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Note

Evaluating the efficacy of granular copper and triclopyr alone and in combination for control of flowering rush (*Butomus umbellatus*)

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INTRODUCTION

The invasive, emergent aquatic plant, flowering rush (*Butomus umbellatus* L.), was first introduced into North American lakes and rivers in the late 1800s. Since its introduction, flowering rush has become a problem in many northern tier U.S. states and southern Canada (Core 1941, Countryman 1970; Anderson et al. 1974; Kliber and Eckert 2005). Flowering rush thrives in lakes, reservoirs, and water bodies with high water exchange rates (Core 1941) as a submersed or emergent plant (Countryman 1970). Flowering rush forms dense rhizomatous networks that produce aboveground foliage from rhizome buds annually (Marko et al. 2015). Although the emergent plants are susceptible to foliar applications of herbicides (Wersal et al. 2014), there are no widely accepted use patterns for managing submersed plants, especially if plants are growing in flowing water. Small-scale research found little to no control with subsurface applications of 2,4-D, triclopyr, or imazamox (Wersal at al. 2014). Submersed applications of the contact herbicides endothall and flumioxazin, alone or in combination with auxinic herbicides, reduced shoot and root biomass but failed to reduce rhizome biomass in a growth chamber trial (Poovey et al. 2013). Field trials using two submersed diquat applications per year in the Detroit Lakes successfully controlled shoot biomass and reduced rhizome bud density (Madsen et al. 2016a).

Most of the herbicides evaluated for control of flowering rush have been liquid formulations, with few if any studies focusing on the use granular formulations of herbicides (Wersal et al. 2014; Poovey et al. 2012, 2013; Madsen et al. 2016a, 2017). Granular herbicides are regularly used when the desired herbicide application needs to be made near the sediment surface or to maintain herbicide concentration at a site with high water exchange rates (Koschnick et al. 2010; Haug and Bellaud 2013) and, thus, may be an effective option for flowering rush management in those areas by minimizing the herbicide dissipation that is often seen with liquid products. The objective of this study was to evaluate flowering rush response to liquid and granular copper-ethylenediamine and granular triclopyr formulations, alone and in combination, to control flowering rush.

MATERIALS AND METHODS

The study was conducted at the R. R. Foil Plant Science Research Center (Mississippi State University, Starkville, MS) in 39 mesocosms (1,140 L) from September 2011 to April 2012. Flowering rush was propagated from stock cultures at Mississippi State University, which were originally collected from Idaho and Minnesota. Genetic analysis using amplified fragment-length polymorphisms confirmed both populations were identical (Poovey et al. 2012). In September 2011, six rhizome segments (15 cm) were planted into flat containers (0.19 m^2) filled with a mixture of topsoil, loam, and masonry sand. The sediment was amended with Osmocote[1] (19–6–12 [N–P–K]) fertilizer at a rate of 2 g L^{-1} of soil to encourage plant growth. Two containers were placed into each of the 1,140 L mesocosms, with water volume of approximately 757 L (41 cm depth). Three additional mesocosms were planted for pretreatment biomass assessments. Flowering rush was allowed to overwinter and regrow in the spring before herbicide application.

After regrowth started in the spring, plants were allowed to grow until they reached an average height of 0.31 m (12.20 in), which follows treatment recommendations in the granular copper-ethylenediamine label for a 0.75 mg L^{-1} application to submersed vegetation (Lonza 2013). Before herbicide application, pretreatment plants were harvested by separating aboveground and belowground biomass. Plant structures were washed to remove dirt and debris, placed into labeled paper bags, and dried at 70 C for 5 d. After pretreatment harvest, the granular and liquid herbicides listed in Table 1 were applied to flowering rush. Granular herbicides were spread evenly over the water surface, whereas liquid herbicides were applied subsurface as a

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Table 1. Herbicides and concentrations for control of flowering rush. Protein solution in Treatments 6–8 was added at the rate of 1μm L^{-1}, rather than at a target concentration.

Treatment	Herbicide	Target Concentration (μg/L)
1	Granular copper–ethylenediamine[3]	750
2	Copper–ethanolamine complex[4]	500
3	Granular triclopyr[5]	1,500
4	Granular copper–ethylenediamine[3] + granular triclopyr[5]	750 + 1,500
5	Copper–ethanolamine complex[4] + granular triclopyr[5]	500 + 1,500
6	Protein solution[6] + granular copper–ethylenediamine[3]	1[b] + 750
7	Protein solution[6] + granular triclopyr[5]	1[b] + 1,500
8	Protein solution[6] + copper–ethanolamine complex[4] + granular triclopyr[5]	1[b] + 500 + 1,500
9	Untreated reference	0

concentrated aqueous solution to achieve the target concentrations. All treatments were maintained as a static exposure and replicated four times. At 6 wk after treatment (WAT), all viable aboveground and belowground biomass was harvested, washed, and dried using the same methods as performed with pretreatment samples.

A general linear model was used to analyze treatment effects on both aboveground and belowground biomass using SAS software[2] (Stokes et al. 2000). If a significant treatment effect was detected, means were separated using the Fisher's Protected LSD procedure at $P > 0.05$ significance level.

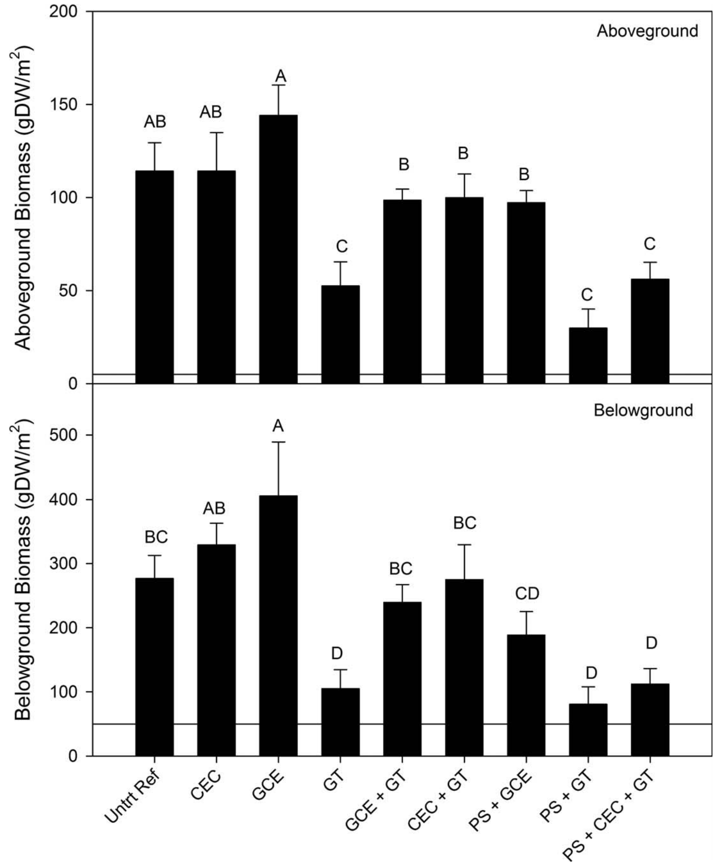

Figure 1. Mean (± 1 SE) aboveground and belowground biomass of flowering rush 6 wk after treatment with combinations of copper, triclopyr, and protein solution. Bars sharing the same letters are not significantly different according to a Fisher's Protected LSD test ($P < 0.05$). The solid horizontal lines represent pretreatment biomass. In labels on the x-axis, Untrt Ref = untreated reference, CEC = copper ethanolamine complex, GCE = granular copper ethylenediamine, GT = granular triclopyr, PS = protein solution. Herbicide concentrations are reported as milligrams per liter in parentheses after abbreviations.

RESULTS AND DISCUSSION

Copper, regardless of formulation, and in combination with triclopyr, failed to control flowering rush. The addition of protein solution to copper treatments yielded no increase in control of aboveground or belowground biomass, except when granular triclopyr was also added to the mixture (Figure 1). Plants treated with granular triclopyr alone and in combination with copper and the protein solution had significant reductions in biomass over the course of the study (Figure 1). Results for both aboveground and belowground biomass suggest that there may be an antagonistic interaction between copper and triclopyr formulations when used in combination on submersed flowering rush, although that would need to be verified with a balanced study and the use of the Isobole or Colby methods (Colby 1967, Armel et al. 2007) to test for a specific interaction effect.

Triclopyr applied to flowering rush, alone or in combination with the protein solution, resulted in a significant reduction in both aboveground and belowground biomass. Aboveground biomass was reduced 51 and 74% when triclopyr was applied alone or with a protein solution, respectively (Figure 1). Similarly, belowground biomass was reduced 60 and 71% in the same treatments, respectively. Madsen et al. (2017) reported liquid triclopyr applied at 18.75 L ha^{-1} directly to moist soil resulted in a reduction of aboveground biomass by 12 WAT and a reduction in belowground biomass by 24 WAT. Those results suggest that triclopyr applied as a bare-ground treatment or an in-water treatment may be effective in reducing rhizome biomass under field conditions. However, limited data exist with respect to field trials on flowering rush both as in water and bare-ground treatments (Madsen et al. 2017).

It is unclear why copper would have a negative interaction with triclopyr because the use of contact herbicides with auxin herbicides has been established in both small and field-scale trials for control of submersed plant species (Madsen and Wersal 2009, Madsen et al. 2010, Wersal et al. 2011, Getsinger et al. 2013, 2014). In addition, it is unclear why the addition of an herbicide adjuvant (e.g., protein solution) would have lessened that interaction, although, from this study, there was a clear advantage to including the protein solution when copper and triclopyr were mixed. The addition of protein solution to granular triclopyr yielded no statistical increase in control (74% aboveground and 71% belowground biomass reduction compared with reference plants) over plants treated with triclopyr alone (54% aboveground and 62% belowground reduction compared with reference; Figure 1). The addition of the copper products to granular triclopyr had no effect on flowering rush biomass when compared with reference plants. However, when protein solution was added to the triclopyr-copper mixture, control levels were statistically similar (51% aboveground and 60% belowground biomass reduction compared with reference; Figure 1) to those of triclopyr alone or in combination with protein solution. It is hypothesized that the addition of the protein solution may have enhanced the growth of flowering rush, thereby increasing herbicide uptake of both copper and triclopyr. The increased uptake of triclopyr may have offset any negative interactions of being combined with copper because more of the systemic herbicide could have been present at sites of action before tissue degradation by the contact herbicide. Based on these results, granular triclopyr is an effective control option not only to reduce aboveground biomass but also to reduce belowground biomass of flowering rush, one of few products to do so (Poovey et al. 2013, Wersal et al. 2014). However, formulation may be a key factor in controlling flowering rush with triclopyr. In a mesocosm trial, Madsen et al. (2016b) found that a liquid formulation of triclopyr at a rate of 2.0 mg L^{-1} had no effect on flowering rush biomass. Despite the efficacy of three of the treatments used in this study, none of the treatments provided > 74% aboveground or 71% belowground biomass reduction. Investigations assessing the control of flowering rush by granular and liquid triclopyr formulations alone and in mixture with the protein solution used here should be performed. Future studies should be conducted to establish concentration exposure–time relationships with granular triclopyr products when applied to flowering rush.

SOURCES OF MATERIALS

[1]Osmocote, Scotts-Sierra Horticultural Products Company, 14111 Scottslawn Road, Marysville, OH 43041.

[2]SAS statistical software, SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513-2414.

[3]Harpoon Granular Aquatic Herbicide, Applied Biochemists, W175N11163 Stonewood Drive, Suite 234, Germantown, WI 53022.

[4]Cutrine-Ultra Algaecide/Herbicide/Cyanobactericide, Applied Biochemists, W175N11163 Stonewood Drive, Suite 234, Germantown, WI 53022.

[5]Navitrol DPF, Applied Biochemists, W175N11163 Stonewood Drive, Suite 234, Germantown, WI 53022.

[6]Aqua-Prep, Applied Biochemists, W175N11163 Stonewood Drive, Suite 234, Germantown, WI 53022.

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