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Aquatic Plant Control Research Program

Comparison of Generic and Proprietary Aquatic Herbicides for Control of Invasive Vegetation

Part 3: Submersed Plants

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Comparison of Generic and Proprietary Aquatic Herbicides for Control of Invasive Vegetation

Part 3, Submersed Plants

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Abstract

Herbicide selection is key to efficiently managing nuisance vegetation in our nation's waterways. After selecting the active ingredient, there still remains multiple proprietary and generic products to choose from. Recent small-scale research has been conducted to compare the efficacy of these herbicides against floating and emergent species. Therefore, a series of mesocosm and growth chamber trials were conducted to evaluate subsurface applications of the following herbicides against submersed plants: diquat versus coontail (*Ceratophyllum demersum* L.), hydrilla (*Hydrilla verticillata* L.f. Royle), southern naiad (*Najas guadalupensis* (Sprengel) Magnus), and Eurasian watermilfoil (*Myriophyllum spicatum* L.); flumioxazin versus coontail, hydrilla, and Eurasian watermilfoil; and triclopyr against Eurasian watermilfoil. All active ingredients were applied at concentrations commonly used to manage these species in public waters. Visually, all herbicides within a particular active ingredient performed similarly with regard to the onset and severity of injury symptoms throughout the trials. All trials, except diquat versus Eurasian watermilfoil, resulted in no differences in efficacy among the 14 proprietary and generic herbicides tested, and all herbicides provided 43%–100% control, regardless of active ingredient and trial. Under mesocosm and growth chamber conditions, the majority of the generic and proprietary herbicides evaluated against submersed plants provided similar control.

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Preface

The work reported herein was conducted for the US Army Corps of Engineers (HQUSACE) and is assigned to the US Army Engineer Research and Development Center (ERDC) under the purview of the Environmental Laboratory (EL), Vicksburg, MS as part of the Aquatic Plant Control Research Program (APRCP). Funding was provided under Funding Account Code U4364280 and AMSCO Code 075098. The APCRP is managed under the Civil Works Environmental Engineering and Sciences Office.

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1 Introduction

1.1 Background

Nuisance invasive aquatic plants are continuously introduced into the United States, negatively impacting US Army Corps of Engineer (USACE), state, and private water bodies. Nuisance aquatic vegetation can disrupt waterborne transportation, block potable water and irrigation intakes, degrade water quality, and displace native plant and wildlife communities, including critical habitat for threatened and endangered species (Getsinger et al. 2014). Chemical control, using registered aquatic herbicides, is a technique widely employed by aquatic plant managers in the United States (Netherland 2014). Aquatic herbicides registered by the US Environmental Protection Agency (USEPA) have been used to prevent further spread and provide control of existing populations of invasive plants. In general, herbicides are selected because they have a high level of efficacy against the target species, relatively short aqueous half-lives, and limited impacts on nontarget and non-native plant species (Mudge 2007).

The standard herbicide registration provides a 17-year patent for proprietary rights for brand name, formula, inert ingredients, and production of the proprietary brand-name or trademark product when initially registered (McFalls et al. 2015). After this period ends, other companies can synthesize, manufacture, or distribute the herbicide under a different name (that is, off-patent herbicide) (McFalls et al. 2015), commonly referred to as *generic* products (or *me-too* labels), using registration data provided by the original registrant. These generic products also have branded names—though different from the original, proprietary brand names. Although only 15 active ingredients are registered for aquatic sites by the USEPA for nationwide use (Section 3 Registration) (Netherland and Jones 2012; University of Florida 2018), multiple registrants selling off-patent generic herbicides exist under a variety of branded names. In particular, end users can choose from a large selection of available generic herbicides registered for decades for aquatic use (for example, 2,4-D, glyphosate, and diquat dibromide). However, many of the recently registered aquatic herbicides do not have a generic counterpart, either because the original patent life has not expired or because the cost or difficulty to manufacture the active ingredients remains high.

There are advantages and disadvantages to using proprietary or generic aquatic herbicides. Often, proprietary herbicide manufacturers provide a wide range of customer- and product-support services and some level of product warranty to protect the end user after rare cases of unacceptable performance. In addition, familiarity with proprietary products, well-documented performance in the field, and manufacturer recognition are selling points to the end user. Conversely, proprietary herbicides may come with added expenses, even after patent expiration. Proprietary registrants must recover high costs associated with initial discovery, development, registration, and marketing expenses over an extended period due to the relatively minor market share for aquatic herbicides. In addition, the USEPA requires a comprehensive registration review process every 15 years for all products seeking to maintain existing registrations (USEPA 2017). In most cases, the effort and costs associated with this process are heavily underwritten by the proprietary registrant.

Alternatively, generic products generally have a lower initial investment than their proprietary counterpart (McFalls et al. 2015), since the generic manufacturer does not pay the full cost of product development or registration. Lower initial investment costs allow these products to be offered at a lower market price. Moreover, some generic manufacturers provide little to no customer or product services, which also impacts market price. However, the generic product may carry a negative connotation or stigma of being an inferior product, even though it has the same active ingredient and percent composition as the proprietary herbicide. To be used as a viable alternative, the generic counterpart, most managers believe, should deliver the same or similar level of performance (that is, efficacy) as the proprietary herbicide. Although active ingredient disclosure is required by the USEPA, non-pesticidal inert or inactive ingredients such as solvents, stabilizers, emulsifiers, surfactants, and other additives vary among products and are considered proprietary information. Inert active ingredients of products must be reported to the USEPA, and they are evaluated for potential impacts to human health and the environment.

Limited research has been conducted to evaluate the efficacy of generic herbicides alone, or direct comparisons of generic versus proprietary aquatic herbicides. Previous research comparing generic versus proprietary aquatic herbicides has focused on subsurface applications of fluridone and copper (Langeland et al. 2002; Koschnick et al. 2003; Poovey, Skogerboe, Getsinger 2004; Bultemeier et al. 2009; Turnage, Madsen, Wersal 2015).

Similarly, agriculture research has evaluated foliar applications of glyphosate, triclopyr, and clopyralid for efficacy against a variety of weed species (Hinklin et al. 2002; Siekman and Sandell 2008). The limited data directly comparing herbicide performance in an aquatic setting has forced managers to rely on product name brand recognition, as well as anecdotal evidence, when selecting an herbicide. Often, the resource manager or practitioner does not know whether the chosen product is as effective as other available options or whether the product provides any added management values or benefits. In addition, considerable procurement pressure gets applied on, and by, public agencies to use the lowest bid when selecting herbicide brands, which may ignore product performance and valued-added customer service by the registrant. Because of the sensitive nature of applying pesticides to surface waters, resource managers must ensure that products perform as advertised and protection of the public and the environment is maintained.

Because of the limited amount of empirical evidence directly comparing the performance of identical active ingredients, research is needed to fully understand the scope of generic herbicide utility. Over the past decade, these comparative evaluations have been requested by several USACE districts and state agencies searching for technical guidance for potential use of generic products in operational control programs in public waters. In fiscal year 2016, the USACE–Jacksonville District (SAJ) formally submitted a statement of need (SON 2015-ER-16) through the USACE's Aquatic Plant Control Research Program (APCRP) to compare efficacy of generic versus proprietary herbicides and determine their utility as a viable option for managing aquatic vegetation in public waterways. In the era of annual budget uncertainties and the proliferation of generic labels, key stakeholders need data on head-to-head efficacy comparisons to make informed and cost-effective management decisions. Once resource managers fully understand any differences between proprietary and generic products, they can make more informed performance and procurement decisions in the best interests of the public while still controlling invasive aquatic vegetation.

Previously, Mudge and Getsinger (2019, 2021) found limited differences between generic and proprietary products when applied as foliar treatments to floating and emergent plants. In addition to the limited trials comparing generic versus proprietary herbicides in an aquatic setting, the majority of published research focuses on the original registered proprietary products (for example, Clipper, Renovate, Reward), and limited efforts have been made to showcase findings of generic herbicides when testing efficacy. As the final document of a three-part series, this technical report provides results on the efficacy of selected proprietary and generic products used to manage invasive floating, emergent, and submersed vegetation. Plant species, products, and application rates were selected based on extensive discussions with key USACE district and state personnel responsible for managing invasive aquatic plants.

1.2 Objectives

The objectives of this research were to (1) evaluate the efficacy of commonly used herbicides, both generic and proprietary products, for controlling key submersed aquatic plants found throughout the United States in small-scale mesocosm and environmental growth chamber settings and (2) determine whether differences exist between generic and proprietary product performance.

2 Materials and Methods

A series of outdoor, replicated mesocosm trials were conducted at the Louisiana State University (LSU) AgCenter Aquaculture Research Facility (AARF) in Baton Rouge, Louisiana, as well as at ERDC in Vicksburg, Mississippi, to evaluate the efficacy of generic and proprietary diquat dibromide, flumioxazin, and triclopyr (triethylamine salt) against coontail, hydrilla, Eurasian watermilfoil, and southern naiad. Both generic and proprietary herbicides commonly used by USACE districts and state agencies against problematic submersed aquatic plants were evaluated. The trials were conducted from January 2019 through August 2019. All plants were collected from cultures maintained at LSU AARF or ERDC.

For the 13 mesocosm trials at LSU AARF, four sprigs (25 cm* in length) of coontail, hydrilla (fluridone-susceptible dioecious biotype), or Eurasian watermilfoil, or 1 cluster (about 25 sprigs) of southern naiad (25 cm in length) were planted separately into 3 L high-density polyethylene (HDPE) pots filled with Timberline Top Soil (Oldcastle Lawn and Garden, Atlanta, Georgia). The topsoil was amended with Osmocote (19-6-12) (The Scotts Company, Marysville, Ohio) fertilizer at a rate of 2 g Kg^{-1} sediment and saturated with water. Each sprig or cluster of plants were planted approximately 4 cm deep into the topsoil, and a 1 cm layer of play sand was added to the soil surface to reduce particulate matter and nutrient re-suspension into the water column to prevent algal contamination. Immediately after planting, two pots of each species were placed inside 76 L plastic containers (49.5 cm diameter by 58.4 cm height) (Figure 1) filled with water (pH 8.0–8.5) collected from ponds at LSU AARF. Water level was maintained weekly at 60 L by the addition of pond water.

Three additional trials (diquat versus Eurasian watermilfoil and hydrilla; triclopyr versus Eurasian watermilfoil) were conducted indoors in a controlled-environment growth chamber equipped with 55 L glass aquaria and artificial lighting specifically designed for growing submersed plants at ERDC (Netherland et al. 1991; Mudge and Theel 2011) (Figure 2). Conditions conducive for maintaining healthy plant growth included: temperature of 22°C, water pH 7.5–8.0, and a 14 hr:10 hr (light:dark)

*. For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

photoperiod. Similar to the mesocosm trials, four-25 cm sprigs of hydrilla or Eurasian watermilfoil were planted in 750 ml plastic containers filled with the same type and rates of topsoil, fertilizer, and sand. Three pots of each species were placed into separate aquaria filled with 48 L of growth culture solution (Smart and Barko 1985).

Figure 1. Experimental setup of submersed aquatic plants growing outdoors in 76 L HDPE containers at the LSU AgCenter Aquaculture Research Facility in Baton Rouge, Louisiana, in 2019.

Figure 2. Experimental setup of submersed aquatic plants growing in an environmental growth chamber within 55 L glass aquaria at the US Army Engineer Research and Development Center in Vicksburg, Mississippi, in 2019.

All plants, regardless of trial or location, were allowed to acclimate under experimental conditions for four weeks prior to herbicide application and were in a healthy and active growing state at time of treatments. Herbicides were chosen according to recommendations and current products used by the USACE Buffalo (LRB), Ft. Worth (SWF), Jacksonville (SAJ), Mobile (SAM), New Orleans (MVN), and St. Paul (MVP) Districts (Table 1). At 4 weeks after planting (WAP), diquat, flumioxazin, or triclopyr were applied as a subsurface treatment to coontail, hydrilla, Eurasian watermilfoil, or southern naiad at concentrations listed in Table 2, and plants were exposed to the herbicide treatments for 24 hr. Since all three active ingredients have aqueous half-lives that range from minutes to a few days (Petty et al. 2003, Mudge et al. 2010), the 24 hr exposure period was chosen to simulate field conditions where the product would degrade relatively quickly. All herbicides within a given trial were applied at equivalent rates. Each product was mixed into stock solution with water, applied at the appropriate concentration with a pipette directly into the water column, and stirred thoroughly to ensure equal distribution throughout the water column. At the termination of the assigned exposure period, plants were moved to new plastic containers in the outdoor mesocosm trials or the aquaria were drained and refilled twice with reverse osmosis (RO) water and a third time with fresh growth-culture solution (Smart and Barko 1985) to remove aqueous herbicide residues. Nontreated control (reference) plants within plastic containers or aquaria were also used to compare plant growth in the absence of herbicide. Each treatment was replicated five times (three pots per aquaria times five replicates equals 15 pots per treatment) in a completely randomized design and all trials except triclopyr versus Eurasian watermilfoil were repeated.

Table 1. Generic brand and proprietary brand aquatic herbicides trade name, active ingredient, and manufacturer of products evaluated against submersed plants.

Active Ingredient	Trade Name[a,b]	Manufacturer	Address
Diquat	Reward	Syngenta Crop Protection	Greensboro, NC
	Tribune	Syngenta Crop Protection	Greensboro, NC
	Littora	SePRO Corporation	Carmel, IN
	Diquat SPC 2L	Nufarm Americas Inc.	Burr Ridge, IL
	Weedtrine D	Applied Biochemists	Alpharetta, GA
	Diquat	Alligare LLC	Opelika, AL
	Tsunami DQ	Sanco Industries, Inc.	Fort Wayne, IN
	Harvester	Applied Biochemists	Alpharetta, GA
Flumioxazin	Clipper	Valent	Walnut Creek, CA
	FlumiGard	Alligare LLC	Opelika, AL
	Semera	Atticus	Cary, North Carolina
Triclopyr	Renovate 3	SePRO Corporation	Carmel, IN
	Garlon 3A	Corteva Agriscience	Indianapolis, IN
	Triclopyr 3,	Alligare LLC	Opelika, AL

b Proprietary herbicides: Reward, Clipper, and Renovate 3.
c Consult state regulations concerning the use of these products for aquatic sites.

Qualitative data, including onset of injury symptoms and percent injury, were assessed periodically throughout the trial on a scale of 0–100, where 0 = no injury and 100 = complete death. At 4 weeks after treatment (WAT), all viable shoot tissue were harvested, dried to a constant weight at 65°C for one week, weighed, and analyzed for dry weight biomass. Biomass data were subjected to an ANOVA and means separated using Fisher's Protected LSD ($p \leq 0.05$). A two-way ANOVA detected no differences between experimental runs ($p \leq 0.05$) for all trials except for diquat versus coontail; therefore, all other data were pooled across experimental runs.

Table 2. Generic brand and proprietary brand aquatic herbicides evaluated against submersed plants in growth chamber trials.[a]

Active Ingredient (a.i.)	Plant Species	Herbicide Concentrations (µg a.i. L^{-1})[d]
Diquat[b,c]	Coontail	185
	Southern naid	
	Eurasian watermilfoil	
	Hydrilla	370
Flumioxazin	Coontail	200
	Eurasian watermilfoil	
	Hydrilla	400
Triclopyr	Eurasian watermilfoil	250

a. All trials, except diquat versus Eurasian watermilfoil, diquat versus hydrilla, and triclopyr versus Eurasian watermilfoil, were conducted under outdoor mesocosm conductions. These three were conducted indoors in an environmental growth chamber.

b. Proprietary herbicides: Reward, Clipper, and Renovate 3.

c. Consult state regulations concerning the use of these products for aquatic sites.

d. Plants exposed to subsurface applications for 24 hr regardless of active ingredient.

3 Results and Discussion

3.1 General observations

The onset, progression, and severity of plant injury symptoms within a given trial and particular active ingredient for all generic and proprietary herbicides evaluated were similar regardless of mesocosm or growth chamber trial. Onset of injury symptoms were observed at approximately 1, 1, and 2 days after treatment (DAT) for plants treated with flumioxazin, triclopyr, and diquat, respectively. All plants recovered from the herbicide treatments between 1 (flumioxazin versus hydrilla) and 4 WAT (triclopyr versus Eurasian watermilfoil). Plant recovery was conveyed as the production of healthy tissue emerging as new leaves or stems from the injured plant tissue above and below the soil surface of herbicide treated plants.

3.2 Diquat

Subsurface applications of diquat (185 µg a.i. L^{-1}, 24 hr exposure) provided 98–100% reductions in coontail dry weight at 4 WAT, and no differences were detected among the eight products evaluated (Figure 1). All products provided rapid injury (necrosis), and differences in speed of control were not detected among the eight diquat products evaluated in the mesocosm research (data not shown). Similarly, Mudge (2013) evaluated diquat (Reward) at 100 µg a.i. L^{-1} versus coontail and found the subsurface application provided 100% control of shoots following an 8 hr exposure period.

Similar to the diquat versus coontail trials, Eurasian watermilfoil was rapidly injured by diquat, and all treatments reduced plant dry weight by ≥80% (Figure 2); however, differences were detected among treatments at 4 WAT. Treatment with Tribune resulted in 20% less control than Diquat SPC 2L, Reward, and Weedtrine-D. All diquat treatments except Tribune resulted in dry weight reductions of 96–100%. The reason for the reduced control provided by Tribune is unknown. Wersal et al. (2010) also noted 85–100% reductions in Eurasian watermilfoil biomass when diquat (Reward) was applied at 190 and 370 µg ai L^{-1} under a 24 hr exposure period. Under extremely short half-lives (2.5 and 4.5 hr), Reward also provided 97–99% control of Eurasian watermilfoil when treated with 185 and 370 µg ai L^{-1} (Skogerboe, Getsinger, Glomski 2006).

There were no differences among diquat products when applied subsurface to hydrilla at 370 µg a.i. L^{-1} in the mesocosm and growth chamber trials, as well as against southern naiad at 185 µg a.i. L^{-1} in the mesocosm trials (Figures 3 and 4). Diquat reduced hydrilla dry weight by 73–97% compared to the non-treated control (Figure 3), while the same active ingredient at the lower concentration reduced southern naiad biomass by 80–93% (Figure 4). Typically, diquat (Reward) applied alone has limited activity on hydrilla (Glomski, Skogerboe, Getsinger 2005) and is tank mixed with copper to provide acceptable control (Sutton et al. 1972). Previous mesocosm research (Mudge and Getsinger 2019) evaluated the same eight diquat products and found only one product (Weedtrine-D) provided less control than five of the products when applied as a foliar application to water lettuce (*Pistia stratiotes* L.) when applied at 841 g a.i. ha^{-1}.

Figure 3. Mean dry weight (g) of coontail 4 weeks after treatment (WAT) with generic and proprietary aquatic diquat in mesocosm trials. Data are pooled across experimental runs. Plants were exposed to diquat at 185 µg active ingredient (a.i.) L-1 for 24 hr. Means sharing the same letter within a trial are not different according to Fisher's Protected LSD test ($p \leq 0.05$; n = 10). Horizontal lines represent pretreatment biomass. Error bars denote standard error of the mean.

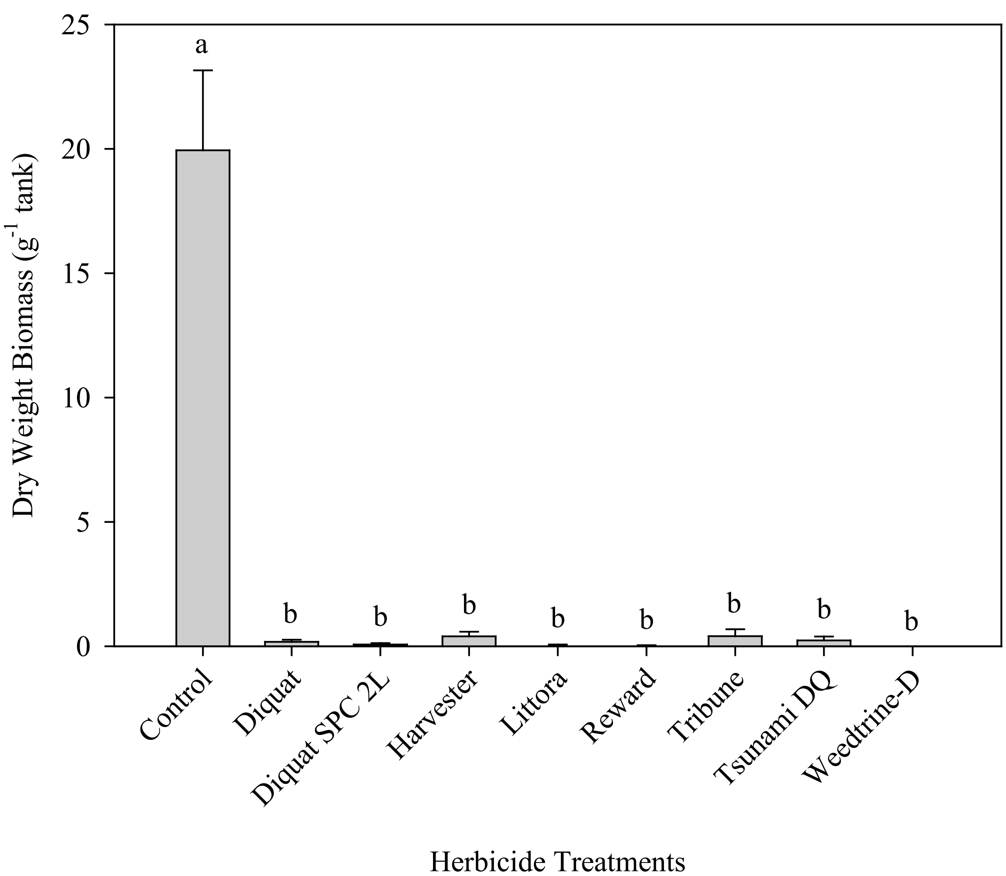
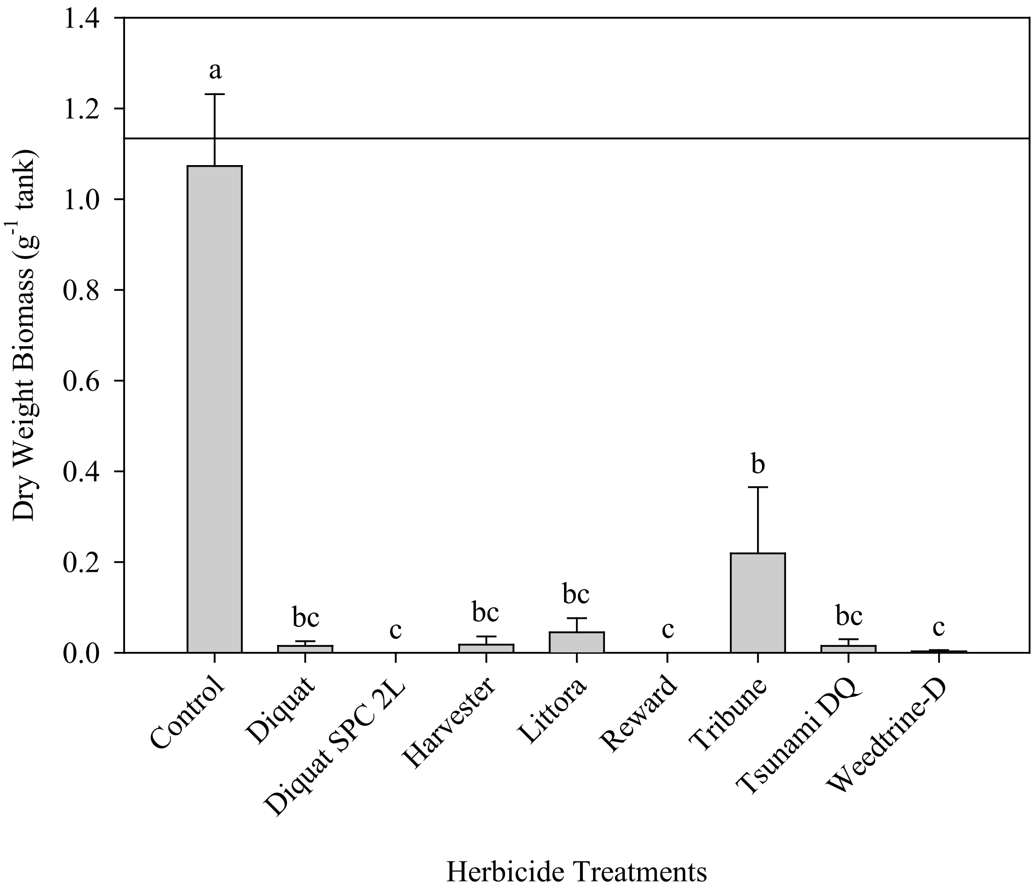


Figure 4. Mean dry weight (g) of Eurasian watermilfoil 4 WAT with generic and proprietary aquatic diquat in growth chamber and mesocosm trials. Data are pooled across experimental runs. Plants were exposed to diquat at 185 µg a.i. L-1 for 24 hr. Means sharing the same letter are not different according to Fisher's Protected LSD test ($p \leq 0.05$; n = 10). Horizontal lines represent pretreatment biomass. Error bars denote standard error of the mean.



3.3 Flumioxazin

Generic and proprietary flumioxazin applied subsurface to coontail (Figure 5), Eurasian watermilfoil (Figure 6), and hydrilla (Figure 7) resulted in rapid injury to all species tested in the outdoor mesocosm trials, but plants recovered by the production of new, healthy shoots within 2 WAT. Shoot dry weights were reduced 67–84%, 65–71%, and 82–88% for coontail, Eurasian watermilfoil, and hydrilla, respectively, at 4 WAT when Clipper, FlumiGard, and Semera were applied subsurface. To date, no previous comparisons have been conducted to evaluate flumioxazin products since FlumiGard and Semera were recently registered by the USEPA in 2018 and 2019, respectively, (Alligare 2018, USEPA 2019), whereas Clipper was registered in 2010 (USEPA 2010). Previous research conducted under greenhouse and shade house conditions found flumioxazin (Clipper) was highly efficacious against coontail and hydrilla when applied at 50–1600 µg

L^{-1} to plants growing in water with pH 7.0; however, flumioxazin control significantly decreased when water pH increased to 9.0. Flumioxazin is rapidly degraded by hydrolysis and half-life decreases substantially as the water pH increases (Katagi 2003; Senseman 2007; Mudge et al. 2010). In the current trials, the water pH ranged 7.5–8.0 when flumioxazin was administered at 0800 hours to coontail, Eurasian watermilfoil, and hydrilla. The slightly basic water pH is the likely cause of increased degradation and decreased efficacy.

Figure 5. Mean dry weight (g) of hydrilla 4 WAT with generic and proprietary aquatic diquat in growth chamber and mesocosm trials. Data are pooled across experimental runs. Plants were exposed to diquat at 370 µg a.i. L^{-1} for 24 hr. Means sharing the same letter are not different according to Fisher's Protected LSD test ($p \leq 0.05$; n = 10). Horizontal lines represent pre-treatment biomass. Error bars denote standard error of the mean.

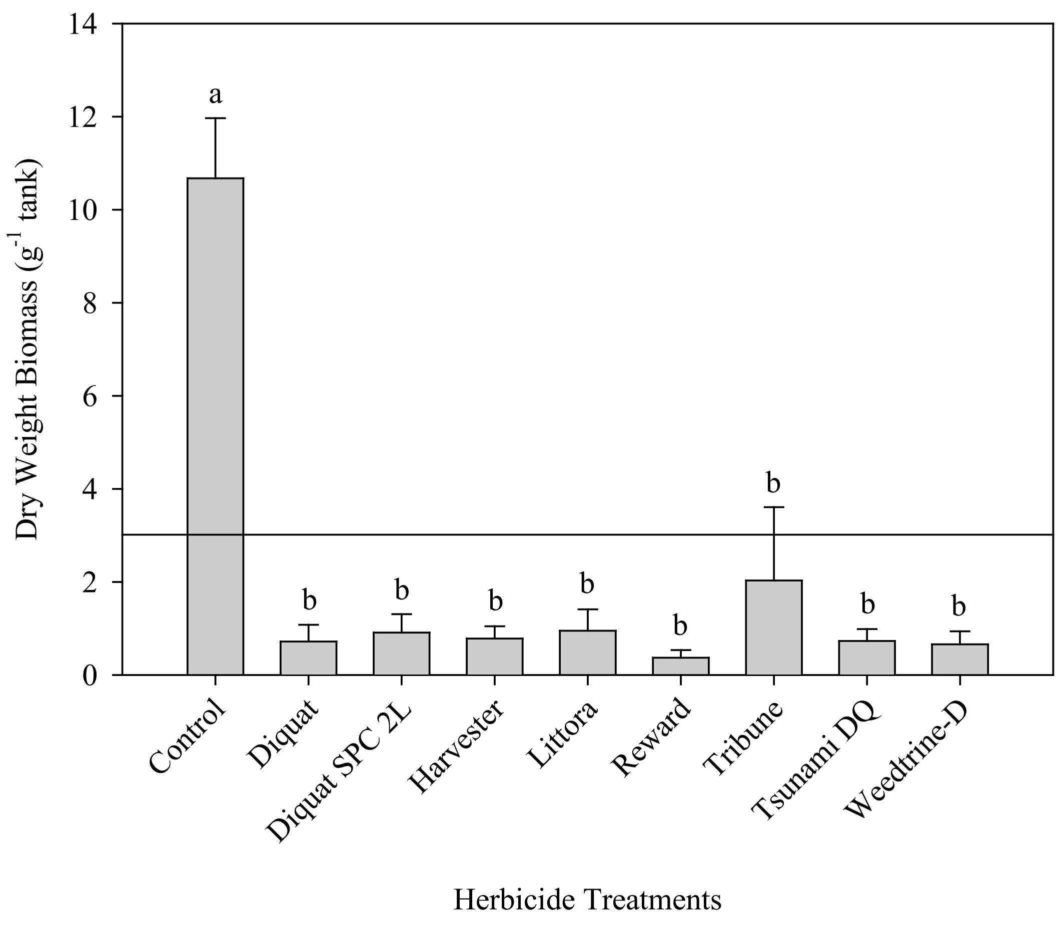


Figure 6. Mean dry weight (g) of southern naiad 4 WAT with generic and proprietary aquatic diquat in mesocosm trials. Data are pooled across experimental runs. Plants were exposed to diquat at 185 µg a.i. L^{-1} for 24 hr. Means sharing the same letter are not different according to Fisher's Protected LSD test ($p \leq 0.05$; n = 10). Horizontal lines represent pretreatment biomass. Error bars denote standard error of the mean.

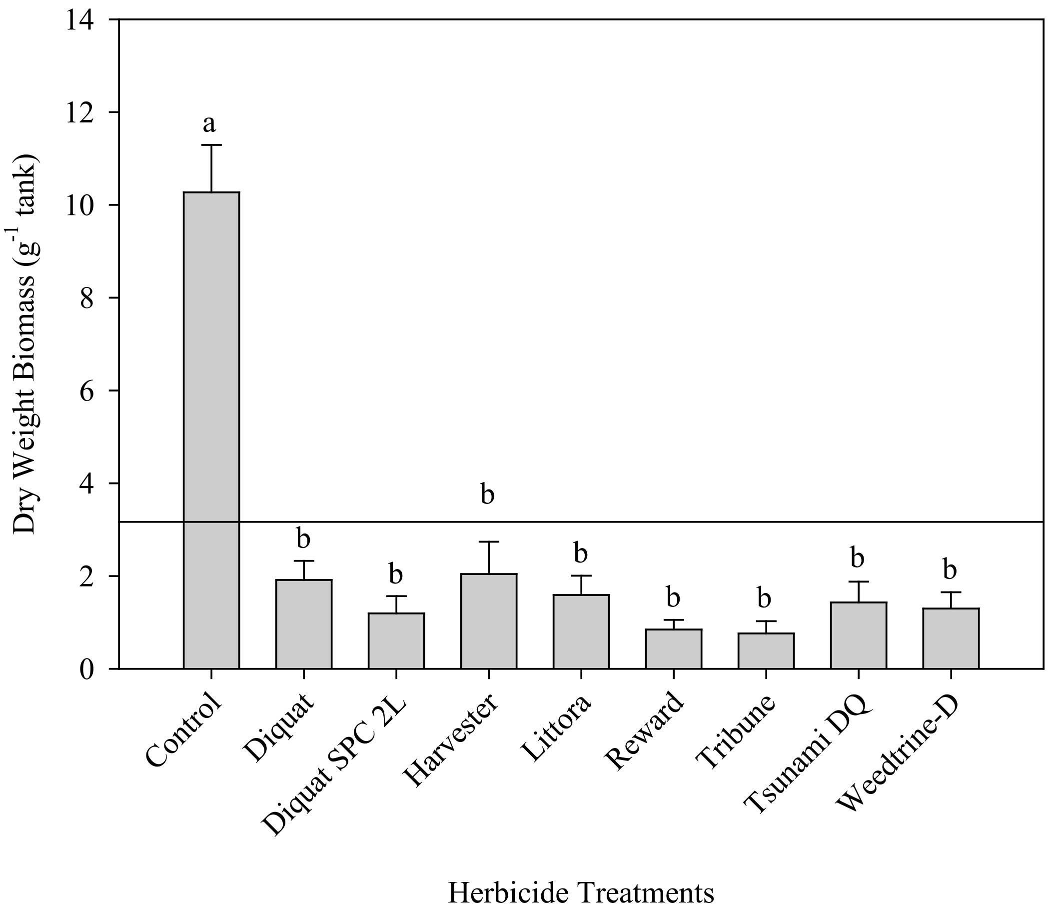
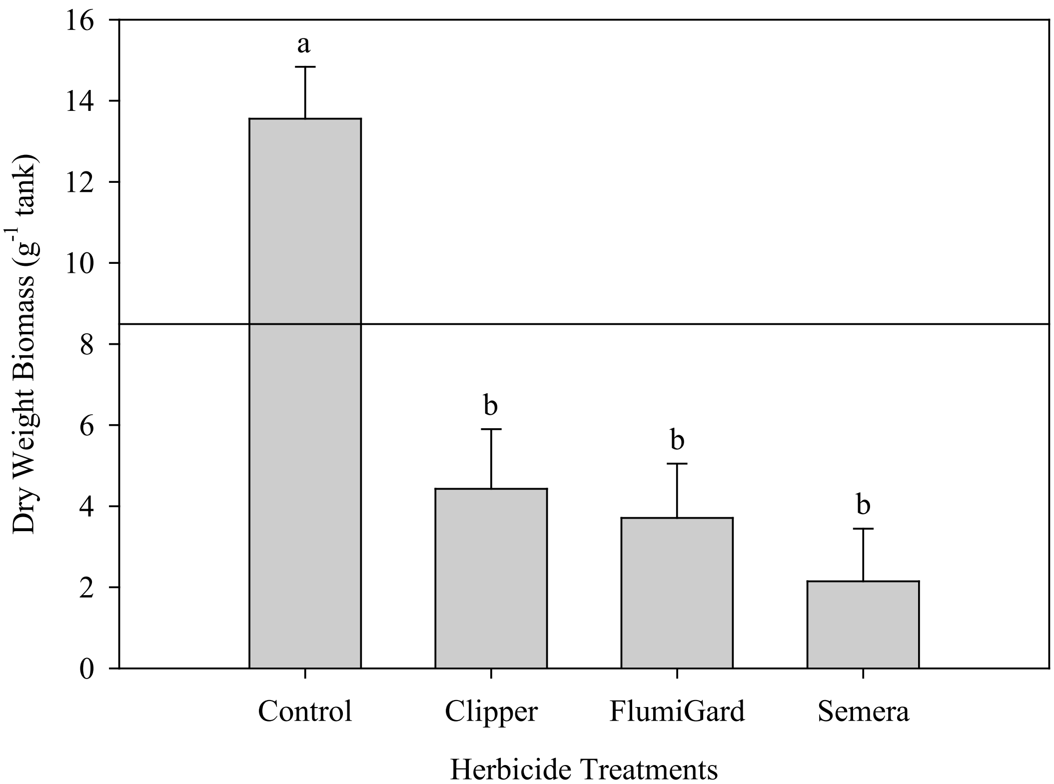


Figure 7. Mean dry weight (g) of coontail 4 WAT with generic and proprietary aquatic flumioxazin in mesocosm trials. Data are pooled across experimental runs. Plants were exposed to flumioxazin at 200 µg a.i. L^{-1} for 24 hr. Means sharing the same letter are not different according to Fisher's Protected LSD test ($p \leq 0.05$; n = 10). Horizontal lines represent pretreatment biomass. Error bars denote standard error of the mean.



3.4 Triclopyr

The three triclopyr herbicides resulted in rapid leaf twisting (epinasty) of Eurasian watermilfoil within 1 DAT and rapid injury (for example, chlorosis, necrosis, stem detachment) throughout the remainder of the growth chamber trial. Garlon 3 A, Renovate 3, and Triclopyr 3 provided 43–67% control at 4 WAT (Figure 8), and all plants recovered 3–4 WAT (Figures 9-10). Triclopyr was evaluated at a relatively low concentration (250 µg a.i. L^{-1}) against Eurasian watermilfoil and higher doses or longer exposure periods or both would likely have resulted in increased plant control. The triclopyr concentration used in the current growth chamber trial was relatively low compared to previous growth chamber research that demonstrated concentrations ≥1.0 mg L^{-1} or exposure periods ≥48 hr were required to substantially reduce Eurasian watermilfoil shoot biomass (Netherland and Getsinger 1992). Similarly, Mudge and Getsinger (2021) noted similar levels of efficacy when the aforementioned triclopyr products as well as Trycera provided 100% control of water hyacinth when applied at 1682.1 g acid equivalent (a.e.) ha^{-1}. In addition, these same proprietary and generic triclopyr herbicides resulted in 39–99% control over the course of four mesocosm trials when applied to the foliage of alligator-weed (*Alternanthera philoxeroides* (Mart.) Griseb.) and creeping water primrose (*Ludwigia peploides* (Kunth) P.H. Raven) (Mudge and Getsinger 2021). Despite the varying levels of control exhibited in these trials, no differences were detected among the four products when applied at 2523 g a.e. ha^{-1}.

Figure 8. Mean dry weight (g) of Eurasian watermilfoil 4 WAT with generic and proprietary aquatic flumioxazin in mesocosm trials. Data are pooled across experimental runs. Plants were exposed to flumioxazin at 200 µg a.i. L^{-1} for 24 hr. Means sharing the same letter are not different according to Fisher's Protected LSD test ($p \leq 0.05$; n = 10). Horizontal lines represent pretreatment biomass. Error bars denote standard error of the mean.

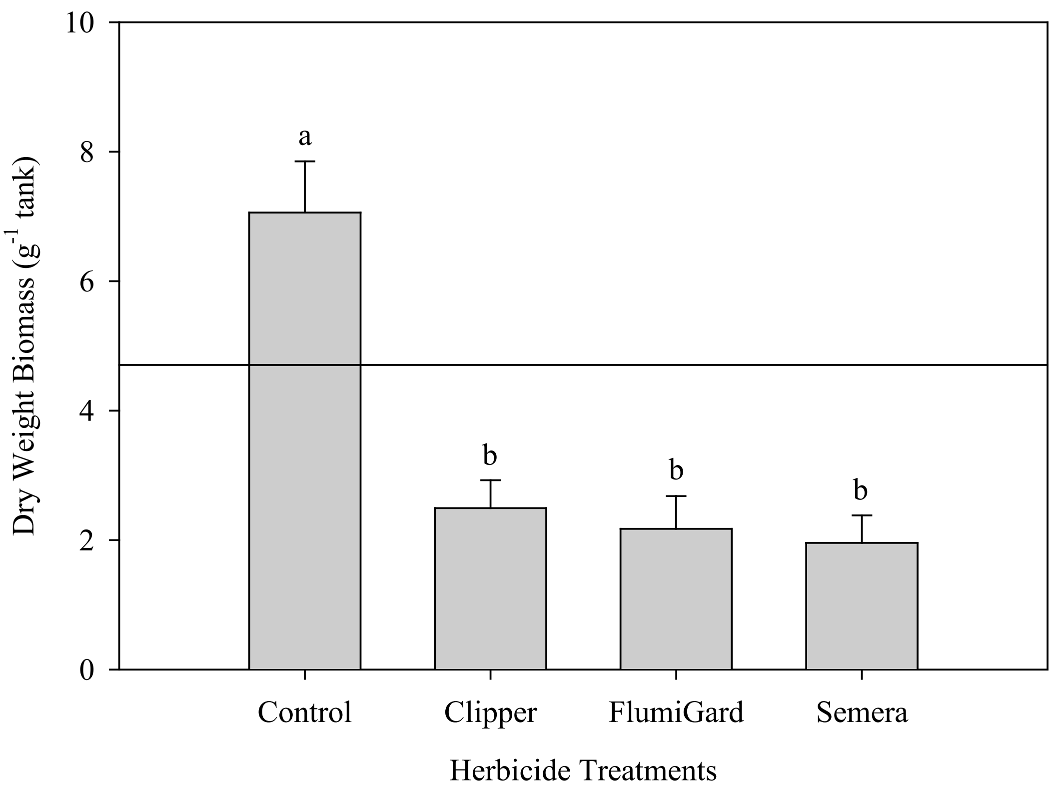


Figure 9. Mean dry weight (g) of hydrilla 4 WAT with generic and proprietary aquatic flumioxazin in mesocosm trials. Data are pooled across experimental runs. Plants were exposed to flumioxazin at 400 µg a.i. L-1 for 24 hr. Means sharing the same letter are not different according to Fisher's Protected LSD test ($p \leq 0.05$; n = 10). Horizontal lines represent pretreatment biomass. Error bars denote standard error of the mean.

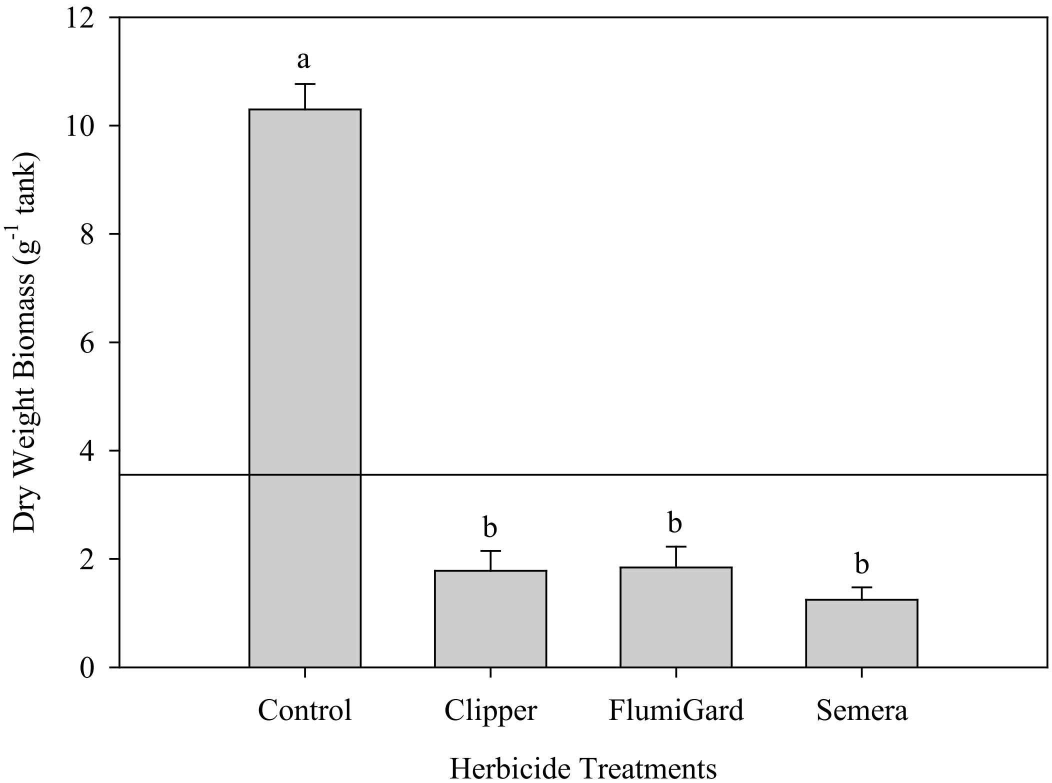
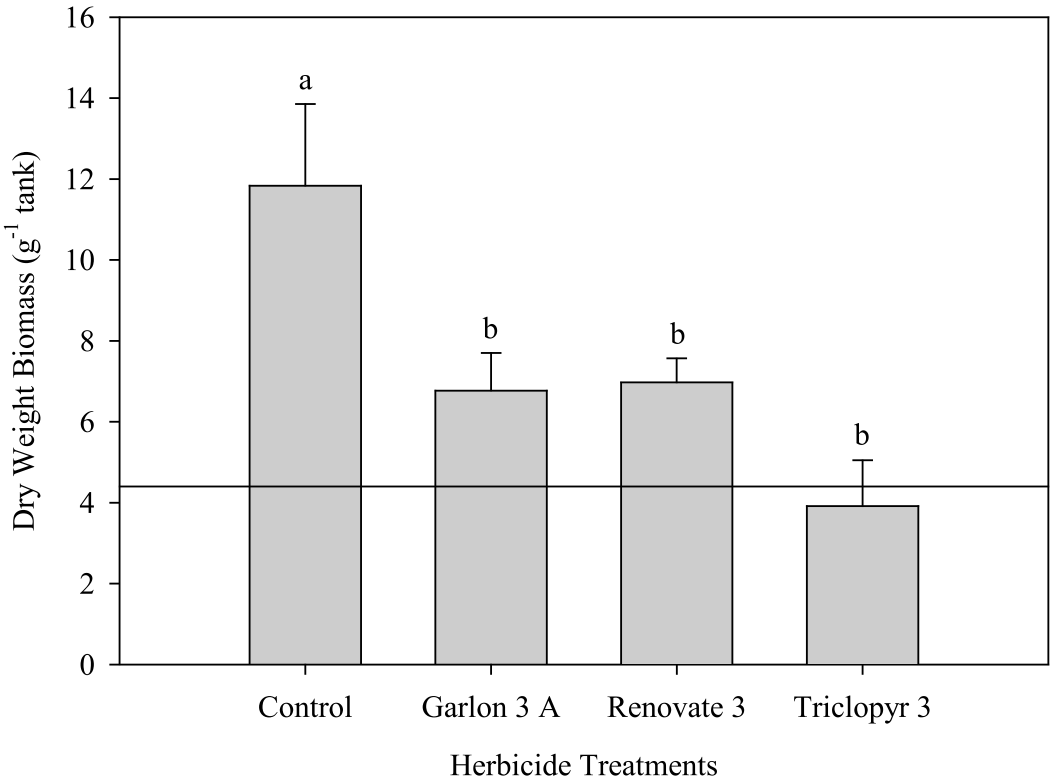


Figure 10. Mean dry weight (g) of Eurasian watermilfoil 4 WAT with generic and proprietary aquatic triclopyr in mesocosm trials. Plants were exposed to triclopyr at 250 µg a.e. L-1 for 24 hr. Means sharing the same letter are not different according to Fisher's Protected LSD test ($p \leq 0.05$; n = 5). Horizontal lines represent pretreatment biomass. Error bars denote standard error of the mean.



4 Conclusions

These mesocosm and growth chamber trials evaluated a total of 15 products. Resultant dry weight data across all trials demonstrated that the majority of diquat, flumioxazin, and triclopyr products provided similar control of coontail, hydrilla, Eurasian watermilfoil, and southern naiad. Previous aquatic (Koschnick et al. 2003; Bultemeier et al. 2009; Turnage, Madsen, Wersal 2015), row crop (Siekman and Sandell 2008), and roadside (McFalls et al. 2015) herbicide research also found little to no differences in efficacy between generic and proprietary clopyralid, copper, glyphosate, metsulfuron-methyl, and triclopyr. The current small-scale trials as well as results from proprietary versus generic herbicides trials to test efficacy against floating and emergent species conducted under outdoor mesocosm conditions (Mudge and Getsinger 2019; Mudge and Getsinger 2021) are crucial for providing reliable operational guidance for direct comparisons among registered aquatic herbicides. Although these results did not indicate any appreciable differences among products, except for diquat versus Eurasian watermilfoil, field verification of these small-scale evaluations could validate results. The mesocosm and growth chamber research evaluated the same formulations for each of the active ingredients. However, other active ingredients of the same parent molecule could result in differences in efficacy, signal words for toxicity, applicator safety, and other outcomes. Examples of products that may produce different results include salts or formulations of glyphosate, triclopyr, 2,4-D, florpyrauxifen-benzyl, or endothall.

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Acronyms and Abbreviations

Acronym	Meaning
AARF	AgCenter Aquaculture Research Facility
APCRP	Aquatic Plant Control Research Program
DAT	days after treatment
DoD	Department of Defense
EL	Environmental Laboratory
ERDC	Engineer Research and Development Center
LSU	Louisiana State University
SON	Statement of Need
USACE	US Army Corps of Engineers
USEPA	US Environmental Protection Agency
WAP	weeks after planting
WAT	weeks after treatment

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14. ABSTRACT

Herbicide selection is key to efficiently managing nuisance vegetation in our nation's waterways. After selecting the active ingredient, there still remains multiple proprietary and generic products to choose from. Recent small-scale research has been conducted to compare the efficacy of these herbicides against floating and emergent species. Therefore, a series of mesocosm and growth chamber trials were conducted to evaluate subsurface applications of the following herbicides against submersed plants: diquat versus coontail (*Ceratophyllum demersum* L.), hydrilla (*Hydrilla verticillata* L.f. Royle), southern naiad (*Najas guadalupensis* (Sprengel) Magnus), and Eurasian watermilfoil (*Myriophyllum spicatum* L.); flumioxazin versus coontail, hydrilla, and Eurasian watermilfoil; and triclopyr against Eurasian watermilfoil. All active ingredients were applied at concentrations commonly used to manage these species in public waters. Visually, all herbicides within a particular active ingredient performed similarly with regard to the onset and severity of injury symptoms throughout the trials. All trials, except diquat versus Eurasian watermilfoil, resulted in no differences in efficacy among the 14 proprietary and generic herbicides tested, and all herbicides provided 43%–100% control, regardless of active ingredient and trial. Under mesocosm and growth chamber conditions, the majority of the generic and proprietary herbicides evaluated against submersed plants provided similar control.

15. SUBJECT TERMS

Invasive plants	Introduced organisms	Aquatic plants
Aquatic weeds	Aquatic herbicides--Evaluation	

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