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Liverwort Control: An Ancillary Role for Ozone-based Irrigation Water Treatment Systems?

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***Abstract. Marchantia polymorpha* L. (a thalloid liverwort) is a common plant pest in nursery and greenhouse production systems. The rapid growth and dissemination of this pest can result in heavy mats of thallus tissue on the surface of pots, which restrict water penetration, compete for nutrients, and provide a habitat for other pests and disease vectors. The sensitivity of liverwort to aqueous ozone was examined to determine if routine use of ozone, as a component of an irrigation water remediation strategy, could provide ancillary services in the form of liverwort management. Three experiments were performed to evaluate contact time (CT) thresholds and application frequencies suitable for liverwort management applications. The first two experiments confirmed that CT is a suitable process control parameter with a base liverwort management threshold occurring between CT 0.84 and 1.68 mg·L^{-1}·min under the conditions used. The third experiment examined the effect of application frequency at a CT of 3.75 mg·L^{-1}·min, which was previously determined to be compatible with select woody perennial species. Three and five applications per week resulted in reduced liverwort growth and fecundity.**

Marchantia polymorpha L., a common thalloid liverwort, is a significant weed species in nursery and greenhouse operations across North America and Europe, being particularly problematic in propagation houses where the environmental conditions maintained for newly established potted plants are ideal for rapid liverwort establishment (Svenson et al., 1997) (Note: for the purposes of this article, the term liverwort refers only to the species *M. polymorpha*). Liverwort reproduces sexually through spore formation and asexually through tissue fragmentation and the production of gemmae, clonal fragments produced in specialized structures called gemma cups (Altland et al., 2003; Svenson et al., 1997). Combined, these reproductive strategies enable the rapid distribution and development of liverwort on the surface of nursery container growth substrates (Fig. 1).

In potted plant production, liverwort infestations present a clear impediment to water and nutrient infiltration (Fig. 1), thereby reducing the growth and value of the crop (Svenson et al., 1997). This diversion results in higher water and fertilizer demands, which translates to greater production costs, reduced productivity, and environmental impacts in the form of excessive water taking and increased nutrient discharge from the production facility.

A heavy liverwort infestation also provides a habitat for other pests and potential pathogens such as fungus gnats (*Bradysia* spp. *Sciaridae*), snails (e.g., *Helix* spp.), slugs (e.g., *Deroceras* spp.), and a host of microbial threats such as *Fusarium* spp. and *Pythium* spp. (Svenson et al., 1997). Additional costs to control these pests, combined with production losses resulting from their activity, further erode profit margins.

Impacts of a significant liverwort infestation (on profit margins) continue to be realized once a potted crop reaches marketable size. The presence of liverwort is considered unsightly and often taken as an indication of reduced quality or plant vigor, all of which impact the final valuation of the crop.

A significant amount of research has been conducted to evaluate chemical compounds for the control of liverwort (Newby, 2006). Svenson et al. (1997) provide a list of compounds purported to have some efficacy in the control of liverwort. Although potentially effective under prescribed conditions, many of the listed chemicals are not registered for liverwort control. Lack of registered control products leaves growers with few options beyond hand removal.

Hand removal is a costly method of weed control by any measure and can increase the unit cost of production dramatically. Estimates put the cost of supplemental hand weeding (not exclusive to liverwort) at \$1235–\$9880 per ha (Case et al., 2005; Judge et al., 2004). In addition to the direct labor costs associated with hand removal, the physical removal of weeds also removes a portion of the upper layer of substrate (including surface-applied slow-release fertilizer), thereby damaging roots in the upper segment of the pot. The cost of hand removal and the impacts that the practice has on substrate structure and root vigor necessitates continued effort to develop alternative control strategies.

Dissolving highly reactive ozone (O_3) gas in irrigation solutions (ozonation) is an emerging agricultural water remediation technology that has garnered favor on both environmental and operational efficacy grounds. Ozone is a highly effective antimicrobial agent while also being reactive with many chemical contaminants that may be present in irrigation source water. Furthermore, in a time when organic markets are outpacing traditional agricultural commodity markets, with organic products commanding significant price premiums (Kendrick, 2008), ozone is one of the few disinfection options compatible with organic production methods and certification bodies. Ozone's acceptance as an organically compatible intervention technology is based largely on the fact that there are no ozone residuals remaining on the crop after application. Residual ozone (not consumed as a part of the treatment) spontaneously reverts to diatomic oxygen (O_2) in a complex process that further enhances the antimicrobial effect.

This study has focused on aqueous ozone [$O_{3(aq)}$] (in the context of this study, aqueous ozone refers to water that retains a residual ozone concentration) as a potential component of an overall liverwort management program when the technology (ozonation system) is already used as an irrigation water remediation tool. Aqueous ozone has a long history of water and wastewater treatment applications and in recent years has also gained some momentum as an irrigation water treatment technology in nursery and greenhouse production (Ehret et al., 2001; Graham et al., 2009; McDonald, 2007). Operators that use ozonation as a component of their irrigation water treatment system tend to use it in batch format. The water is treated with ozone and stored in tanks to allow the residual ozone to revert to O_2. Alternatively, the solutions are passed through filters that break down the residual ozone.

The removal of the ozone before distribution to the crop provides an opportunity for re-inoculation of the solution from biofilms found on the distribution system hardware. The removal of the disinfecting agent also disallows any potential for in situ pathogen control through direct ozone contact with

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