

Efficacy of combinations of diquat or triclopyr with fluridone for control of flowering rush

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ABSTRACT

Flowering rush (*Butomus umbellatus* L.) is an emerging invasive aquatic weed in the northern tier of the United States and southern Canada. Although several management approaches have been tested, submersed treatment with diquat is the only use pattern substantiated with field efficacy data. We tested treatments of fluridone ($30 \mu\text{g L}^{-1}$) with and without prior treatment with either diquat (0.19 mg L^{-1}) or triclopyr (2 mg L^{-1}), as well as diquat (0.19 mg L^{-1}) or triclopyr (2 mg L^{-1}) alone. Each treatment, and an untreated reference, was replicated in four 380-L tanks at an experimental mesocosm facility. After 8 wk, all treatments were harvested, and pots separated into above- and belowground biomass. The number of ramets and rhizome buds in each pot was also counted. Triclopyr was not effective in reducing above- or belowground biomass, or rhizome bud density. Both diquat and fluridone alone were effective in reducing above- and belowground biomass and rhizome bud density, with no statistical difference between treatments. Pretreatment with diquat did not improve the efficacy of fluridone treatments. Results suggest fluridone may be an option for flowering rush control in sites where an adequate exposure time can be maintained.

Key words: aquatic weed, *Butomus umbellatus* L., herbicide, invasive plant, management.

INTRODUCTION

Flowering rush (*Butomus umbellatus* L.) is an emerging invasive plant in the Great Lakes and Pacific Northwest regions (Ling 2009, Woolf et al. 2011). It is native to Europe and Asia and first entered the United States in 1928 (Muenscher 1930, Tutin et al. 1980). The biology and ecology of flowering rush is not well understood in its North American range, and this lack of phenological information limits the development of effective management approaches. Although some success has been shown with submersed treatments of the contact herbicide diquat in the laboratory and field, repeated treatments are required to achieve acceptable control, and some jurisdictions limit diquat application (Madsen et al. 2012, Poovey et al. 2012, Madsen et al. 2013). For example, some states and

federal agencies in the Pacific Northwest will not approve the use of diquat in waters under their purview because of concerns with endangered species survival, primarily salmonid species. Multiple herbicide approaches must be developed for flowering rush management, in addition to the submersed use of diquat. Currently, there are no herbicide use patterns demonstrating effective control of flowering rush in field settings that utilize a systemic herbicide, and no management plans for flowering rush that demonstrate more than seasonal control. Clearly, an effective herbicide use pattern for long-term flowering rush control is needed by natural resource managers and irrigation districts in the Pacific Northwest and the Great Lakes regions. The purpose of this study was to evaluate a new management strategy in which either diquat or triclopyr is used to control standing flowering rush (chemical burn-down of standing vegetation), followed by a sustained control with fluridone. We hypothesized that early re-growth of flowering rush shoots after removal of mature shoots with diquat or triclopyr will be more sensitive to fluridone than will mature standing leaf biomass.

MATERIALS AND METHODS

This experiment was conducted at the R. R. Foil Plant Research Center, Mississippi State University, MS, in aboveground 380-L tanks at the experimental mesocosm facility. Six treatments were utilized: an untreated reference, diquat¹ alone (0.19 mg L^{-1}), a combination of diquat (0.19 mg L^{-1}) and fluridone² ($30 \mu\text{g L}^{-1}$), triclopyr³ alone (2 mg L^{-1}), a combination of triclopyr (2 mg L^{-1}) and fluridone ($30 \mu\text{g L}^{-1}$), and fluridone alone ($30 \mu\text{g L}^{-1}$). Each treatment was replicated in four tanks, for a total of 24 tanks. Treatments were made as subsurface injections of herbicide, not to emergent foliage. Seven 3.8-L pots⁴ were planted with two flowering rush rhizome segments each, with one pot per tank harvested for pretreatment biomass the day before treatment. Flowering rush plants were obtained from a culture of triploid plants from Detroit Lakes, MN (Lui et al. 2005). Flowering rush was planted in a soil medium of sand amended with 1 g of granular fertilizer.⁵ Tanks were brought to a volume of 276 L, with water supplied from an irrigation source pond on the experimental farm land.

This study was planted on 7 June 2013 and treated on 24 June 2013. At the time of treatment, plants were growing vigorously and were approximately 50 cm tall. The total water depth in the tanks was *ca.* 40 cm, with 25 cm of plant leaf submersed and another 25 cm of the leaves emergent. Biomass samples were collected before treatment on 23 June 2013. As with posttreatment vegetation sampling,

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plants were divided into belowground (rhizomes and roots) and aboveground (shoots and inflorescences, if any) biomass, with the number of ramets and rhizome buds recorded. Treated water was drained from all tanks 72 h after treatment, refilled, and drained twice to remove herbicide residues. Tanks that were originally treated with fluridone were retreated at this time using the same initial concentration of fluridone. Therefore, the combination treatments are best expressed as either diquat or triclopyr followed by a fluridone treatment. Water remained in retreated and nonretreated tanks for the duration of the study. After retreatment, a visual estimate of percent control relative to the untreated reference was recorded weekly for the duration of the study. Visual percent control estimates were based on the status of the treatment tanks relative to the untreated reference tanks. Treatment percent control was based on plant color, plant height, plant density and abundance, and number of empty pots (e.g., complete control). At 8 wk after treatment (WAT), all plants were harvested. The number of rhizome buds and ramets in each pot was recorded before drying the samples. Samples were dried for 72 h at 70 C. After drying, above- and belowground biomass were measured. Rhizome bud density, ramet density, aboveground biomass, and belowground biomass are all metrics that can be used to ascertain energy allocation within the plant and to measure effectiveness of herbicide treatments.

Statistical analysis compared rhizome bud density, ramet density, aboveground biomass, and belowground biomass for each treatment using an analysis of variance, with mean separation by Fisher's Protected LSD, using commercially-available software⁶ for statistical analysis.

RESULTS AND DISCUSSION

On the basis of a visual estimate of percent control, diquat and diquat followed by fluridone mixtures showed 90 and 85% visual control, respectively, by 1 WAT. However, by the end of the study (8 WAT), plants treated with diquat were starting to recover (60% control), whereas plants treated with diquat and fluridone still showed 85% visual control. Triclopyr, triclopyr followed by fluridone, and fluridone treatments exhibited 30, 30, and 20% control, respectively, 1 WAT, and mortality did not exceed 45% during this experiment. At harvest 8 WAT, mortality of these three treatments was 5, 28, and 28%, respectively. By 8 WAT, plants treated with triclopyr alone showed almost no difference in aboveground biomass when compared with reference plants.

No significant difference in rhizome bud density was observed between reference plants and those treated with only triclopyr (Figure 1A). Plants treated with diquat, diquat followed by fluridone, triclopyr followed by fluridone, and fluridone had a significantly lower rhizome bud density than the reference plants. Diquat, diquat followed by fluridone, and fluridone had the lowest rhizome bud density recorded. Statistically, there was no increase in rhizome bud control by following a diquat treatment with a fluridone treatment, and no difference between treating with diquat alone or fluridone alone. Diquat and fluridone treatments significantly reduced bud density. Since the rhizome bud is the critical

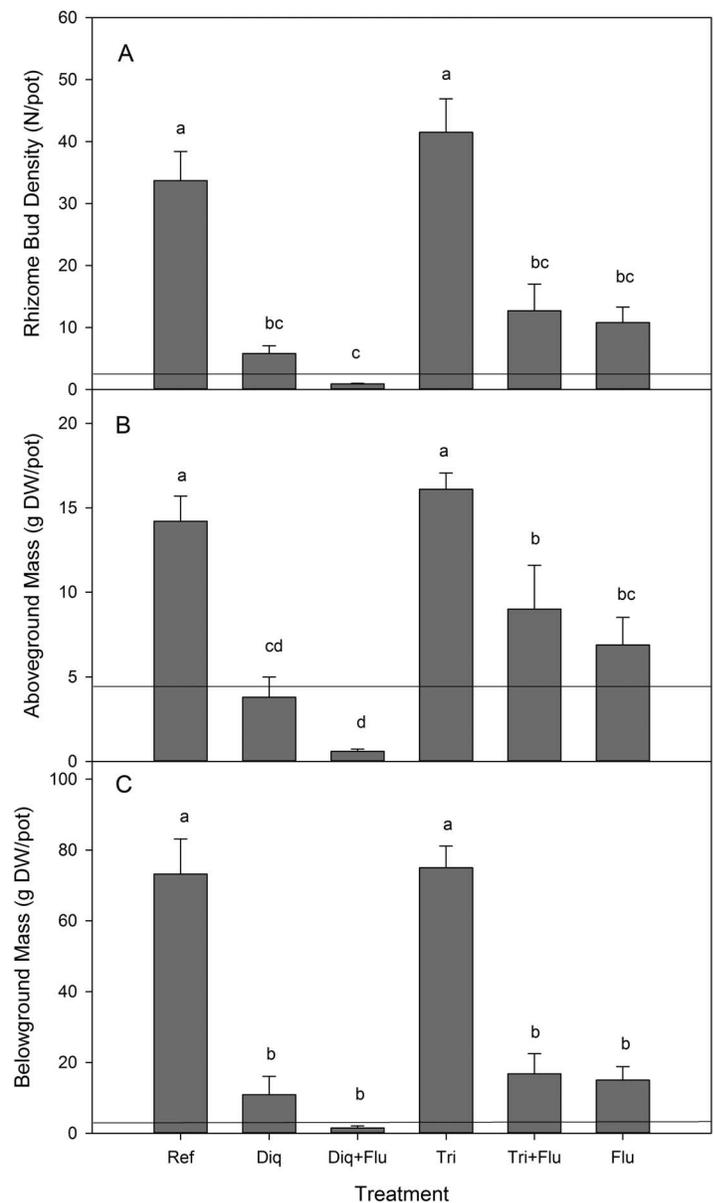


Figure 1. Flowering rush (*Butomus umbellatus* L.) response to six herbicide treatments at 8 wk after treatment (WAT) in a mesocosm tank experiment in Starkville, MS. Treatments are Ref, untreated reference; Diq, diquat alone; Diq fb Flu, diquat followed by fluridone; Tri, triclopyr alone; Tri fb Flu, triclopyr followed by fluridone; Flu, fluridone alone. (A) Rhizome bud density (n/pot) for untreated reference and six treatments at 8 WAT. Bars sharing the same letter are not significantly different, $P < 0.05$. Error bars represent +1 standard error of the mean. (B) Flowering rush aboveground biomass (g dry weight [DW]/pot) at 8 WAT. Solid line is pretreatment number of buds per pot. Bars sharing the same letter are not significantly different, $P < 0.05$. (C) Flowering rush belowground biomass (gDW/pot) at 8 WAT. Bars sharing the same letter are not significantly different, $P < 0.05$. Error bars represent +1 standard error of the mean.

propagule for regenerating or dispersing flowering rush, controlling these propagules is a key factor for providing long-term control of this plant (Marko et al. 2015).

Aboveground biomass is the best measure of nuisance growth and perception. Triclopyr alone was not significantly different from the untreated reference by 8 WAT (Figure

1B). All treatments that included fluridone or diquat produced significantly less biomass than the untreated reference. Diquat followed by fluridone-treated tanks had significantly less aboveground biomass compared with fluridone alone or triclopyr followed by fluridone.

There was no difference between reference and triclopyr treatments, whereas all other treatments resulted in significantly lower belowground biomass (Figure 1C). Only the diquat followed by fluridone-treated plants had belowground biomass below pretreatment levels.

Treatments with only triclopyr exhibited no visual difference, propagule difference, or biomass difference from the reference plants, suggesting that triclopyr has little or no effect on flowering rush when applied alone as a submersed treatment (Figure 1). Furthermore, treatments containing triclopyr followed by fluridone and fluridone alone had similar levels of activity late in this experiment, suggesting that fluridone rather than triclopyr was causing most of the damage to these plants, and pretreating with triclopyr provided no benefit over treating with fluridone alone. In a 4-ha field trial on Lake Pend Oreille, ID (2013 to 2014), triclopyr was applied at 2.5 mg L^{-1} , immediately followed by a fluridone treatment at $90 \text{ } \mu\text{g L}^{-1}$. At 21 d after treatment, a second fluridone treatment was applied at $60 \text{ } \mu\text{g L}^{-1}$. These applications provided about 70% control of flowering rush by 1 yr posttreatment (author's unpublished data). Results from the current mesocosm study would suggest that control was likely the result of sequential fluridone applications. Poovey et al. (2013) also showed that moderate to no control of flowering rush was achieved in a growth chamber experiment when submersed plants were exposed to in-water rates of triclopyr of 1.25 to 2.5 mg L^{-1} for up to 48 h of herbicide exposure.

Fluridone significantly reduced rhizome bud density, ramet density, aboveground biomass, and belowground biomass when compared with the reference tanks (Figure 1). This is desirable because rhizome buds are the main form of propagation and spread for this species. In a 5-wk growth chamber experiment, Poovey et al. (2013) reported no significant reduction in shoots, roots, or rhizomes when submersed flowering rush was treated with fluridone at 10 and $20 \text{ } \mu\text{g L}^{-1}$. In our study, increasing concentrations to $30 \text{ } \mu\text{g L}^{-1}$ resulted in significant reduction in these parameters. When used alone, fluridone and diquat significantly reduced rhizome bud density and aboveground and belowground biomass (Figure 1). Treating with diquat alone was just as effective as treating with diquat followed by a fluridone treatment for controlling flowering rush. Results by Poovey et al. (2012) indicated that concentrations of diquat at 0.37 mg L^{-1} for 6- to 12-h exposure times in a growth chamber study reduced submersed flowering rush shoot mass by > 70%, but did not significantly affect root/rhizome biomass. In our study, the increased exposure times to diquat likely allowed for more thorough control of aboveground biomass and subsequent impacts to belowground biomass.

Results to date suggest that submersed flowering rush can be seasonally controlled by applications of some herbicides, depending upon aqueous concentrations and exposure times. However, a viable long-term management strategy using herbicides against submersed stands of the plant is

still lacking. One of the key challenges is the wide range of herbicide exposure times that result from treatment of flowering rush in high flow environments versus more static environments. Results of our work suggest that diquat alone remains the most effective herbicide studied for high water-exchange environments, whereas fluridone may provide additional options for more static sites. Until standard treatment approaches are developed, parallel work to evaluate treatments on the emergent growth phases of the plant and on herbicide applications to dewatered sites for pre-emerging or newly sprouted shoots should be continued. In addition, life-cycle studies of flowering rush in North America should be undertaken to link control strategies with weak points in phenological events to improve control of the plant.

SOURCES OF MATERIALS

¹Reward[®] Landscape and Aquatic Herbicide, Syngenta Crop Protection, Inc., 410 South Swing Road, Greensboro, NC 27419.

²Sonar[®] AS Aquatic Herbicide, SePRO Corporation, 11550 North Meridian Street, Suite 600, Carmel, IN 46032.

³Renovate[®] 3 Aquatic Herbicide, SePRO Corporation, 11550 North Meridian Street, Suite 600, Carmel, IN 46032.

⁴Poly-Cel Horticultural Growing Containers, Hummert International, 4500 Earth City Expressway, Earth City, MO 63045.

⁵Osmocote[®] Coated Fertilizer, Evrerris, Israeli Chemicals Ltd., Millenium Tower, 23 Aranha Street, Tel Aviv 61070, Israel.

⁶Statistix 9.0, Analytical Software, 2105 Miller Landing Road, Tallahassee, FL 32312.

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