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Aquatic Plant Control Research Program

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

Part 2. Emergent Plants

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Abstract

Aquatic herbicides are one of the most effective and widespread ways to manage nuisance vegetation in the United States. After selecting the active ingredient, numerous proprietary and generic branded products exist to choose from. To date, few efforts have directly compared the efficacy of brand name and generic herbicides; therefore, a total of 20 mesocosm trials were conducted to evaluate various 2,4-D [(2,4-dichlorophenoxy)acetic acid], glyphosate (N-(phosphonomethyl)glycine), imazapyr (±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-pyridinecarboxylic acid), and triclopyr ([(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid) products against alligatorweed (*Alternanthera philoxeroides* [Mart.] Griseb.), southern cattail (cattail, *Typha domingensis* Pers.), and creeping water primrose (primrose, *Ludwigia peploides* (Kunth) P.H. Raven). All active ingredients were applied to foliage at broadcast rates commonly used in applications to public waters. Proprietary and generic 2,4-D, glyphosate, imazapyr, and triclopyr were efficacious and provided 39–99% control of alligatorweed, cattail, and primrose in 19 of the 20 trials. No significant differences occurred in product performance except glyphosate versus alligatorweed (trial 1, Rodeo versus Roundup Custom) and glyphosate versus cattail (trial 1, Rodeo versus Glyphosate 5.4). These results demonstrate under small-scale conditions that the majority of the generic and proprietary herbicides provided similar control of emergent vegetation, regardless of active ingredient.

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Preface

This study was conducted as part of the Aquatic Plant Control Research Program (APRCP). The APCRP is sponsored by Headquarters, 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, Mississippi. The APCRP is managed under the Civil Works Environmental Engineering and Sciences Office, Dr. Jennifer Seiter-Moser, EL, Acting Technical Director. Dr. Christine M. VanZomeren, EL, was Acting Assistant Technical Director, and Mrs. Heather Theel was Acting Program Manager for the APCRP. The USACE Jacksonville District (SAJ) also provided funding for this research.

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1 Introduction

1.1 Background

Invasive submersed, floating, and emergent aquatic plants have been repeatedly introduced into the United States and negatively impact US Army Corps of Engineers (USACE), federal, state, and other public and private water bodies. Invasive aquatic vegetation disrupts waterborne transportation, blocks potable water and irrigation intakes, degrades water quality, and displaces native plant and wildlife communities, including critical habitat for listed species (Getsinger et al. 2014). Chemical control, through the use of 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 selectively control existing populations of invasive plants and prevent their spread. In general, herbicides are selected for efficacy against the target species, possess relatively short aqueous half-lives, and have been shown to have limited impacts on nontarget and non-native plant species (Mudge 2007).

The original herbicide registration process provides a 17-year patent for proprietary rights for brand name and trademark, formula, and production of the proprietary product when it is first registered (McFalls et al. 2015). After this period concludes, any company 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 the original registration data. This registration process is regulated by the USEPA. Although there are currently only 15 active ingredients registered for aquatic sites by the USEPA for nationwide use (Section 3 Registration) (Netherland and Jones 2012, University of Florida 2018), there are multiple registrants offering generic herbicides under a variety of branded names. In particular, end users have a large selection of available generic options when choosing some of the legacy chemicals (for example, 2,4-D, glyphosate, and diquat). However, many of the more recently registered proprietary aquatic herbicides do not have a generic counterpart because original patent life has not expired or because of the cost or difficulty to manufacture the active ingredients.

There are advantages and disadvantages to using proprietary or generic aquatic herbicides. Often, proprietary herbicide manufacturers provide strong customer and product support services and some level of product warranty to protect the end user for 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 because of the relatively minor market share for aquatic herbicides. In addition, the USEPA requires a comprehensive registration review every 15 years for all products seeking to maintain existing registrations (USEPA 2017), and in most cases the effort and costs associated with this process are heavily underwritten by the proprietary registrants.

Alternatively, generic products generally have a lower initial investment than their proprietary counterpart (McFalls et al. 2015), which allows these products to be offered at a lower market price, since the generic manufacturer does not pay the full cost of product development or registration. 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, a generic counterpart 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, nonpesticidal inert or inactive ingredients such as solvents, stabilizers, emulsifiers, surfactants, and other additives can 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 negative 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. Mudge and Getsinger (2019) evaluated foliar applications of 2,4-D, glyphosate, diquat (6,7-dihydrodipyrido[1,2-a:29,19-c]pyrazinediium ion), and triclopyr against giant salvinia (*Salvinia molesta* Mitchell), water hyacinth (*Eichhornia crassipes* (Mart.) Solms), and water lettuce (*Pistia stratiotes* L.) and found limited differences in generic versus proprietary product performance with regard to plant injury and herbicide efficacy. In addition, previous research comparing generic versus proprietary aquatic herbicides has focused on subsurface applications of fluridone (1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl]-4(1H)-pyridinone) and copper (Langeland et al. 2002; Koschnick et al. 2003; Poovey, Skogerboe, and Getsinger 2004; Bultemeier et al. 2009; Turnage, Madsen, Wersal 2015). Similarly, agriculture research has evaluated foliar applications of glyphosate, triclopyr, clopyralid (3,6-dichloro-2-pyridinecarboxylic acid), glufosinate (2-amino-4-(hydroxymethylphosphinyl)butanoic acid), and metsulfuron-methyl (2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoic acid) for efficacy against a variety of terrestrial weed species (Hinklin et al. 2002; Siekman and Sandell 2008). The limited data directly comparing herbicide performance in an aquatic setting have forced managers to rely on product name brand recognition as well as anecdotal evidence when selecting an herbicide. Often, the resource manager or practitioner has no information on whether the chosen product is as effective as other available options or if the product provides any added management values or benefits.

Due to the limited amount of empirical evidence directly comparing the performance of identical active ingredients, research is needed to fully understand the utility of generic herbicides. Over the past decade, these comparative evaluations have been requested by several USACE districts and state agencies searching for technical guidance for the use of generic products in operational control programs in public waters. In fiscal year 2016, the SAJ submitted a statement of need (SON) to the APCRP to compare efficacy of generic versus proprietary herbicides and determine their utility as a viable option for managing aquatic vegetation in our nation's waterways. If no differences can be detected between products, generic herbicides may offer a cost-saving opportunity for USACE districts and other natural resource agencies (federal, state, and local). Procuring aquatic plant control products at lower costs will permit agencies to purchase more product and chemically treat more acreage with respect to previous years when higher priced herbicides were purchased.

As the second 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 routinely managed across the country. Plant species, products, and application rates were selected according to 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 19 commonly used herbicides, both generic and proprietary products, for controlling key emergent aquatic plants found throughout the United States in small-scale mesocosm trials 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, Lousiana, to evaluate the efficacy of generic and proprietary 2,4-D, glyphosate, imazapyr, and triclopyr against alligatorweed, cattail, and primrose (table 1). The trials evaluated both generic and proprietary herbicides commonly used by USACE districts and state agencies against problematic emergent aquatic plants. The outdoor trials were conducted from April through November 2018 (table 2). All plants were collected from local plant populations at LSU AARF. Throughout the spring and summer of 2018, four 20 cm[1] sprigs (alligatorweed or primrose) or one rhizome (cattail) were placed into 3.8 L or 7.5 L high-density polyethylene (HDPE) pots, respectively, and filled with Timberline Top Soil (Oldcastle, Atlanta, Georgia) that was amended with 2 g L^{-1} Osmocote (16-8-12, The Scotts Company, Marysville, Ohio) fertilizer and capped with a 2.5 cm layer of masonry sand to limit nutrient exchange with the water column. Two pots of each species were placed into separate (that is, one species per container) 76 L plastic containers (49.5 cm diameter by 58.4 cm height; that is, mesocosms) that were slowly filled with pond water (pH 8.5) over time until a final water height of 28 cm was reached, which was 5 cm above the top of the pot, and maintained at that level during the study period. In addition, Miracle-Gro Lawn Fertilizer at 41.6 mg L^{-1} (36-6-6, The Scotts Company, Marysville, Ohio) was applied directly to the water column 4 weeks after planting and 4 weeks after herbicide treatment.

Alligatorweed and primrose were allowed to acclimate under experimental conditions for approximately 4 weeks prior to herbicide application, while cattail was acclimated 6 weeks, and all species were healthy and actively growing at the time of treatment. Herbicides were applied to plants using a forced air CO_2-powered[2] sprayer at an equivalent of 935 L ha^{-1} diluent delivered through a single TeeJet (Spraying Systems Company, Wheaton,

[1]. 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.

[2]. For a full list of the spelled-out forms of the chemical elements used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 265, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

Illinois) 80-0067 nozzle at 138 kPa. This application technique provided even coverage of herbicides over the leaf and shoot surfaces. Herbicides were applied to foliage at broadcast rates commonly used in applications to public waters (tables 2 and 3). All herbicides within a given trial were applied at the same g acid equivalent (a.e.) regardless of g a.e. L^{-1} within each container. A nonionic surfactant (Surf-AC 910, 0.25% v/v) was included with all herbicides. A nontreated control was also included with each trial to compare plant growth in the absence of herbicide. Treatments were randomly assigned and replicated five times, except glyphosate versus cattail (n=4), and all trials were repeated.

At 7–8 weeks after treatment (WAT), all viable aboveground material (that is, shoots, stems, flowers, seeds) were harvested, dried at 65°C for one week to a constant weight, and dry weight biomass was determined. Biomass data were analyzed using ANOVA, and if differences were detected, means were separated using Fisher's Protected LSD ($p \leq 0.05$). Since some of the biomass data did not meet the assumptions of normality or equal variance, the following data were transformed: glyphosate versus alligatorweed trial 1 (square root transformation), imazapyr versus cattail trial 2 (plus 1, square root transformation), imazapyr versus primrose trial 1 (square root transformation), triclopyr versus alligatorweed (square transformation), and triclopyr versus primrose trial 1 (square root transformation). Imazapyr versus alligatorweed was the only trial where data were pooled across repeated trials, since no differences between repetitions were detected ($p \leq 0.05$). All other trials are presented separately.

Table 1. Generic and proprietary aquatic herbicides evaluated against emergent plants[a].

Active Ingredient	Trade Name	Manufacturer	Address
2,4-D	2,4-D Amine	Alligare	Opelika, AL
2,4-D	DMA® 4 IVM	Dow AgroSciences	Indianapolis, IN
2,4-D	Shredder® Amine	Winfield Solutions	St. Paul, MN
2,4-D	WEEDestroy® AM-40	Nufarm Americas	Burr Ridge, IL
2,4-D	Weedar® 64	Nufarm Americas	Burr Ridge, IL
glyphosate	Rodeo®	Dow AgroSciences	Indianapolis, IN
glyphosate	Roundup Custom™	Monsanto Company	St. Louis, MO
glyphosate	AquaPro®	SePRO Corporation	Carmel, IN
glyphosate	AquaNeat®	Nufarm Americas	Burr Ridge, IL
glyphosate	Refuge™	Syngenta Crop Protection	Greensboro, NC
glyphosate	Glyphosate 5.4	Alligare	Opelika, AL
imazapyr	Arsenal®	BASF Corporation	Research Triangle Park, NC
imazapyr	Habitat®	SePRO Corporation	Carmel, IN
imazapyr	Imazapyr 4 SL	Alligare	Opelika, AL
imazapyr	Polaris®	Nufarm Americas	Burr Ridge, IL
triclopyr	Renovate® 3	SePRO Corporation	Carmel, IN
triclopyr	Garlon® 3A	Dow AgroSciences	Indianapolis, IN
triclopyr	Triclopyr 3	Alligare	Opelika, AL
triclopyr	Trycera®	Helena Chemical Company	Collierville, TN

[a] Proprietary herbicides: Weedar 64, Rodeo, Arsenal, and Renovate 3.

Table 2. Treatment dates for proprietary brand generic and brand aquatic herbicide trials.

Active Ingredient	Species	2018 Treatment Dates
2,4-D	Alligatorweed	22 June, 4 September
	Creeping water primrose	22 June, 15 August
Glyphosate	Alligatorweed	24 May, 8 August
	Southern cattail	8 August, 4 September
	Creeping water primrose	15 May, 8 August
Imazapyr	Alligatorweed	24 May, 4 September
	Southern cattail	15 May, 13 September
	Creeping water primrose	29 May, 4 September
Triclopyr	Alligatorweed	5 June, 4 September
	Creeping water primrose	5 July, 4 September

Table 3. Generic and proprietary aquatic herbicide rates evaluated against emergent plants.

Active Ingredient	Products[a,b,c]	Rates (g a.e. ha^{-1})[d]	Plants Evaluated[e]
2,4-D	Weedar 64, 2,4-D Amine, DMA 4 IVM, Shredder Amine, WEEDestroy AM-40	2131	Alligatorweed, creeping water primrose
Glyphosate	Rodeo, Roundup Custom, AquaPro, AquaNeat, Refuge, Glyphosate 5.4	2243	Alligatorweed, southern cattail, primrose
Imazapyr	Arsenal, Habitat, Imazapyr 4 SL, Polaris	561, 1121	Alligatorweed, southern cattail, creeping water primrose
Triclopyr	Renovate 3, Garlon 3A, Triclopyr 3, Trycera	2523	Alligatorweed, creeping water primrose

[a] Proprietary herbicides: Weedar 64, Rodeo, Arsenal, and Renovate 3.

[b] Consult state regulations concerning the use of these products for aquatic sites.

[c] All treatments included a nonionic surfactant applied at 0.25% v v^{-1} (Surf-AC 910).

[d] Imazapyr applied at 561 g a.e. ha^{-1} to alligatorweed and primrose, and to cattail at 1121 g a.e. ha^{-1}.

[e] Abbreviations: a.e., acid equivalent.

3 Results and Discussion

3.1 General observations

Visual observations noted throughout the mesocosm research determined that all generic and proprietary herbicides evaluated within a trial and particular active ingredient performed similarly with respect to severity and development of injury symptoms (data not shown), and symptoms were typical of those associated with the application of these active ingredients. Injury symptoms were observed <2 hr after treatment for plants treated with the systemic herbicides 2,4-D and triclopyr as well as 5–7 days after treatment (DAT) for plants treated with imazapyr and glyphosate (data not shown). All alligatorweed and primrose plants exposed to foliar applications of the auxin herbicides 2,4-D and triclopyr exhibited uncontrolled growth and stem and leaf twisting (that is, epinasty) the day of herbicide application followed by canopy collapse 1 to 2 DAT and necrosis >1 WAT. Imazapyr- and glyphosate-treated plants required at least 5 DAT to display chlorosis for alligatorweed and primrose, whereas cattail demonstrated this injury symptom ≥5 DAT. Necrosis was present approximately 10–14 DAT for alligatorweed and primrose treated with glyphosate or imazapyr, whereas necrosis was not present until ≥21 DAT for cattail treated with the same herbicides. All species, regardless of herbicide treatment (proprietary and generic), showed signs of recovery from the treatments 1–7 WAT. Since plant recovery (that is, formation of new leaves and stems) timing was not consistent across repetitions or trials, and it occurred within all containers and pots, it is difficult to identify a specific trend or date of this occurrence.

It should also be noted that differences in plant size and growth were visually observed prior to herbicide application and throughout the initial and repeat trials, particularly for the control plants. There was considerably less biomass for the controls in the repeat trials at harvest (7–8 WAT). The initial trials were treated with foliar herbicide applications in May through August, while the repeat trials were treated in August and September. Often, growth of emergent annual and perennial species slows substantially in the late summer or fall, and these species initiate seed production or carbohydrate allocation to belowground storage organs (that is, rhizomes) prior to winter. Herbicide application timing and changes in growth patterns are the likely causes of large biomass differences between trials, which prevented the data from being pooled in all but one of the trials.

Regardless, plants within a particular trial responded to the herbicides in the same manner during early or late season herbicide applications.

3.2 Quantitative responses

3.2.1 2,4-D

Alligatorweed treated with foliar applications of proprietary and generic 2,4-D at 2131 g a.e. ha^{-1} was reduced in aboveground biomass by 42–60% and 59–77% of the control 8 WAT in trials 1 and 2, respectively (table 4). Similarly, the same rate of 2,4-D provided 93–96% and 91–94% primrose control 8 WAT in trials 1 and 2, respectively. In all four mesocosm trials, no differences occurred in product performance when 2,4-D Amine, DMA 4 IVM, Shredder Amine, WEEDestroy AM-40 or Weedar 64 were applied to the foliage of actively growing alligatorweed and primrose, which is similar to previous research (Mudge and Getsinger 2019) that evaluated similar 2,4-D products against water hyacinth and found no differences in product performance. The systemic 2,4-D is one of the oldest synthetic herbicides that has been registered in the United States (1946) to control weeds in aquatic, agricultural, and other settings (WDNR 2012; USEPA 2019).

Table 4. Efficacy (mean g dry weight, ± SE) of generic and proprietary aquatic 2,4-D brands against alligatorweed and creeping water primrose 8 weeks after treatment (WAT)[a].

	Alligatorweed		Creeping Water Primrose	
Herbicide[b,c]	Trial 1	Trial 2	Trial 1	Trial 2
Control	63.9 ± 14.4 a[d]	40.8 ± 6.0 a	102.6 ± 3.7 a	52.1 ± 11.6 a
DMA 4 IVM	25.5 ± 2.8 b	16.8 ± 3.7 b	6.9 ± 1.6 b	3.3 ± 1.0 b
Shredder Amine	7.1 ± 5.4 b	9.6 ± 1.8 b	4.6 ± 1.4 b	3.6 ± 0.4 b
WEEDestroy AM-40	31.3 ± 7.3 b	12.4 ± 2.1 b	5.2 ± 1.5 b	3.8 ± 1.1 b
Weedar 64	35.2 ± 8.7 b	16.5 ± 2.1 b	7.6 ± 2.0 b	4.7 ± 0.7 b
2,4-D Amine	29.4 ± 2.6 b	16.7 ± 2.4 b	6.0 ± 1.5 b	3.7 ± 0.6 b

[a] Pre-treatment weights for alligatorweed trials 1 and 2 were 47.1 ± 2.3 and 8.8 ± 1.0 g, respectively, and pre-treatment weights were 59.7 ± 17.1 and 20.0± 2.8 g for creeping water primrose trials 1 and 2, respectively.

[b] All herbicides applied at 2131 g a.e. ha^{-1}.

[c] All treatments included a non-ionic surfactant (Surf-AC 910) applied at 0.25% v v^{-1}.

[d] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$; n = 5.

3.2.2 Glyphosate

Glyphosate applied at 2243 g a.e ha^{-1} against alligatorweed, primrose, and cattail provided similar results as the 2,4-D trials. Although statistical differences in product performance were detected between Roundup Custom (82% control) and Rodeo (96% control) in glyphosate versus alligatorweed trial 1, no differences were detected among the other treatments, and control ranged 82–96% regardless of herbicide at 8 WAT (table 5). Despite the level of efficacy provided in the initial trial, none of the proprietary or generic herbicides provided acceptable control (<44%) in the repeat glyphosate versus alligatorweed trial, and all treatments were statistically the same as the nontreated control. Although the development and severity of herbicide injury was initially similar in both trials, plant control ceased—and plant recovery occurred—sooner in the second trial. Although the reason for poor control is unknown, plant growth at herbicide application timing (24 May versus 8 August) may have influenced efficacy. Future small-scale research should investigate the influence of herbicide application timing and plant growth stage on proprietary versus generic herbicide performance.

In trial 1 of glyphosate versus cattail, all treatments reduced plant dry weight >48%, but a difference in product performance was observed between Rodeo and Glyphosate 5.4. (49% versus 75% control, respectively). Conversely, all glyphosate treatments in the repeat trial performed similarly and provided ≥84% cattail control. All proprietary and generic glyphosate herbicides evaluated against primrose in trial 1 and 2 were efficacious and provided 54–67% and 48–68% control, respectively, by the conclusion of the research. Mudge and Getsinger (2018) also found minor differences in efficacy when glyphosate at 2242.8 and 3364.1 g a.e. ha^{-1} was applied to the foliage of water hyacinth and giant salvinia, respectively.

Table 5. Efficacy (mean g dry weight, ± SE) of generic and proprietary aquatic glyphosate brands against alligatorweed, southern cattail, and creeping water primrose 8 WAT[a].

	Alligatorweed		Southern Cattail		Creeping Water Primrose	
Herbicide[b,c]	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Control	93.9 ± 17.8 a[d]	51.5 ± 11.4	93.4 ± 12.8 a	30.4 ± 5.8 a	127.6 ± 12.2 a	32.7 ± 4.6 a
AquaNeat	6.7 ± 2.8 bc	45.7 ± 6.7	41.7 ± 13.2 bc	4.9 ± 3.0 b	58.7 ± 17.4 b	10.3 ± 1.7 b
AquaPro	8.6 ± 4.5 bc	50.4 ± 6.5	31.0 ± 11.8 bc	2.4 ± 2.4 b	44.9 ± 12.2 b	11.6 ± 4.2 b
Glyphosate 5.4	13.8 ± 5.3 bc	28.9 ± 5.0	51.1 ± 7.2 b	4.5 ± 1.6 b	50.2 ± 12.8 b	14.6 ± 4.3 b

Refuge	7.1 ± 2.4 bc	50.5 ± 11.8	35.4 ± 7.5 bc	2.5 ± 1.5 b	50.6 ± 8.8 b	16.9 ± 3.1 b
Rodeo	3.7 ± 1.1 c	39.6 ± 9.8	20.5 ± 11.4 c	0.6 ± 0.7 b	41.8 ± 10.0 b	10.9 ± 2.6 b
Roundup Custom	16.7 ± 4.1 b	44.4 ± 6.6	41.4 ± 11.0 bc	2.6 ± 1.1 b	51.9 ± 6.0 b	15.4 ± 2.7 b

[a] Pre-treatment weights were as follows: alligatorweed 48.8 ± 4.7 and 50.5 ± 11.8 g for trials 1 and 2 respectively; cattail 44.4 ± 2.3 and 28.8± 3.0 g for trials 1 and 2, respectively; primrose 28.2 ± 5.8 and 34.3 ± 8.0 g for trials 1 and 2, respectively.

[b] All herbicides applied at 2243 g acid equivalent (a.e) ha^{-1}.

[c] All treatments included a non-ionic surfactant applied at 0.25% v v^{-1} (Surf-AC 910).

[d] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$; n = 5.

3.2.3 Imazapyr

There were no differences in proprietary versus generic product performance with regard to the initial or repeat imazapyr versus alligatorweed, primrose, or cattail trials (table 6). In the imazapyr (561 g a.i. ha^{-1}) versus alligatorweed trials, Arsenal, Habitat, Imazapyr 4, and Polaris provided 75–84% control at 8 WAT when the herbicide was applied to the foliage of this troublesome emergent species. Primrose control with imazapyr ranged 82–86% and 59–81% in trials 1 and 2, respectively, when applied at the same rate. In cattail trials 1 and 2, the slow-acting, systemic herbicide imazapyr provided 64–93% and 82–99% reductions in dry weight, respectively, when applied at twice the rate (1121 g a.i. ha^{-1}) of what was used in the alligatorweed and primrose trials.

Table 6. Efficacy (mean g dry weight, ± SE) of generic and proprietary aquatic imazapyr brands against alligatorweed, southern cattail, and creeping water primrose 8 WAT.[a]

	Alligatorweed	Creeping Water Primrose		Southern Cattail	
		Trial 1	Trial 2	Trial 1	Trial 2
	Rate (g a.i. ha^{-1})				
Herbicide[b]	561			1121	
Control	57.5 ± 9.8 a[c]	167.1 ± 14.2 a	49.6 ± 4.2 a	185.4 ± 9.4 a	53.0 ± 14.3 a
Arsenal	12.5 ± 2.3 b	24.0 ± 3.9 b	20.5 ± 6.1 b	60.1 ± 17.3 b	9.7 ± 5.1 b
Habitat	11.9 ± 2.9 b	30.2 ± 2.6 b	16.3 ± 3.2 b	49.0 ± 23.1 b	0.8 ± 0.8 b
Imazapyr 4 SL	14.4 ± 4.1 b	22.4 ± 3.4 b	9.4 ± 2.6 b	67.0 ± 31.7 b	4.7 ± 2.2 b
Polaris	9.2 ± 1.6 b	27.8 ± 5.6 b	13.1 ± 4.4 b	13.5 ± 13.5 b	8.3 ± 4.1 b

[a] Pre-treatment weights were as follows: alligatorweed 30.0 ± 4.8 g; primrose 32.6 ± 2.5 and 20.9 ± 4.4 g for trials 1 and 2, respectively; southern cattail 48.4 ± 5.6 and 21.2 ± 4.6 g for trials 1 and 2, respectively.

[b] All treatments included a non-ionic surfactant (Surf-AC 910) applied at 0.25% v v^{-1}.

[c] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$; n = 10 for alligatorweed since trials pooled and n = 5 for primrose and southern cattail.

3.2.4 Triclopyr

Similar to the imazapyr trials, foliar applications of Renovate 3, Garlon 3A, Triclopyr, and Trycera at 2523 g a.e ha^{-1} provided varying levels of control when applied to the invasive emergent species alligatorweed and primrose. Plant dry weights were reduced by 39–53 and 77–86% in the first and second triclopyr versus alligatorweed trials, respectively (table 7). In the primrose research, plant control with triclopyr was substantially higher and ranged from 87–93% and 98–99% in trials 1 and 2, respectively. Previous research by Sartain, Wersal, and Madsen (2015) demonstrated the auxin mimic triclopyr at 3400 g a.e ha^{-1} provided 92% control of water primrose (*Ludwigia peploides* [Kunth] P.H. Raven ssp. glabrescens [Kuntze] P.H. Raven) at 12 WAT.

Table 7. Efficacy (mean g dry weight, ± SE) of generic and proprietary aquatic triclopyr brands against alligatorweed and creeping water primrose 8 WAT.[a]

	Alligatorweed		Creeping Water Primrose	
Herbicide[b,c]	Trial 1	Trial 2	Trial 1	Trial 2
Control	93.3 ± 15.9 a[d]	35.1 ± 4.2 a	61.8 ± 11.2 a	62.4 ± 10.4 a
Garlon 3A	57.3 ± 3.7 b	7.7 ± 1.0 b	5.1 ± 2.4 b	0.6 ± 0.4 b
Renovate 3	48.5 ± 7.2 b	8.2 ± 1.6 b	5.1 ± 1.9 b	1.5 ± 0.8 b
Triclopyr	43.9 ± 5.7 b	7.1 ± 0.9 b	4.3 ± 0.7 b	2.1 ± 0.7 b
Trycera	46.6 ± 8.5 b	4.8 ± 0.6 b	8.3 ± 2.4 b	1.3 ± 1.0 b

[a] Pretreatment weights for alligatorweed trials 1 and 2 were 35.2 ± 4.8 and 11.5 ± 1.4 g, respectively, and pretreatment weights were 23.0 ± 5.6 and 24.1 ± 2.7 g for primrose trials 1 and 2, respectively.

[b] All herbicides applied at 2523 g a.e. ha^{-1}.

[c] All treatments included a nonionic surfactant (Surf-AC 910) applied at 0.25% v v^{-1}.

[d] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$; n = 5.

4 Conclusions

Prior to, during, and after herbicide application, a portion (10–20%) of the plant's aboveground biomass was positioned below the water surface. This partial subaquatic situation may have hindered efficacy by limiting herbicide movement to the lower plant appendages (for example, leaves, stems, and roots) but also teased out potential differences among proprietary and generic herbicides by not allowing the herbicide spray solution to come in complete contact with the entire plant. Future research should re-evaluate these products against plants cultured in less water or dewatered, bare-ground situations to determine whether product performances are enhanced and whether further differences among products can be detected.

Four active ingredients—2,4-D, glyphosate, imazapyr, and triclopyr (19 products)—were evaluated against three commonly found emergent species in 20 small-scale, mesocosm trials, and the results demonstrated that the majority of the herbicides provided similar control regardless of active ingredient or foliar application rate. Previous research conducted in aquatic (Koschnick et al. 2003; Bultemeier et al. 2009; Turnage, Madsen, and Wersal 2015; Mudge and Getsinger 2019), row crop (Siekman and Sandell 2008), and roadside (McFalls et al. 2015) settings also found limited differences in product performance when generic and proprietary 2,4-D, clopyralid, copper, glyphosate, imazapyr, metsulfuron-methyl, and triclopyr were applied as foliar or subsurface applications. The current small-scale trials and results are a necessary starting point for developing reliable operational guidance for direct comparisons among generic and proprietary products. Although these results did not indicate any appreciable differences among products, except for glyphosate versus alligatorweed (trial 1) and glyphosate versus cattail (trial 1), field verification of these small-scale evaluations should be initiated with USACE districts to verify and refine guidance for use in large-scale operational settings. The data generated in the current and previous research (Mudge and Getsinger 2019) will be useful to USACE districts as well as other federal, state, and local agencies when selecting generic and proprietary 2,4-D, glyphosate, imazapyr, and triclopyr when target emergent and floating species need to be managed.

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14. ABSTRACT
Aquatic herbicides are one of the most effective and widespread ways to manage nuisance vegetation in the US After the active ingredient is selected, often there are numerous proprietary and generic branded products to select from. To date, limited efforts have been made to compare the efficacy of brand name and generic herbicides head to head; therefore, at total of 20 mesocosm trials were conducted to evaluate various 2,4-D, glyphosate, imazapyr, and triclopyr products against alligatorweed (*Alternanthera philoxeroides* (Mart.) Griseb.), southern cattail (hereafter referred to as cattail, *Typha domingensis* Pers.), and creeping water primrose (hereafter referred as primrose, *Ludwigia peploides* (Kunth) P.H. Raven). All active ingredients were applied to foliage at broadcast rates commonly used in applications to public waters. Proprietary and generic 2,4-D, glyphosate, imazapyr, and triclopyr were efficacious and provided 39 to 99% control control of alligatorweed, cattail and primrose in 19 of the 20 trials. There were no significant differences in product performance except glyphosate vs. alligatorweed (trial 1, Rodeo vs. Roundup Custom) and glyphosate vs. cattail (trial 1, Rodeo vs. Glyphosate 5.4). These results demonstrate under small-scale conditions, the majority of the generic and proprietary herbicides provided similar control of emergent vegetation, regardless of active ingredient.

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