INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

No IV/1/2017, POLISH ACADEMY OF SCIENCES, Cracow Branch, pp. 1387–1400
Commission of Technical Rural Infrastructure

DOI: http://dx.medra.org/10.14597/infraeco.2017.4.1.106

NECESSITY OF DISINFECTING WATER FOR CROP IRRIGATION

Leszek B. Orlikowski, Waldemar Treder, Magdalena Ptaszek, Aleksandra Trzewik, Waldemar Kowalczyk, Urszula Łazęcka
Research Institute of Horticulture, Skierniewice

Abstract

The purpose of that article was to show the significance of water as the source of plant pathogens, and need of it effective disinfection methods in modern agriculture and horticulture. The increase in the cost of agricultural water use for crop irrigation and the necessity of using the same water several times, as well as the changing climatic conditions, including prolonged shortage of atmospheric precipitation and often extreme temperatures during the summer, necessitate the selection of an effective, easy to apply and economical method of disinfecting recirculated water to eliminate or minimize the occurrence of the most serious plant pathogens inhabiting various water sources. Among them, microorganisms of the genera *Phytophthora*, *Pythium* and *Fusarium*, and the species *Rhizoctonia solani*, *Verticillium dahliae* and some pathogenic bacteria pose the most serious threat. Some of them can be found in rivers, streams, ponds and water reservoirs, others are soil-borne pathogens that cause root and stem base rot of many plant species. The available literature describes at least a dozen methods of water disinfection, among them slow filtration through sand or lava filters, chlorination and heating. The literature data indicates that the use of sand filters is the most effective, safe and cheapest method of water disinfection.

Keywords: water, soil-borne pathogens, disinfection methods, application

INTRODUCTION

The acquisition of large areas of land by owners or leaseholders in the past 30 years has resulted in the emergence of many specialized, high productivity farms. One of the most important factors affecting their functioning is the availability of water so that, regardless of weather conditions, the farming can be profitable. In Poland, irrigation is already widely used not only in protected cultivation but also in the open-field cultivation of vegetables, orchards and ornamental plants.

WATER AS A SOURCE OF MICROORGANISMS, INCLUDING PLANT PATHOGENS

Systematic irrigation of crops has been conducted on horticultural farms for many years, mainly in protected cultivation, container nurseries, orchards and in vegetable production (Stewart-Wade, 2011). The sources of water are water reservoirs, ponds, streams, rivers, as well as deep water wells. Along with the water taken from natural watercourses and reservoirs, plant pathogens can be carried to the crops, during periods of a significant increase in their numbers or abundant rainfall, from forests and groves through which streams and rivers flow, as well as from container nurseries, orchards and vegetable gardens, and sometimes from cultivated crops (Brenner et al. 2000, Orlikowski and Ptaszek 2009). Hong and Moorman (2005) argued that microorganisms from different groups can live in the water. Among them, the most dangerous are soil-borne pathogens, including species of the genera *Cylindrocladium*, *Phytophthora*, *Pythium*, special forms of *Fusarium oxysporum*, and also *Alternaria, Aspergillus, Ascochyta, Botrytis, Cephalosporium, Cladosporium, Colletotrichum*, *Diplodia, Gnomonia radicicola*, *Helminthosporium*, *Isaria*, *Macrophoma*, *Monilia*, *Mucor, Penicillium*, *Pestalotia, Phoma*, *Phomopsis sclerotioides, Pyrenochaeta, Rhizoctonia solani, Sclerotium rolfsii, Stachybotrys, Thielaviopsis basicola, Trichoderma* spp. and *Verticillium*, as well as pathogenic bacteria and viruses (Mafia et al. 2008, McPherson et al. 1995, Orlikowski et al. 2011b, McIntosh 1966, Thomson and Allen 1974, Werres et al. 2007).

The first information on the occurrence of *Phytophthora* in the water was published in 1921 by Bewley and Buddin, who isolated *Phytophthora cryptogea* from water intended for watering plants in greenhouse cultivation. After about a 30-year break, many other works have appeared showing that water is one of the most important sources of microorganisms, including plant pathogens. On the other hand, microorganisms present in plant material or in the soil can be brought into the water causing it to become contaminated. In the opinion of Milgroom and Peever (2003) water is the fastest source of pathogen spread in a par-

ticular region, country or even continent. Hong and Moorman (2005), in turn, further expand the role of water in the spread of pathogens claiming that it is the principal, if not the only, source of *Phytophthora* species in nurseries, orchards and vegetable crops. The authors also point to this group of microorganisms as the most dangerous plant pathogens. This has been confirmed by other researchers, including Thomson and Allen (1974), Themann et al. (2002a, b), Werres et al. (2007), who consider species of this genus as the main cause of root and stem base rot. According to Baker and Matkin (1978), the most significant role in the rapid spread of this group of pathogens is played by zoospores. Studies conducted over the past quarter of a century in Poland also point to *Phytophthora*, mainly *P. cactorum, P. cinnamomi, P. cambivora, P. citrophthora, P. cryptogea* and *P. plurivora* as one of the most dangerous pathogens in nurseries, which often cause mass withering of coniferous, ericaceous and deciduous plants, and, in the past 10 years, also perennials (Orlikowski et al. 2012, Ptaszek 2017). Phytophthorosis also occurs in apple orchards and on gooseberry, highbush blueberry and raspberry plantings (Bielenin and Borecki 1970, Meszka and Bielenin 2011, Orlikowski et al. 2015).

NEED FOR WATER DISINFECTION

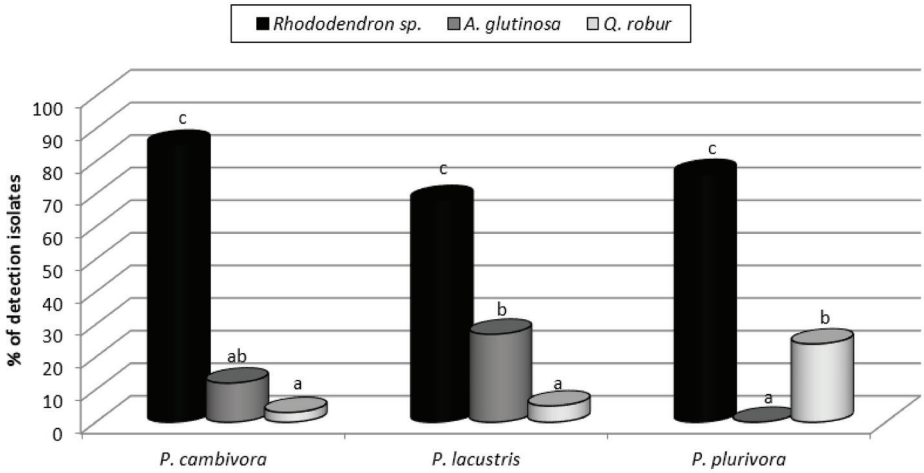
Due to the possibility of irrigation water being inhabited by plant pathogens carried during heavy rains from forests, groves and arable fields, it is necessary to disinfect it before further use. In closed systems of nutrient circulation, in the cultivation of plants under cover and in container nurseries, contamination of water occurs by unconscious introduction into cultivation, even sporadically, of infected cuttings, seedlings or older plants. The cultivation conditions that are beneficial to the growth of plants, and often leading to them becoming overly delicate, also promote root system infections and rapid disease development, combined with abundant sporulation of microorganisms on the infected tissues, which in turn affects the growth of populations of pathogens, including various species of fungi and fungus-like organisms, viruses and nematodes (Amsing and Runia 1995, Norman et al. 2003) and their entry into the water. Themann et al. (2002a) detected 12 species of *Phytophthora*, with the dominance of *P. cryptogea*, in the water. Repeated use of such contaminated water to irrigate plantings under cover or open-field crops may lead to significant losses in the irrigated production. Reused irrigation water can often be the main source of a pathogen in new plantings and, besides infecting plants, also a cause of soil contamination (Hong et al. 2001). An increase in the number of infected plants is usually associated with the intensification of chemical protection and water pollution with pesticide residues (James et al. 1995). For these reasons, Lane (2004) believes that disinfection of water used repeatedly to irrigate plants should be

a priority, not only to eliminate pathogens from it but to reduce the use of plant protection products.

DETECTION OF PATHOGENS IN WATER

The composition of microorganisms and nematodes occurring in water depends on the location of its source, pH and temperature, the time of year, weather pattern, species of cultivated plants, organic matter and mineral content (Baker and Matkin 1978, Ehret et al. 2001, Hong et al. 2001, Hong and Moorman 2005, MacDonald et al. 1994, Themann et al. 2002a, Werres et al. 2007). One of the methods used for detecting microorganisms is water filtration, followed by the laying out of the filters onto a growth medium suitable for a given genus (Bush et al. 2003, Hong et al. 2002, Hong and Moorman 2005). Using a 5 μm pore filter, this method enables detection of *Pythium* and *Phytophthora* species (Hong et al. 2002). Quite popular are also plant baits that are placed in the water or soil, and after symptoms of rotting have appeared on them, the affected fragments are transferred onto a growth medium (Bush et al. 2003, Hong and Moorman 2005). Shokes and McCarter (1979) found plant baits to be very effective for detecting *Pythium* species, explaining that the baits were rapidly colonized by zoospores. For the detection of *Phytophthora* spp., Steddom (2009) found the use of baiting plants much more effective than other methods. This was also confirmed by Themann et al. (2002a). Studies by Orlikowski et al. (2011a) showed particularly high usefulness of the leaves of rhododendron, as well as alder and lilac, for detecting *Phytophthora* species in water. An additional advantage is the possibility of using rhododendron leaves throughout the year irrespective of the temperature and pH of the water (Orlikowski et al. 2012). The authors showed (Tab. 1) that, regardless of the source of water and the time of year, eight *Phytophthora* species, with the dominance of *P. plurivora*, were present in watercourses and reservoirs. Hong and Moorman (2005) and Kong et al. (2003) emphasize the high usefulness of the PCR technique for the identification of microorganisms from the water.

Of the eight species found in the water, only *P. lacustris* and *P. plurivora* occurred regardless of its source. Other species were detected mainly in the ponds tested (Tab. 1). Orlikowski et al. (2012) found the occurrence of *Phytophthora* spp. in the water to be independent of the time of year. Only in February did the authors not detect any of the *Phytophthora* species in the tested water sources. It is likely that with the water surface being frozen in that month *Phytophthora* species were present in bottom sediments.



Means in columns, followed by the same letter, do not differ according to Duncan's multiple range test

Figure 1. Frequency of *Phytophthora* spp. detection depending on the baiting plant species (Orlikowski et al. 2011a)

Table 1. *Phytophthora* species occurring in rivers, canals and ponds (Orlikowski et al. 2011a)

Phytophthora species	**Rivers**	**Canals**	**Ponds**
P. cactorum	-	-	+
P. cambivora	+	-	-
P. cinnamomi	-	+	+
P. citrophthora	-	+	+
P. cryptogea	-	+	+
P. lacustris	+	+	+
P. megasperma	+	-	-
P. plurivora	+	+	+

POSSIBLE METHODS OF WATER DISINFECTION

1. SLOW FILTRATION

In the case where the filter matrix consists of sand, the method is referred to as slow sand filtration (SSF). It has been used for over 100 years for municipal water treatment and for about 40 years for disinfecting water in closed circuits, mainly in protected cultivation (Wohanka et al. 1999). The method gives

the possibility of eliminating species of the genera *Fusarium, Cylindrocladium, Phytophthora, Pythium, Thielaviopsis, Verticillium, Xanthomonas*, and the nematode *Rodopholus similis* from the water (Brand and Wohanka 2001, Calvo-Bado et al. 2003a, Zheng and Dunets 2012). Sand, volcanic lava, granular mineral wool, charcoal are used as the filtering substrate. The most commonly used is sand with a particle size of 0.15 to 0.35 mm, which is much more effective than the 0.5 to 1.6 mm fraction (van Os et al. 1998). The effectiveness of filtering depends on the amount of inoculum in the water, water flow rate, pathogen species, and also the presence of microorganisms antagonistic towards the pathogens, and organic matter content (Brenner et al. 2000, Calvo-Bodo et al. 2003b, Pettitt et al. 1998). The optimal flow rate of water through the filter is considered to be from 100 to 300 l/m^2/h, giving the elimination of pathogens from 93 to 100% (Ehret et al. 1999, van Os et al. 1998). Filtration effectiveness increases when isolates of *Pseudomonas putida* or *Bacillus cereus*, which are antagonistic towards many pathogens, are introduced into the filter matrix (Déniel et al. 2004). The advantage of a sand matrix is low installation cost, low energy consumption for disinfection, no residue in the filtered water, adaptability to almost any conditions, independence from water pH, and low cost of disinfection (Ufer et al. 2008a, b). The disadvantage is the necessity of replacing the individual sand fractions, the difficulty in changing the filtering site due to the considerable weight of the filtering substrate, slow disinfection of water, decreased filtration effectiveness over time due to the accumulation of organic and inorganic parts and peat, and, with an increase in filtering temperature above 20°C, the possibility of the occurrence of *Legionella* sp., bacteria harmful to humans (Calvo-Bodo et al. 2003a, Wohanka and Helle 1996).

Apart from sand, granular mineral wool is considered to be the most useful product for slow water filtration, as it is about 10 times lighter than sand, easier in the construction and relocation of the filtering installation, and does not require, as is the case with sand, several layers of different grain size, and does not suffer from frequent clogging of pores. It also has a larger filtering surface, but is four times as expensive as sand and does not guarantee the complete elimination of harmful microorganisms (Chin 2005, Ufer et al. 2008a, b, Wohanka and Helle 1996, Wohanka et al. 1999).

The use of volcanic lava as the filter matrix allows water to flow faster than through sand, eliminates pathogens of the genera *Fusarium, Pythium* and *Phytophthora* to the extent of almost 100%, and gives the possibility of disinfecting water at temperatures between 5 and 25°C. The system requires less space because of the faster flow of water, and can be operated for longer than a sand filter (Ufer et al. 2008a, b).

Park et al. (1998) and Wohanka and Helle (1996) are of the opinion that charcoal can be the most useful substrate for filtering, as evidenced by the elimination of more than 90% of *Fusarium oxysporum* spores from the water, com-

pared with about 80% for a sand filter and only about 50% for perlite. Such properties are also ascribed to 'keramzyt' (LECA – light expanded clay aggregate), but it is much more expensive to use and less effective than either sand or mineral wool (Wohanka and Helle 1996).

2. UV IRRADIATION

UV radiation is often used for disinfecting water when plants are grown under cover. A centrally mounted lamp emits UV-C rays at 254 nm destroying the RNA and DNA of water-dwelling microorganisms (Newman, 2004). To eliminate plant pathogens, including viruses, it is recommended to use UV radiation at doses of 100 mJ/cm^2 and 250 mJ/cm^2. To eliminate nematodes, the dose should be doubled (Amsing and Runia 1995). According to Jamart (1998) and Mebalds et al. (1996), UV radiation is most useful in eliminating zoospores of *Phytophthora* spp., as the most common forms of this group of pathogens (Baker and Matkin 1978), and spores of *Fusarium oxysporum* and *Colletotrichum capsici*, but is less effective against *Alternaria zinniae* and *Fusarium solani*. Runia and Boonstra (2004) believe that the effectiveness of UV radiation can be increased by adding 200 to 400 ppm hydrogen peroxide to the water immediately prior to disinfection. The effectiveness of irradiation depends on the water flow rate and the presence of organic debris, including plant parts and mineral salts. The disadvantage of the system is the inhibition of the development of plants irrigated with water immediately after it has been irradiated, the destruction of iron chelates, high operating costs, elimination of beneficial microorganisms, and no effect on pathogens present within plant debris (Daughtrey and Schippers 1980, Nasser et al. 2006).

3. CHLORINATION

For disinfection, chlorine can be added in a solid form as calcium chloride, a liquid form as sodium hypochlorite, or a gaseous form (Chin 2005, Clark and Smajstrla 1992). The decomposition of these compounds results in the formation of hypochlorous acid, which causes oxidation and elimination of microorganisms. In addition, OH ions are released, which cause the pH of the water to increase. Mebalds et al. (1996) showed that at pH 6 the effectiveness of disinfection was about 96%, and with an increase to pH 7, the effectiveness decreased to 73%. A further increase in pH eliminates only about 22% of pathogens (Mebalds et al. 1996). The use of chlorine in a gaseous form, despite its strong effect on pathogens, including *Phytophthora*, is dangerous because of the possibility of causing irritation of the respiratory tract, especially at high concentrations (Clark and Smajstrla 1992). It has been shown that many microorganisms already respond to 1-3 mg Cl/l, but 5-10 mg Cl/l should be applied to water containing more mineral compounds. With a high level of organic and inorganic substanc-

es, the dose should be increased to 25-30 mg Cl/l (Clark and Smajstrla 1992). A study by Hong et al. (2003) indicates that 2 mg of free chlorine per 1 litre of water kills zoospores of *Phytophthora* spp., whereas the hyphae of *P. nicotianae* can still survive at 8 mg/l of this element. Taking into account the possibility of some pathogens, especially *Phytophthora*, surviving within organic debris, the effectiveness of chlorination can be improved by subjecting water, before the treatment, to sedimentation (Steadman et al. 1979) or slow sand filtration (Ufer et al. 2008a, b).

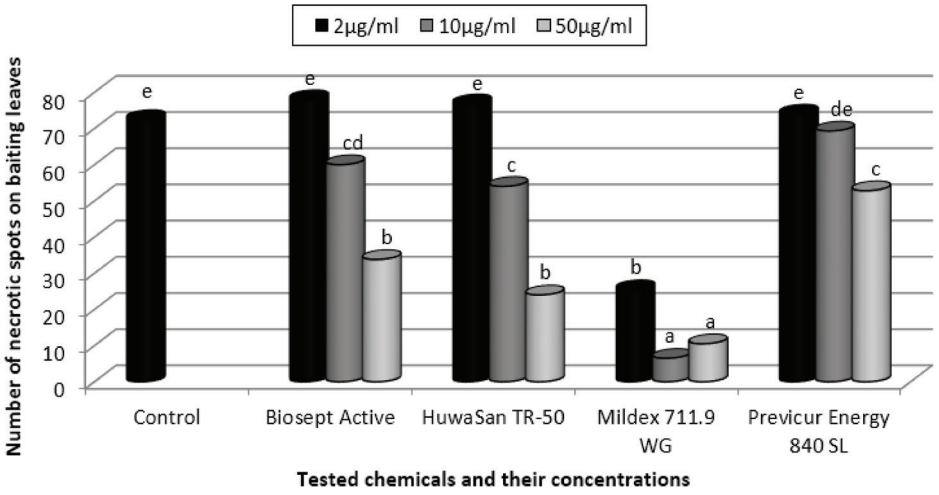
4. HYDROGEN PEROXIDE

Newman (2004) considers hydrogen peroxide to be a potent oxidant used to minimize the occurrence of pathogens in the water and also to eliminate algae (Vanninen and Kuskula 1998). A study by Chikthimmah et al. (2005) indicates that, in addition to the important role of this agent in inducing plant resistance to pathogenic bacteria, it plays an important role in controlling the populations of *Pseudomonas*, *Cladosporium* and *Botrytis* species. Hydrogen peroxide is also used for the disinfection of greenhouses and polytunnels. To improve the stability of the agent and increase its effectiveness, silver ions are added to it. A product available in Poland is Huwa San TR 50 containing 50% hydrogen peroxide and 0.036% silver. Rompaey (2015) has shown that the agent can be successfully used to eliminate the biofilm from an irrigation system, an important component of which is *Agrobacterium rhizogenes*, the bacterium that causes the 'crazy roots' disease in tomatoes. The authors' own studies also indicate the possibility of using this agent to minimize the occurrence of *Phytophthora* species in the water used for irrigating nurseries of ornamental plants. A double application of the agent to the water at a dose of 50 ml/m^3 resulted in an approx. 4 times reduction in the population size of *P. plurivora* (Fig. 2).

5. HEATING

This is a method of disinfecting recycled water in the protected cultivation of crops (Newman 2004). In the first stage, the water is pumped into a heat exchanger, where it is heated by the heat generated by the cooling of the already disinfected water, and then it enters another heat exchanger, where it is heated to the desired temperature. This method offers the possibility of eliminating species of the genera *Pythium* and *Phytophthora*, and also *Fusarium oxysporum*, *Verticillium dahliae*, *Erwinia chrysanthemi*, the nematode *Rodopholus similis*, as well as the tobacco and tomato mosaic viruses (Runia and Amsing 2001). According to Pettitt et al. (1998), instead of heating the water up to 95°C, it is sufficient to heat it up to 60°C for 2 minutes to eliminate pathogenic bacteria, fungi, fungus-like organisms and nematodes. This results in a 42% reduction in energy costs. However, to eliminate viruses, 85°C for 3 minutes is necessary (Runia

and Amsing 2001). To disinfect 10 thousand litres of recycled water, approx. 1 GJ of energy must be used in the form of fuel gas (Yiasoumi 2005). At the same time, it is important to remember to cool the disinfected water before using it for irrigation, which entails additional costs (Ehret et al. 2001).



Means in columns, followed by the same letter, do not differ according to Duncan's multiple range test

Figure 2. Relationship between tested compounds, their concentrations and efficacy in the control of *Phytophthora plurivora* in water (Orlikowski et al, unpublished)

CONCLUSIONS

1. Water shortages associated with drought or low rainfall and limited access to deep underground water make it necessary to use it repeatedly for the irrigation of crops grown under cover and in closed-circuit field cultivation.
2. The use of irrigation water from natural sources can introduce into cultivated crops very dangerous soil-borne pathogens, which can cause losses occasionally reaching as much as several dozen percent.
3. The most commonly found in the water are species of the genera *Phytophthora* and *Pythium*, forms of *Fusarium oxysporum*, *Cylindrocladium* spp., *Verticillium dahliae*, *Erwinia chrysanthemi*.
4. Pathogens can also originate from cuttings or seedlings brought into plantings, on which they multiply rapidly and then enter the irrigation water.
5. Before planting and irrigating plantings, the composition of harmful microorganisms present in the water should be determined using for this purpose, for example, the baiting plant method, which is easy to use, cheap, and available throughout the year.

6. Among the various methods of water disinfection in the protected cultivation of crops in Poland, the most commonly used is UV irradiation.
7. Literature data indicate great advantages of water filtration, including the use of sand, granular mineral wool or volcanic lava filters for this purpose. Due to the high effectiveness and low operational costs, this method has the potential of being widely introduced into the disinfection of recycled water.

ACKNOWLEDGMENT

This publication was produced under the project: "Sustainable irrigation of ornamental nurseries" – contract number PBS3/A8/29/2015. The project was co-financed by the National Centre for Research and Development (NCBR) within the framework of the Applied Research Programme (PBS).

REFERENCES

Amsing J.J., Runia W.T. (1995). *Disinfestation of nematode-infested recirculation water by ultra-violet radiation.* Mededelingen. Faculteit Landbouwkundige en Toegepaste Biologische Wetenschappen Univ. Gent 60(3b), 1087-1092.

Baker K.F., Matkin O.A. (1978). *Detection and control of pathogens in water*. Ornamentals Northwest Archives, April-May 2(2), 12-13.

Bewley W.F., Buddin W. (1921). *On the fungus flora of glasshouse water supplies in relation to plant disease*. Ann. Appl. Biology 8(1), 10-19.

Bielenin A., Borecki Z. (1970). *Zgnilizna pierścieniowa podstawy pnia drzew owocowych powodowana przez grzyb Phytophthora cactorum (Lep. et Cohn) Schroeter.* Acta Agrobotanica 23 (2), 353-366.

Brand T., Wohanka W. (2001). *Importance and characterization of the biological component in slow filters.* Acta Hortic. 554, 313-321.

Brenner A., Shandalov S., Messalem R., Yakierevich A., Oron G., Rebhun M. (2000). *Wastewater reclamation for agricultural reuse in Israel: trends and experimental results.* Water, Air and Soil Pollution 123, 167-182.

Bush E.A., Hong C.X., Stromberg E.L. (2003). *Fluctuations of Phytophtora and Pythium spp. in components of a recycling irrigation system.* Plant Dis. 87(12), 1500-1506.

Calvo-Bado L.A., Morgan J.A., Sergeant M., Pettitt T.R., Whipps J.M. (2003a). *Molecular characterization of Legionella populations present within slow sand filters used for fungal plant pathogen suppression in horticultural crops.* Appl. Environ. Microbiol. 69(1), 533-541.

Calvo-Bado L.A., Pettitt T.R., Parsons N., Petch G.M., Morgan J.A.W., Whipps J.M. (2003b). *Spatial and temporal analysis of the microbial community in slow sand filters used for treating horticultural irrigation water.* Appl. Environ. Microbiol. 69(4), 2116-2125.

Chikthimmah N., LaBorde L.F., Beelman R.B. (2005). *Hydrogen peroxide and calcium chloride added to irrigation water as strategy to reduce bacterial populations and improve quality of fresh mushrooms*. J. Food Sci. 70(6), 273-278.

Chin R. (2005). *New water treatment systems for the nursery industry.* Paper presented at the Nursery and garden industry conference proceedings, Fremantle, WA, Australia.

Clark G.A., Smajstrla A.G. (1992). *Treating irrigation systems with chlorine*. Foliage Digest 15(6), 3-5.

Daughtrey M.L., Schippers P.A. (1980). *Root death and associated problems.* Acta Hortic. 98, 283-291.
Déniel F., Rey P., Chérif M., Guillou A., Tirilly Y. (2004). *Indigenous bacteria with antagonistic and plant-growth-promoting activities improve slow-filtration efficiency in soilless cultivation.* Can. J. Microbiol. 50(7), 499-508.

Ehret D.L., Alsanius B., Wohanka W., Menzies J.G., Utkhede R. (2001). *Disinfestation of recirculating nutrient solutions in greenhouse horticulture.* Agronomie 21(4), 323-339.

Ehret D.L., Bogdanoff C., Utkhede R., Lévesque A., Menzies J.G., Ng K., Portree J. (1999). *Disease control with slow filtration for greenhouse crops grown in recirculation.* Final Report of the BC Greenhouse Veg. Res. Council, Project 96-15, 37 pp.

Hong C.X., Bush E.A., Richardson P.A., Stromberg E.L. (2001). *The major deterrent to recycling irrigation water in nursery and greenhouse operations despite lack of alternatives for limiting nonpoint source pollution.* Proc. Virginia Water Res. Symposium 1, 72-77.

Hong C., Cohn D., Kong P., Richardson P.A. (2002). *Economic significance to nursery production of Phytophthora species present in irrigation water.* SNA Res. Conf. 47, 237-240.

Hong C.X., Moorman G.W. (2005). *Plant pathogens in irrigation water: challenges and opportunities.* Critic. Rev. Plant Sci. 24(3), 189-208.

Hong C.X., Richardson P.A., Kong P., Bush E.A. (2003). *Efficacy of chlorine on multiple species of Phytophthora in recycled nursery irrigation water.* Plant Dis. 87(10), 1183-1189.

Jamart G. (1998). *The control of Phytophthora spp. in drainage water of Rhododendron in closed cultivation system.* Verbondsnieuws 42, 30-32.

James E., Bodman K., Forsberg L., De Hayr R. (1995). *Is irrigation water the culprit?* Flower Link (June), 31-41.

Kong P., Hong C.X., Jeffers S.N., Richardson P.A. (2003). *A species-specific polymerase chain reaction assay for rapid detection of Phytophthora nicotianae in irrigation water.* Phytopathology 93(7), 822-831.

Lane V. (2004). *Audit and gap analysis of nursery waste–water research and communication.* Horticulture Australia Final Report NY02024, 288 ss.

MacDonald J.D., Ali-Shtayeh M.S., Kabashima J., Stites J. (1994). *Occurrence of Phytophthora species in recirculated nursery irrigation effluents.* Plant Dis. 78(6), 607-611.

Mafia R.G., Alfenas A.C., Ferreira E.M., Machado P.S., Binoti D.H.B., Leite F.P., Souza F.L. (2008). *Reuse of untreated irrigation water as a vehicle of inoculum of pathogens in eucalyptus clonal nursery.* Trop. Plant Pathol. 33(2), 96-102.

McIntosh D.L. (1966). *The occurrence of Phytophthora spp. in irrigation systems in British Columbia.* Can. J. Bot. 44(12), 1591-1596.

McPherson G.M., Harriman M.R., Pattison D. (1995). *The potential for spread of root diseases in recirculating hydroponic systems and their control with disinfection.* Med. Fac. Landbouwkundige en Toegepaste Biologische Wetenschappen Univ. Gent 60(2b), 371-379.

Mebalds M., van der Linden A., Bankier M., Beardsell D. (1996). *Using ultra violet radiation and chlorine dioxide to control fungal plant pathogens in water.* The Nursery Papers Issue 5, 1-2.

Meszka B., Bielenin A. (2011). *Agrest – nowym gospodarzem dla Phytophthora cactorum.* Progress in Plant Protection 51(3), 1184-1187.

Milgroom M.G., Peever T.L. (2003). *Population biology of plant pathogens: The synthesis of plant disease epidemiology and population genetics.* Plant Dis. 87(6), 608-617.

Newman S.E. (2004). *Disinfecting irrigation water for disease management*. Paper presented at the 20th annual conference on pest management on ornamentals society of american florists, San Jose, California, 20-22 February, 1-10.

Norman D.J., Yuen J.M.F., Resendiz R., Boswell J. (2003). *Characterization of Erwinia populations from nursery retention ponds and lakes infecting ornamental plants in Florida.* Plant Dis. 87(2), 193-196.

Orlikowski L.B., Ptaszek M. (2009). *Rola chwastów ruderalnych i wody w przeżywalności i rozprzestrzenianiu Phytophthora cryptogea w środowisku.* Progress in Plant Protection 49(3), 1085-1091.

Orlikowski L.B., Ptaszek M., Meszka B. (2015). *Phytophthora cinnamomi – nowy patogen borówki wysokiej w Polsce.* Progress In Plant Protection 55(4), 472-477.

Orlikowski L.B. Ptaszek M., Trzewik A., Orlikowska T. (2011a). *Przydatność pułapek liściowych do detekcji Phytophthora spp. z wody.* Sylwan 155(7), 493-499.

Orlikowski L.B., Ptaszek M., Trzewik A., Orlikowska T. (2011b). *Occurrence of Phytophthora species in rivers, canals and water reservoirs in relation to its location, seasonal analysis and fungicide residues.* Ecological Chemistry and Engineering A 18(11), 1551-1556.

Orlikowski L.B., Ptaszek M., Trzewik A., Wierzchowski M. (2012). *Występowanie i ocena chorobotwórczości izolatów Phytophthora spp. uzyskanych z rzek i zbiornika wodnego.* Sylwan 156(7), 533-541.

Ptaszek M. (2017). *Byliny jako potencjalne źródło Phytophthora spp. dla roślin uprawnych*. Praca doktorska wykonana w Instytucie Ogrodnictwa, Skierniewice, 248 ss.

Park K.W., Lee G.P., Kim M.S., Lee S.J., Seo M.W. (1998). *Control of several fungi in the recirculating hydroponic system by modified slow sand filtration.* Korean J. Hortic. Sci. Technol. 16(3), 347-349.

Pettitt T.R., Finlay A.R., Scott M.A., Davies E.M. (1998). *Development of a system simulating commercial production conditions for assessing the potential spread of Phytophthora cryptogea root rot of hardy nursery stock in recirculating irrigation water.* Ann. App. Biol. 132(1), 61-75.

Rompaey G.V. (2015). Het maandelijkse vakblad voor glastuinbouw. Onder Glas, 1-3

Runia W.T., Amsing J.J. (2001). *Lethal temperatures of soilborne pathogens in recirculation water from closed cultivation systems.* Acta Hortic. 554, 333-339.

Runia W.T., Boonstra S. (2004). *UV-oxidation technology for disinfection of recirculation water in protected cultivation.* Acta Hortic. 644, 549-555.

Shokes F.M., McCarter S.M. (1979). *Occurrence, dissemination, and survival of plant pathogens in surface irrigation ponds in southern Georgia.* Phytopathology 69(5), 510-516.

Steadman J.R., Bay R.W., Hammer M.J. (1979). *Plant pathogen contamination in reused irrigation waste water.* Proc. Water Reuse Symposium 3, 2038-2045.

Steddom K. (2009). *Detecting Phytophthora in recycled nursery irrigation water in East Texas.* Phytopathology 99, S124.

Stewart-Wade S.M. (2011). *Plant pathogens in recycled irrigation water in commercial plant nurseries and greenhouses: their detection and management.* Irrigation Science 29(4), 267-297.

Themann K., Werres S., Diener H.A., Lüttmann R. (2002a). *Comparison of different methods to detect Phytophthora spp. in recycling water from nurseries.* J. Plant Pathol. 84(1), 41-51.

Themann K., Werres S., Lüttmann R., Diener H.A. (2002b). *Observations of Phytophthora spp. in water recirculation systems in commercial hardy ornamental nursery stock.* European J. Plant Pathol. 108(4), 337-343.

Thomson S.V., Allen R.M. (1974). *Occurrence of Phytophthora species and other potential plant pathogens in recycled irrigation water.* Plant Dis. Rep. 58(10): 945-949.

Ufer T., Posner M., Wessels H.P., Werres S. (2008a). *Untersuchungen zur Eliminierung von Phytophthora spp. aus recyclingwasser in Baumschulen mit Hilfe von Filtrationsverfahren.* Nachr. Dt. Pflanzenschutzd. 60(3), 45-61.

Ufer T., Werres S., Posner M., Wessels H.P. (2008b). *Filtration to eliminate Phytophthora spp. from recirculating water systems in commercial nurseries.* Plant Health Progress doi:10.1094/PHP-2008-0314-01-RS

Van Os E.A., van Kuik F.J., Runia W.T., van Buuren J. (1998). *Prospects of slow sand filtration to eliminate pathogens from recirculating nutrient solutions.* Acta Hort. 458, 377-382.

Vanninen I., Koskula H. (1998). Effect of hydrogen peroxide on agal growth, cucumber seedlings and the reproduction od shore flies (*Scatella stagnalis*) in rockwool. Crop Protection 17(6), 547-553

Werres S., Wagner S., Brand T., Kaminski K., Seipp D. (2007). *Survival of Phytophthora ramorum in recirculating irrigation water and subsequent infection of Rhododendron and Viburnum.* Plant Disease 91(8), 1034-1044.

Wohanka W., Helle M. (1996). *Suitability of various filter media for slow filtration*, p: 51-557. In: Proceedings of the Ninth International Congress on Soilless Culture, St Helier, Jersey, Channel Islands, 12-19 April 1996.

Wohanka W., Luedtke H., Ahlers H., Luebke M. (1999). *Optimization of slow filtration as a means for disinfecting nutrient solutions.* Acta Hortic. 481, 539-544.

Yiasoumi W. (2005). *Water disinfecting techniques for plant pathogen control*. Comb. Proc. Int. Plant Prapag. Soc. 55, 138-141.

Zheng Y., Dunets S. (2012). *Slow sand filtration. Greenhouse and nursery water treatment information system.* Univ. of Guelph, Ontario, Canada, 1-9.

Corresponding author: prof. dr hab. Leszek B. Orlikowski
prof. dr hab. Waldemar Treder
mgr Magdalena Ptaszek
mgr Aleksandra Trzewik
dr Waldemar Kowalczyk
Urszula Łazęcka
Research Institute of Horticulture,
Skierniewice, Poland
e-mail: Leszek.Orlikowski@inhort.pl

Received:24.05.2017
Accepted: 10.09.2017