Greenhouse and Nursery Water Treatment Information System
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COPPER-Silver IONIZATION

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Background

Copper has been used as a fungicide for centuries. In the past copper was mainly applied in the form of cupric sulfate salt ($CuSO_4 \cdot 5H_2O$). Recently, the use of electrolytically generated copper (and silver) ions for pathogen control in greenhouses and nurseries has been gaining popularity. Disinfection of water with copper-silver ionization uses electricity to release copper ions into the irrigation water. When electricity is passed through irrigation water, copper ions are released and bond to plant pathogens (as well as other organic material), disrupting their cell wall and ultimately killing them.

Application Method

In order to release copper and silver ions into the irrigation solution copper-silver electrodes are submerged into the stream of irrigation water and an electrical current passed through them. This causes ions to be released from the electrodes into the irrigation stream where they may then react with negatively charged sites on organic materials such as pathogens.
Copper and silver ion output varies depending on electrical conductivity and flow rate of the irrigation solution, which can lead to variability in effectiveness, especially as water quality fluctuates. Systems that maintain constant copper ion output in spite of varying flow rate or EC are available. These systems make adjustments to keep electrical current constant despite fluctuating electrical conductivity.

Safety Concerns and handling information

Copper-silver ionization systems pose no hazard to employees. For a largely closed irrigation system, at the low copper concentrations used for this treatment method, ions in irrigation water occasionally released to the environment should not pose a threat to the environment or drinking water. However, release of large amounts of copper-containing water, especially in sensitive areas, should be avoided.

Critical Levels for Pathogens

The optimum copper ion concentration to treat common plant pathogens is 0.5 to 2 ppm. Refer to the table below for a list of critical levels for different pathogens

Microorganism	Pathogen Propagule	Critical Level (ppm)	Contact Time (hours)
Acidovorax avenae (Choppakatla, 2009)	Bacteria	1.5	Applied daily
Agrobacterium tumefaciens (Wohanka et al., 2006a)	Bacteria	2	24
Algae (Zheng and Dixon, 2008a)	N/A	1.15	N/A
Biofilm	N/A	1-2	N/A
Clavibacter michiganensis (Wohanka and Fehres, 2007a)	Bacteria	2 (>90% elimination)	2
Erwinia carotovora subsp. *carotovora* (Wohanka et al., 2007)	Bacteria	2 (>95% elimination)	1
Fusarium oxysporum (Wohanka and Fehres, 2006b)	Conidia	Ineffective (at 3ppm)	Ineffective? (at 4 hours)
Phytophthora cactorum (Colburn and Jeffers, 2010)	Zoospores	0.8 (copper carbonate) 1.0 (copper-triethanolamine + copper Hydroxide)	0.5
Phytophthora cinnamomi (Toppe and Thinggaard, 2000)	Zoospores	0.28 (decreased disease incidence 80%)	Continuous application
Phytophthora citricola (Colburn and Jeffers, 2010)	Zoospores	0.8 (copper carbonate) 1.0 (copper-triethanolamine + copper Hydroxide)	0.5
Phytophthora citrophthora (Colburn and Jeffers, 2010)	Zoospores	0.8 (copper carbonate) 1.0 (copper-triethanolamine + copper Hydroxide)	0.5
Phytophthora cryptogea (Colburn and Jeffers, 2010)	Zoospores	0.8 (copper carbonate) 1.0 (copper-triethanolamine + copper	0.5

		Hydroxide)	
Phytophthora nicotianae (Colburn and Jeffers, 2010)	Zoospores	0.8 (copper carbonate) 1.0 (copper-triethanolamine + copper Hydroxide)	0.5
Phytophthora palmivora (Colburn and Jeffers, 2010)	Zoospores	0.8 (copper carbonate) 1.0 (copper-triethanolamine + copper Hydroxide)	0.5
Phytophthora ramorum (Colburn and Jeffers, 2010)		0.8 (copper carbonate) 1.0 (copper-triethanolamine + copper Hydroxide)	0.5
Pythium aphanidermatum	Zoospores	Ineffective (at 1ppm)	Ineffective (at 1 hour)
Ralstonia solanacearum (Wohanka and Fehres, 2007b)		2 (>95% elimination)	1
Trichoderma asperellum (Wohanka et al., 2009)	Conidia	Ineffective (at 4ppm)	Ineffective (at 24 hours)
Xanthomonas campestris (Wohanka and Fehres, 2006c)	Oomycete	2 (>95% elimination)	4

If using a copper-silver ion system, critical levels will likely differ from those seen here (most likely lower, due to the higher efficacy of silver ions). Slade and Pegg (1993) studied the toxicity of silver ions (from $AgNO_3$) to various plant pathogens (under laboratory conditions) and found it to be much more toxic than copper. The findings of their study are summarized below.

Microorganism	Pathogen Propagule	Critical Level (ppm)
Fusarium oxysporum f.sp. *lycupersic*	Conidia	0.07-0.1
Fusariurn oxysporuni f.sp. *dianthi*	Conidia	0.5
Phytophthora cryptogea	Zoospores	0.1
Phytophthora nicotianae parasitica	Zoospores	0.1
Pythium aphanidermatum	Zoospores	0.05
Thielaviopsis basicola	Conidia	0.1
Verticillium albo-atrum	Conidia	(for >90% elimination) 0.5 (for complete elimination)

However, there is currently no information on the critical levels for these two ions combined.

It should also be noted that the above critical level values were determined using the application of salts of copper and silver. It is possible that required critical levels of electrolytically generated silver and copper may differ somewhat.

Critical Levels for Plants

While copper is an essential plant nutrient, it is also a heavy metal, and as such high concentrations are toxic to plants. Growers produce numerous plant species, cultivars and varieties with varying sensitivity to copper ions. Dr. Zheng's lab has done extensive research on copper phytotoxicity and below is a table with a list of critical levels for different plants.

Plants	Method of Irrigation	Critical Level (ppm)
Chrysanthemum	Root zone	0.318 (Zheng et al., 2004)
Corn	Root zone	0.635 (Mocquot et al., 2006)
Geranium	Root zone	0.508 (Zheng et al., 2004)
Miniature Rose	Root zone	0.1525 (Zheng et al., 2004)
Silene compacta	Root zone	0.890 (Ouzounidou, 1994)
Taro	Root zone	0.076 (Hill et al., 2000)
Cucumber (*Cucumis sativus*)	Root zone	<1.05 (Zheng et al., 2010)
Pepper (*Capsicum annuum*)	Root zone	0.19 (Zheng et al., 2005)
Tomato (*Solanum lycopersicum*)	Root zone	0.74 (Zheng and Dixon, 2008b)

As is evident, there have been few studies done on copper phytotoxicity in solution culture. Different species, or even cultivars of the same species, may differ widely in regards to critical copper level. It is recommended that the producer perform a phytotoxicity test on a small group of plants under simulated production conditions prior to widespread application. Plant visible root injury is the best indication of copper toxicity, as Zheng et al. (2004) found when plants displayed visible root injury after a certain period of time, growth depression eventually followed.

Again, as silver is more toxic to pathogens than copper, it also likely requires lower levels to be phytotoxic. As such, the phytotoxic copper levels listed here may be higher than the levels that would be phytotoxic with a copper-silver system, as there would not only be the toxic effect of copper but that of silver as well.

The phytotoxic levels listed here are for production in a hydroponic system using inorganic growing substrates. For plants grown in organic substrates (ie. those containing peat moss), larger amounts of copper will be required to produce a toxic effect (the phytotoxicity threshold will be higher) as copper will react with organic compounds and be removed from solution (Zheng et al., 2005).

Monitoring

Ion concentrations may be monitored using colorimetric metres or kits. A copper analyzer may be installed as part of the copper-silver ionization system. Usually a flow metre is supplied along with the copper-ionization system, and is connected with the system control unit so that ion production may be adjusted with a change in water flow rate.

In combination with other technology

Copper ions can bond with some organic compounds, therefor filtration prior to treatment is recommended. Prefiltration is needed especially for producers who use pond water or experience buildup of organic matter such as algae and humic acids in recirculated water.

Cost for Technology

The use of any water treatment technology is dependent on the size of the production facility and the amount of water used. Below are tables that summarize the average water consumption and cost of the technology when using copper at 3 ppm in a small, medium and large facility.

Size of Production Facility	Water Usage (litres/day) Greenhouse[1]	Water Usage (litres/day) Nursery[2]
Small	29,263 – 37,857	700,993 – 2,103,001
Medium	33,560 – 134,244	1,401,997 – 3,219,732
Large	117,057 – 151,431	1,609,854 - 4,829,610

Size of Production Facility	CapitalCost Greenhouse[3]	Operation Cost Greenhouse (per day)[3]	Capital Cost Nursery[3]	Operation Cost Nursery (per day)[3,4]
Small	$9,000-14,000	$1.30-$2.00	$80,000+	$17.50+
Medium	$10,000-30,000	$1.40-$5.00	$120,000+	$35.00+
Large	$14,000-40,000	$3.00-$7.50	$170,000+	$40.00+

[1]Flowers Canada Growers. (2011): http://flowerscanadagrowers.com
[2]Canadian Nursery Landscape Association. (2011): www.canadanursery.com/
[3]Ranges have been estimated from a survey of companies and are only intended to give a rough idea of cost. To determine exact costs for your system, please contact a supplier.
[4]Nurseries usually do not need to treat all their water, so nursery costs are likely overestimates.

Costs- Maintenance

The main maintenance costs come from the need to eventually replace electrodes. How often electrodes will need to be replaced, and as such maintenance costs, depends on the concentration of copper being applied, the amount of water being used, and the EC and pH of the irrigation solution. Generally, they need to be replaced every year or two and cost about $25/kg copper. The costs of replacing these electrodes are included in the operating costs estimated above.

Pros and Cons

Pros:

- Does not involve the use of any chemicals that may be hazardous to workers
- Requires relatively little maintenance, only infrequent replacement of electrodes
- Larger residual effect, ions remain in water for a long period of time and as such provide lasting disinfection and biofilm removal all along the irrigation line
- Unlike some other chemical and physical disinfection methods, effectiveness is not as dependent on organic matter content in the irrigation solution (Fisher, 2011)

Cons:

- Lack of data on efficacy and phytotoxicity. Some currently available information suggests this treatment method may not be effective against some major greenhouse pathogens (ex. *Fusarium* spp.; Stewart-Wade, 2011).
- Release of large amounts of effluent to the environment must be avoided as copper and silver concentrations in the irrigation solution may be potentially hazardous
- If used in a hydroponic system (especially those incorporating inert/inorganic substrates), the level of copper used to kill pathogens may be too high for many plant species to tolerate, as roots will be directly in contact with the irrigation solution. (Zheng et al., 2005; Zheng et al., 2010; Zheng and Dixon, 2008b).
- May accumulate in solution to phytotoxic levels

Summary

Copper-silver ionization systems may be used in certain recirculating systems to prevent biofilm buildup and control pathogens throughout the irrigation system, without the potential safety hazards posed by some chemical treatments. This method is also not as affected by organic matter particles as other chemical treatment methods, and may be useful for operators using a “dirty” water supply. However, it is likely this technology is not appropriate for continuous use in hydroponic systems, especially those using inert/inorganic growth media (Zheng et al., 2005). Phytotoxicity levels for growth in organic substrate still need to be investigated. Ultimately, it may be feasible to design a system where copper and silver ions may be removed from the system before irrigation water comes in contact with plants. More phytotoxicity and efficacy information, particularly in relation to copper-silver ionization systems as opposed to just copper or silver ions, is also currently needed.

Suppliers

Some examples of suppliers of copper-silver ionization systems include:

Suppliers	Producer website
Aqua-Hort	http://www.aqua-hort.dk/
Superior Aqua Systems	http://www.superioraqua.com/index.html
Liquitech	http://liquitech.com/
Agri Ionization Systems Inc.	http://agri-ions.com

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