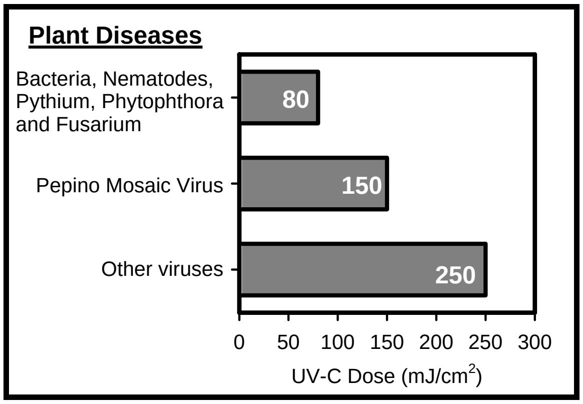

Fig. 1. UV-C dose for controlling plant diseases assuming 25% water clarity as specified for the Priva® Vialux water disinfection system.

UV-C radiation efficiency is affected by water clarity and is absorbed or reflected off any material in water such as peat moss and plant debris. This makes filtration important prior to water treatment by the UV-C unit (Fig. 2). Particles suspended in the water increase turbidity, which reduces the disinfection properties of the lamp. In addition, films and mineral scale may result on lamp reducing its efficacy. As a result, many UV water treatment systems use some form of automatic wiping unit to keep the quartz lamp housing clean. Some systems also incorporate a water softener or phosphate injection to prevent mineral deposits on the lamp.

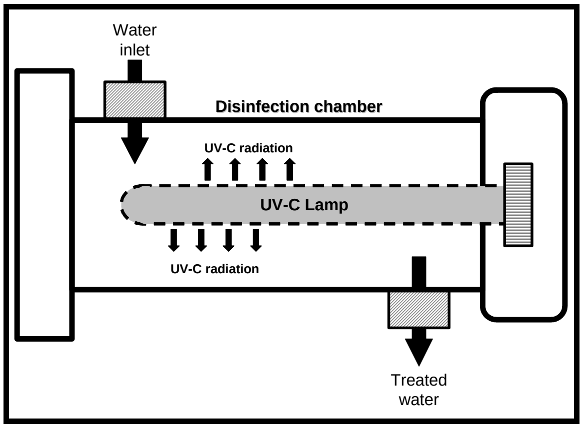

Fig. 2. Cross sectional diagram of typical UV disinfection lamp and housing.

UV-C radiation water treatment is an effective choice for irrigation water treatment in a greenhouse to eliminate plant pathogen, however, since it does not add any chemicals to the water, there is no residual disinfection. Therefore, steps must be made to keep the water clean or to add additional disinfectant chemistry.

Heat Pasteurization of Irrigation Water

Heat pasteurization in the greenhouse has been used for quite some time. Heat pasteurization of root zone substrates is a common practice, but not so for irrigation water. Yet in The Netherlands, heat pasteurization is the most common water treatment system. Typical recommendations for heat pasteurization of irrigation water requires that the water or nutrient solution pass through a heat exchanger and heated to 203/F (95/C) for 30 seconds, yet viruses can be inactivated at 131/F (55/C) and 158/F (70/C) for 90 and 5 minutes, respectively (Chang, et al., 1998). Poncet et al. (2001) reported a total elimination of *Agrobacterium tumefaciens* from recycled irrigation water for cut roses heated to 203/F (95/C) for 30 seconds.

Often a heat exchanger linked to the greenhouse boiler is used for pasteurization of irrigation water. The solution pH is recommended to be reduced to 4.5 to prevent calcium precipitation on the heat exchange plates, which are typically stainless steel or titanium alloys.

Heat pasteurization of irrigation water is an effective choice to eliminate plant pathogens, but as with UV-C radiation, it does not add any chemicals to the water with no residual disinfection. Therefore, steps must be made to keep the water clean or to add additional disinfectant chemistry. In addition, natural gas consumption may be of concern. Natural gas consumption has been reported as high as 270-530 ft^3 of fuel per 100 gallons of water treated (Blom, 2001). That is equivalent to 2.75 to 5.4 therms of fuel per 100 gallons of water treated, which may make this form of water treatment cost prohibitive during times when the boilers are not regularly fired.

Oxidation Reduction Disinfection of Irrigation Water: Chlorine, Ozone and Hydrogen Peroxide

Oxidation reduction reactions originally referred only to reactions that involved the reaction of oxygen with another element or compound and reduction was used to indicate the removal of oxygen from a compound. These reactions now have a much broader definition and are applied to a great number of reactions not involving oxygen. Oxidation is defined as ain increase in the positive oxidation number with a corresponding loss of electrons. Reduction is a the decrease in the positive oxidation number of an ion with a corresponding gain of electrons. Common oxidizing compounds (Table 1) include chorine, bromine, ozone, sodium and calcium hypochlorite, hydrogen peroxide. Common industrial uses of oxidation-reduction include water disinfection, odor control, cyanide destruction, chrome reduction, and metal etching. Note that ozone has

Table 1. Common industrial oxidizers and their potential relative to chlorine.

Oxidant	Oxidation potential (mV)	Oxidation potential relative to chlorine
Fluorine	3,050	2.25
Ozone	2,070	1.52
Hydrogen peroxide	1,780	1.31
Potassium permanganate	1,680	1.25
Chlorine dioxide	1,570	1.15
Chlorine	1,360	1.00
Bromine	1,070	0.79

better than 1.5 times more oxidation potential than chlorine. When these chemicals are present in solution, adding an oxidizer raises the oxidation reduction potential (ORP) value and the addition of a reducer, lowers the ORP. Oxidation reduction potential (ORP) is measured in mV. The ORP value of a solution is dependent on the concentration and the activity of the oxidizer present.

Chemicals that are strong oxidizers, such as chlorine, bromine, and ozone, are excellent sanitizing agents. The sanitizing action is caused by an alteration of the chemical structure of unwanted organisms. More literally, oxidizing compounds "burn" the pathogens as well as other organic material in the water leaving a few harmless chemicals as bi-products. During the process of oxidation, the oxidizing compounds are reduced and their activity is lost. Therefore, it is important to maintain a high enough concentration of the oxidizer in the water to maintain sanitation.

Table 2. Water solutions of sodium hypochlorite and its impact on oxidation reduction potential and pH

NaOCl (%)	Oxidation potential (mV)	pH
Water	210	6.8
0.3	715	8.9
0.5	690	9.6
1.0	655	10.1
1.5	630	10.6
2.0	599	11.2
3.0	570	11.70

Chlorine is the most typical water sanitizing agent and its oxidation characteristics can best describe oxidation reduction chemistry. Chlorine activity is typically reported as free residual chlorine or total chlorine. Chlorine exists in water as HOCl (hypochlorous acid) or OCl^- (hypochlorite). Hypochlorous acid is a strong, fast acting oxidizer, whereas, hypochlorite is much weaker. As the pH of the solution increases, HOCl converts to its ionic form OCl^{-1}. Therefore, measuring the total chlorine of a solution does not indicted the oxidizing strength of a solution. In order to maintain free chlorine in its most active form, the solution pH should be maintained between 7.4 to 7.6 (Table 2 and Fig. 3). Data from the World Health Organization has indicated that an ORP of 650 mV can kill *E. coli* almost instantly regardless of the

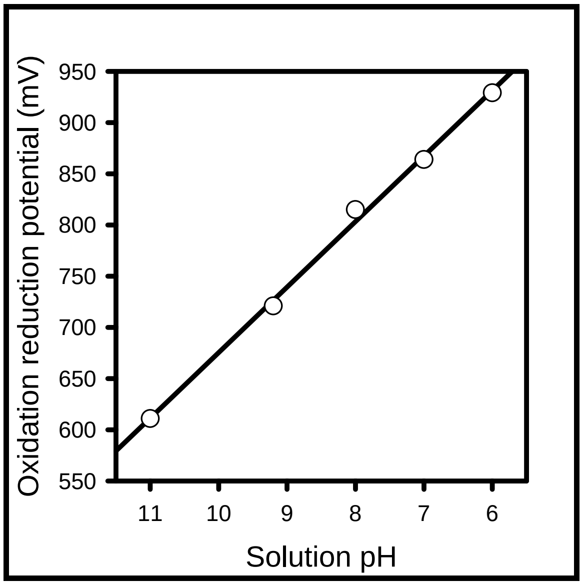

Fig. 3. Relationship of pH adjustment and oxidation reduction potential (ORP) of a 2% sodium hypochlorite solution.

free chlorine level at pH 7.6 (0.3 ppm) or pH 7.8 (0.4 ppm). Yet, free chlorine and ORP are not a linear relationship. That is, a 10-fold increase in free chlorine does not yield a corresponding 10-fold increase in mV (Fig. 4). Irrigation water at the hose end of a Colorado greenhouse using chlorine injection typically has an ORP of 825 mV with 1.4 ppm free chlorine and 2.25 ppm total chlorine

There is little data available on the relationship of ORP and its efficacy on plant pathogens, however, there is considerable information from the produce processing industry on ORP efficacy on human pathogens (Table 3).

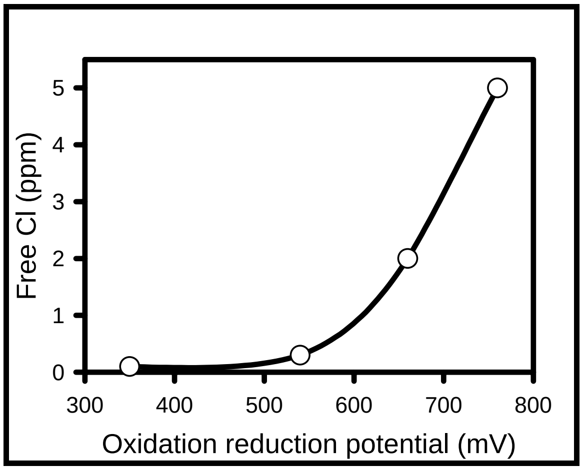

Fig. 4. Relationship between oxidation reduction potential (ORP) and free chlorine.

Table 3. Pathogen survival from laboratory simulations and hydrocooler studies according to Suslow (2003)

	Survival at ORP (mV)		
Pathogen	< 485	550 <x<620	> 665
E. coli O157:H7	> 300 s	< 60 s	< 10 s
Salmonella spp.	> 300 s	> 300 s	< 20 s
L. monocytogenes	> 300 s	> 300 s	< 20 s
Thermotolerant coliform	> 48 h	> 48 h	< 30 s

Measurement of ORP is a very straight forward measurement of the sanitizing power of irrigation water. There have been several improvements in probe design and inexpensive recording devices are available. As with pH and electrical conductivity, there are also inexpensive hand held devices available. The single most important advantage for using ORP for monitoring the disinfectant properties of irrigation water is that rapid, real-time assessment can be determined. In addition, ORP is not impacted by pH and measures the activity of the specific disinfectant being used without interacting with the water constituents. As previously described, chlorine is strongly pH dependent, ozone is moderately sensitive to pH and chlorine dioxide is the least sensitive. Data from many sources establishes that 650 mV ORP is the minimum threshold for typical anti-bacterial activity and has been in place in Europe since mid-1980 for municipal drinking water quality.

<u>*Chlorine sources*</u>*:* Chlorine is probably the most common disinfectant used in water treatment worldwide. For municipal drinking water systems, a slight excess is added to prevent bacterial growth in the distribution system. The typical residual chlorine level is 0.5 to 1 ppm. Chlorine is relatively inexpensive because it is a coproduct of chlorine and caustic soda (NaOH). Chlorine is shipped nationwide in liquid railroad tank cars. Since it is heavier than air and very toxic, chlorine was used in combat during WW I where it collected in trenches to maim and kill.

Table 4. Reactions for different forms of chlorine in water.

Sources of chlorine	Chlorine reaction in water
Chlorine gas	$Cl_2 + H_2O \rightarrow HCl + HOCl$
Sodium hypochlorite	$NaOCl + H_2O \rightarrow NaOH + HOCl$
Calcium hypochlorite	$Ca(OCl)_2 + 2H_2O \rightarrow Ca(OH)_2 + 2HOCl$
Chlorine dioxide	$HOCl + HCl + 2NaClO_2 \rightarrow 2ClO_2 + 2NaCl + H_2O$

Chlorine as a disinfectant is available in three common forms, chlorine gas, hypochlorite (sodium or calcium), and chlorine dioxide (Table 4). Each has relative advantages and disadvantages. Chlorine gas is probably the cheapest form of chlorine available requiring on-site injection equipment. It typically is injected at 25 to 200 ppm and is most active between the pH 6 to 7.5. Chlorine gas requires tight pH and concentration control and is highly corrosive if improperly used. Chlorine gas is dangerous to handle and requires alarms and scrubber technology in the event of a spill.

Sodium hypochlorite is the active ingredient in household bleach, but its ability to effectively whiten textiles was its first commercial use. Louis Pasteur discovered its efficacy against disease-causing microorganisms and it subsequently became widely used as a disinfectant. Household bleach typically contains 3% to 6% NaOCl, whereas industrial bleaches are typically 10% to 12% NaOCl. Sodium hypochlorite when disassociated into water to release hypochlorous acid, there is a concomitant level of sodium hydroxide, which is corrosive to metals and equipment requiring specialized equipment and pumps. As a consequence, sodium hypochlorite is not often used for greenhouse irrigation water disinfection. Yet, as a liquid it is easy to adapt to most greenhouse systems.

Calcium hypochlorite is a dry form of chlorine and when dissolved in water, it is an effective disinfectant that eliminates bacteria, algae, slime, fungi and other microorganisms. Calcium hypochlorite has many advantages over chlorine gas and sodium hypochlorite. Calcium hypochlorite is much safer to handle compared to both chlorine gas and sodium hypochlorite. Calcium hypochlorite is easier to store than sodium hypochlorite not requiring bulk tanks. Also, calcium hypochlorite is not as corrosive and is less harsh on equipment. Calcium hypochlorite is typically sold in tablets and some form of tank must be used for the tablets to dissolve into water. The tanks are designed so that the tablets erode at a consistent rate, releasing a controlled amount of chlorine into the water flow. Calcium hypochlorite delivery technology is relatively inexpensive and requires little adaption to typical greenhouse systems.

Chlorine dioxide is 25 times more effective than chlorine gas as a disinfectant and is a synthetic yellowish-green gas with chlorine like odor. Chlorine dioxide is unstable as a gas, but is stable and soluble in water. The instability of chlorine dioxide requires that it must be produced and used at the same location requiring specialized equipment. Yet, chlorine dioxide is an extremely effective biocide, disinfectant agent and oxidizer even in the presence of high organic load conditions common to recirculated greenhouse irrigation water. Compared to hypochlorous acid, chlorine dioxide is effective over a broader pH range with maximum efficacy at pH of 8.5.

Ozone: Ozone occurs naturally during thunderstorms with lightening. Ozone is detected near copy machines in offices and welders are exposed to ozone produced by arc welders. Many urban centers have ozone concentrations from 0.5-1.0 ppm range from automobile exhaust from cars and industries, which reacts with sunlight. Ozone is a form of oxygen (O_3) typically generated by a corona discharge system by passing dried, oxygen-containing gas through an electrical field. The electrical current splits the oxygen molecules (O_2). The resulting oxygen atoms (O^-), seek stability and will bond to other oxygen molecules (O_2), forming ozone (O_3). The ozone is then injected into irrigation water where it inactivates microorganisms by disrupting cell membranes through oxidation. Ozone is manufactured on site using corona discharge or plasma discharge units. A typical injection rate for greenhouse irrigation water would be 1 oz O_3 / 1,000 gallons of water. For optimum results, the pH of the water should be 4 with a contact time of one hour. Therefore, ozone is typically injected into a water storage system and should be maintained under pressure to prevent off-gassing of the ozone. In clean water, dissolved ozone can be measured with ORP, however, with the strong oxidizing power of ozone, water with moderate turbidity can result in ORP values far below expected levels. Ozone is widely used for treating wash water in the food processing industries.

One of the primary advantages of using an ozone disinfection system is that no additional corrosive chemicals are involved that cause corrosion. Yet, there is no residual disinfectant as with UV-C radiation systems. In addition, ozone may react with some fertilizers oxidizing iron, manganese and sulfides. An added benefit is that ozone flocculates solids and oxidizes pesticide residues.

Hydrogen Peroxide: Hydrogen peroxide (H_2O_2) a strong oxidizer, but not very stable. Hydrogen peroxide is water (H_2O) with an extra oxygen molecule attached and is a natural compound found in trace amounts in rain and snow. Hydrogen peroxide is formed when rain combines with ozone (O_3) in the atmosphere. Ozone loses one oxygen molecule to the water and hydrogen peroxide is formed, but it breaks down readily into water and a single oxygen molecule. Hydrogen peroxide is a simple yet effective disinfectant due to its ability to release a single oxygen molecule, which is very reactive.

Hydrogen peroxide has been described as a water disinfectant, but it is primarily used as a topical disinfectant. Food grade hydrogen peroxide (35%) is used in sterile packaging for the food industry. Hydrogen peroxide use is increasing as environmentally sound alternative to chlorine-based disinfectants. Hydrogen peroxide is available in several concentrations. What is available in the pharmacy is 3%, but industrial and food grade hydrogen peroxide is typically 35%. Hydrogen peroxide has been suggested at a trial rate at 1,000 to 3,000 ppm. Note that the efficacy of hydrogen peroxide is limited with high levels of organic matter. Many recommendations for hydrogen peroxide levels suggest an ORP of 750 mV.

One commercially available hydrogen peroxide formulation is currently labeled as a greenhouse pesticide/disinfectant. Hydrogen dioxide (ZeroTol) kills bacteria, fungus, algae and their spores immediately on contact. It is used as a disinfectant for greenhouse surfaces, equipment, benches, pots, trays and tools, as well as plants. ZeroTol is currently acceptable for use by organic growers. ZeroTol is a strong oxidizer and should not be mixed with any other pesticides or fertilizers. ZeroTol may be applied through an irrigation system, but may be cost prohibitive for constant use.

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