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Note

Curlyleaf pondweed (*Potamogeton crispus*) control using copper–ethylenediamine alone and in combination with endothall

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INTRODUCTION

Curlyleaf pondweed (*Potamogeton crispus* L.) is a submersed, aquatic, invasive plant species in the United States, particularly in northern states (Stuckey 1979). It first arrived in the United States in the 1800s and subsequently spread to the 48 contiguous states (Stuckey 1979, Les and Mehrhoff 1999). Curlyleaf pondweed grows rapidly and is capable of outcompeting native plant species for nutrients and resources, thereby altering biotic and abiotic processes in infested water bodies (Cheruvelil et al. 2002, James et al. 2002). Besides affecting native biota and ecological processes, curlyleaf pondweed forms dense canopies that can inhibit human uses of a water body (i.e., fishing, boating, irrigation, among others). Therefore, continued development of control strategies and a better understanding of the life history are needed to attain control of curlyleaf pondweed–infested water bodies.

In northern U.S. states curlyleaf pondweed behaves as a winter annual, typically reproducing through turion production and rhizome elongation (Bolduan et al. 1994, Woolf and Madsen 2003). Turions are vegetative structures that fall from plants in the early summer, lie dormant on the substrate of a water body during summer months, then sprout and begin growing into new plants in the fall (Sastroutomo 1981, Catling and Dobson 1985, Chambers et al. 1985, Woolf and Madsen 2003). Plant growth slows during winter months and then quickens again in the spring before turion production (Woolf and Madsen 2003). In northern populations, the turion bank in sediments is responsible for regrowth of a population year after year (Woolf and Madsen 2003, Johnson et al. 2012).

Herbicides used to control curlyleaf pondweed are commonly applied in the weeks preceding turion production in the spring to inhibit that process during the period when carbohydrate storage has been depleted and treated plants are less likely to recover from herbicide-induced stress (Netherland et al. 2000, Woolf and Madsen 2003, Johnson et al. 2012). The systemic herbicide fluridone and the contact herbicides endothall and diquat at low doses have repeatedly been shown to control of curlyleaf pondweed biomass and turion production in mesocosm and field settings (Netherland et al. 2000; Skogerboe and Getsinger 2002; Poovey et al. 2002, 2008; Skogerboe et al. 2008; Johnson et al. 2012). However, each of those herbicides have attributes (i.e., nonselective nature, toxicity to fish and aquatic invertebrates, sediment binding, long contact time, water use restrictions, cost) that make them less than ideal for use in some settings. Thus, use patterns of other herbicide technologies need to be studied to provide viable control options in locales in which the use of the aforementioned herbicides is not desired.

Although copper formulations are commonly considered algaecides, some formulations of copper are labeled for control of some submersed, aquatic plant species, including the invasive aquatic plant hydrilla [*Hydrilla verticillata* (L. f.) Royle] (Sartain 2014, Turnage et al. 2015). The mode of action of copper-based herbicides is not well understood, but they are suspected to disrupt the photosynthetic process at photosystem two (Vencill 2002). Archer and Bachman (1974) demonstrated that copper sulfate can control some pondweed species (*Potamogeton* L. spp. and *Zannichellia* L. sp.). Similarly, Sartain (2014) showed that submersed applications of copper–ethylenediamine provided control of hydrilla and sago pondweed [*Stuckenia pectinatus* (L.) Borner] but not American pondweed (*Potamogeton nodosus* Poir) in a mesocosm trial, which would suggest that different plant species have differing levels of tolerance to copper (Schmidt and Kannenburg 1998). However, various copper formulations differ in the level of control seen in submersed, aquatic plant species. Turnage et al. (2015) found in a mesocosm study that copper–ethylenediamine was just as effective as diquat alone, other copper formulations (copper–ethanolamine and emulsified copper–ethanolamine) alone and as mixtures with diquat at controlling hydrilla growing with a native plant species, American lotus (*Nelumbo lutea* Willd.). However, using copper formulations provided selectivity, whereas diquat

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and diquat combinations were not selective in control. We hypothesized that copper–ethylenediamine alone and in tank mixture with endothall would provide significant control of curlyleaf pondweed.

MATERIALS AND METHODS

The study was conducted at the R. R. Foil Plant Science Research Center, Mississippi State University (Starkville, MS) in 40-L (10.6 gal) mesocosms from April through June 2016. Curlyleaf pondweed was propagated from stock cultures at Mississippi State University in April. Turions were collected from the bottom of propagation tanks and placed in an 18.9-L bucket of water for 7 d to stimulate sprouting. Once sprouted, two turions were planted in 0.47-L containers filled with sediment. Sediment was amended with Osmocote[1] (19–6–12 [N–P–K]) fertilizer at rate of 2 g L^{-1} (0.267 oz gal^{-1}) of soil. Plants were allowed to grow for 1 mo before herbicide application. There was an untreated reference and 11 herbicide treatments: three endothall[2] treatments, two copper–ethylenediamine[3] (hereafter *copper*) treatments, and six endothall + copper mixtures, for 12 treatments (Figure 1). In total, there were 48 mesocosms (four per treatment) and 336 containers planted with curlyleaf pondweed (seven per mesocosm). One container was harvested per mesocosm before herbicide application in May 2016. If present, the number of turions per plant was recorded. Harvesting consisted of washing and separating aboveground, belowground, and turion plant tissues and placing them into separate, labeled paper bags. Plant tissues were dried at 70 C for 5 d. After drying, plant tissues were weighed. Plants were exposed to treatments for 24 h, then mesocosms were drained and refilled. At 4 wk after treatment (WAT) and 8 WAT, three containers were harvested from each mesocosm, and plant tissues were processed using the same methodology as that used for pretreatment specimens.

Mean biomass and count data were statistically analyzed using a one-way ANOVA. Any statistical differences detected were further separated using a Fisher's Protected LSD test. All statistical analyses were conducted at the $P =$ 0.05 level of significance in Statistix 9.0 software[4] (Analytical Software 2009).

RESULTS AND DISCUSSION

By 4 WAT, all herbicide treatments provided significant reduction of curlyleaf pondweed aboveground biomass when compared with the untreated reference (Figure 1A). At 4 WAT, both copper treatments provided the same level of control as 0.75 and 1.25 ppmv endothall and all endothall + copper tank mixes. The 0.25 ppmv endothall treatment, although providing significantly less control than the 1.25 ppmv endothall application, had the same level of control as the copper treatments and the 0.75 ppmv endothall treatment and still provided a significant decline in aboveground biomass when compared with the untreated reference. At 4 WAT, all tank mixtures had the greatest level of control, as did the copper treatments and the 0.75 ppmv and 1.25 ppmv endothall treatments.

By 8 WAT, only 1.25 ppmv endothall and the endothall + copper treatments (except 0.25 ppmv endothall + 1.0 ppmv copper) had significantly less aboveground biomass than the untreated reference (Figure 1B). By 8 WAT, all endothall treatments provided an equivalent level of control, and the same as the 1.0 ppmv copper. The low dose of copper had the same level of control as all treatments (including reference plants), except the 1.25 ppmv endothall, which had a statistically higher level of control. Reference plant aboveground biomass also declined from pretreatment levels, suggesting that plant senescence had started to occur by 8 WAT.

By 4 WAT, all herbicide treatments had significantly reduced curlyleaf pondweed belowground biomass, when compared with reference plants that were still near pretreatment levels (Figure 1C).

Belowground biomass in reference plants at 8 WAT was not significantly different from that in herbicide treatments but had declined from pretreatment levels (Figure 1D), again suggesting that plants had started to senesce at that point. Interestingly, belowground biomass in 0.25 ppmv endothall + 1.0 ppmv copper was statistically greater than in all treatments, except 0.5 ppmv copper and reference plants. The 0.5 ppmv copper treatment had the same level of control over belowground biomass as all other herbicide treatments and the reference plants.

Because turion biomass and number are linked, the pattern of control in one was identical to the other. For that reason, we only report the findings of turion biomass here (Figures 1E and 1F). At 4 WAT, all treatments, except 0.25 ppmv endothall, had significantly reduced turion biomass (Figure 1E) when compared with untreated reference plants. However, 0.25 ppmv endothall provided the same statistical level of control over turion biomass as all other herbicide treatments at 4 WAT.

Turion biomass had been significantly reduced at 8 WAT by all treatments, except 0.5 ppmv copper and 0.25 ppmv endothall + 1.0 ppmv copper, when compared with the untreated reference (Figure 1F). Turion biomass of plants exposed to 0.5 ppmv copper had the same level of control as all other treatments, except 0.25 ppmv endothall + 1.0 ppmv copper, which had more turion biomass than all other herbicide treatments. Turion biomass at 8 WAT had increased in reference plants from levels seen pretreatment, which is expected because plants typically produce turions in the weeks preceding senescence.

At this time, it is unknown why the 0.25 ppmv endothall + 1.0 ppmv copper treatment results showed no curlyleaf pondweed control at 8 WAT, because the other tank mixtures of the two herbicides in this study gave significant control of curlyleaf pondweed. The results of this study suggest that copper–ethylenediamine alone and in tank mixtures with endothall is a viable treatment option for controlling curlyleaf pondweed biomass and turion production, which would be beneficial in waters used for irrigation because copper–ethylenediamine carries no irrigation restrictions. Thus, water treated with this herbicide would be usable at the conclusion of the 24-hr exposure period.

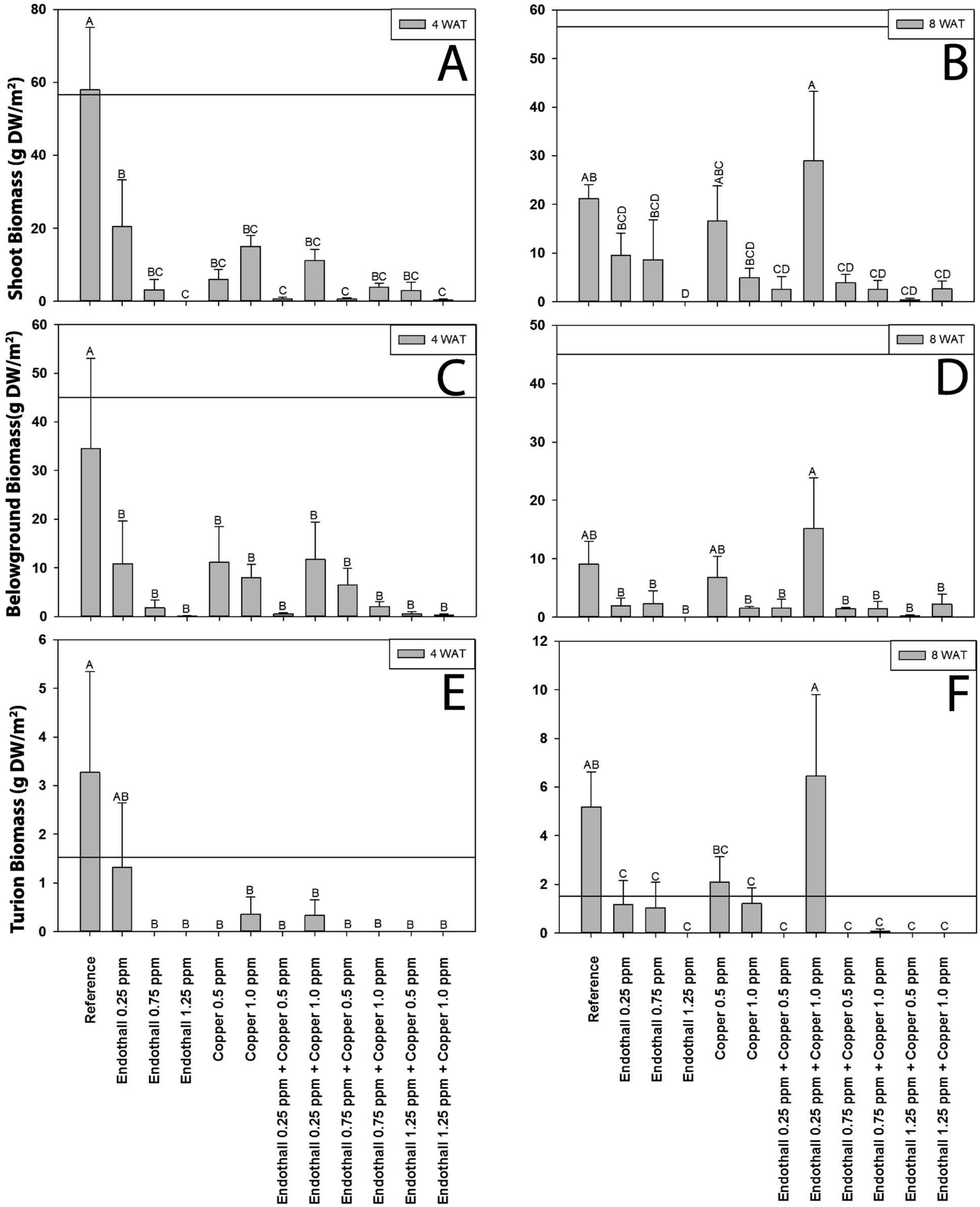

Figure 1. Curlyleaf pondweed mean aboveground biomass (A and B), belowground biomass (C and D), and turion biomass (E and F). Panels in left column are data for 4 wk after treatment (WAT), and the right column is data for 8 WAT. Solid lines are pretreatment means. Within a panel, bars that have the same letter above are not significantly different from one another at the $P = 0.05$ level of significance.

Levels of curlyleaf pondweed control seen in this study were similar to those seen in other mesocosm and growth chamber studies investigating the use of the contact herbicides diquat and endothall for curlyleaf control (Netherland et al. 2000; Poovey et al. 2002; Glomski and Netherland 2013). Glomski and Netherland (2013), in a growth chamber study, showed that curlyleaf pondweed was sensitive to flumioxazin but not carfentrazone-ethyl, both of which are contact herbicides; however, they did not assess biomass levels or turion densities in that study.

Field studies investigating the use of contact and systemic herbicides alone and in combination have also shown similar levels of curlyleaf pondweed control as found in our work (Smith and Pullman 1997; Madsen et al. 2002; Skogerboe and Getsinger 2002, 2006; Skogerboe et al. 2008; Johnson et al. 2012). Endothall has been used extensively in field trials and has shown effective control of curlyleaf pondweed in multiple studies at various application rates (Madsen et al. 2002; Skogerboe and Getsinger 2002, 2006; Skogerboe et al. 2008; Johnson et al. 2012). Fluridone has also been shown to effectively control curlyleaf pondweed in field settings if sufficient concentration–exposure time can be maintained; however, damage to native species usually occurs (Smith and Pullman 1997; Madsen et al. 2002; Johnson et al. 2012).

This work shows that copper-based herbicides may be of use controlling curlyleaf pondweed. Furthermore, damage to native species (except pondweeds) should be minimal because many submersed plant species are tolerant of copper-based herbicides (Vencill 2002). Future studies should investigate multiple exposure times of curlyleaf pondweed to copper–ethylenediamine and other copper herbicide formulations, alone and as tank mixes with other herbicides, in mesocosm and field settings.

SOURCES OF MATERIALS

[1]Osmocote 19–6–12 fertilizer, Scotts-Sierra Horticultural Products Company, 14111 Scottslawn Road, Marysville, OH 43041.

[2]Aquathol K, United Phosphorous Inc., 630 Freedom Business Center Drive, King of Prussia, PA 19406.

[3]Harpoon Aquatic Herbicide (copper ethylenediamine 8%), Applied Biochemists, W175N11163 Stonewood Drive, Suite 234, Germantown, WI 53022.

[4]Statistix 9.0 software, Analytical Software, P.O. Box 12185, Tallahassee, FL, 32317.

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