J. Aquat. Plant Manage. 52: 90–92

NOTES

The efficacy of protox-inhibiting herbicides alone and in combination with glyphosate to control crested floating heart

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INTRODUCTION

Crested floating heart [*Nymphoides cristata* (Roxb.) Kuntze], hereafter referred to as CFH, was first reported in Horseshoe Lake, Collier County, Florida (Burks 2002a) in 1996. A native to Asia, CFH was reported to cover 1.5 ha of Horseshoe Lake in only 3 to 4 wk (Burks 2002b). CFH has also shown potential to expand rapidly in canals and smaller water bodies; however, its recent expansion to cover over 2,428 ha in the Santee Cooper Reservoir, South Carolina is a cause for concern (Willey 2012). This expansion in lakes at more northern latitudes is alarming because it suggests that CFH will grow well at any latitude in FL and many of the southern states. CFH can proliferate in even the largest FL lakes, and is expanding in a reservoir system that is stocked with grass carp as a means to control hydrilla [*Hydrilla verticillata* (L.f.) Royle], suggesting that the plant is not preferred or consumed by the herbivorous fish. According to Burk (2002a), spread of this species to other regions of the United States will not be limited by temperature. Currently, CFH is found throughout Florida and has spread to Louisiana, North Carolina, South Carolina, and Texas (Willey 2012). The weed risk assessment performed on CFH determined that it was high risk, particularly for impact and establishment/spread potential (USDA 2012).

Nymphoides spp. can grow in water 3 m or greater (Sculthorpe 1967) and can be rooted or free-floating (Burks 2002b). It is an aggressive invader that can impede water flow and outcompete native vegetation with its dense floating canopies (Burks 2002b, Willey and Langeland 2011). Dense mats of CFH can reduce light penetration and surface mixing of oxygen (Burks 2002b). CFH also produces vegetative propagules, or ramets (root bundles with small leaves), that develop from the stems of the parent plant and can break away and float off to start new stands (Burks 2002a). These vegetative propagules can also sink to the bottom and remain dormant for extended periods of time, thus remaining untouched by foliar-applied herbicides (Burks 2002a). Limited information exists with regard to the biology or dormancy of these vegetative propagules.

Ongoing management efforts for CFH have been inconsistent. There are currently no host-specific insect herbivores that feed on CFH, and grass carp are ineffective (Singh et al. 1966, Willey and Langeland 2011). Mechanical harvesting and winter draw downs have also proven ineffective at controlling CFH (Middleton 1990, Willey and Langeland 2011). Chemical control might be the best management option and based on preliminary herbicide screening, submersed application of endothall (amine salt, 7-oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid) or diquat (6,7-dihydrodipyrido[1,2-α:2′,1′-*c*]pyrazinediium ion), or foliar applications of imazamox (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid) or imazapyr ((±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl])-3-pyridinecarboxylic acid) appear to have the most potential for controlling CFH (Willey 2012).

Glyphosate (N-(phosphonomethyl)glycine), which is commonly used as a foliar application to control emergent aquatic vegetation failed to control CFH as well as foliar applications of 2,4-D amine ((2,4-dichlorophenoxy)acetic acid) and triclopyr ([(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid), which can be used to control other lily species (Westerdahl and Getsinger 1988, Langeland et al. 1993, Willey 2012). Submersed applications of the protoporphyrinogen oxidase- (protox) inhibiting herbicides carfentrazone-ethyl (X,2-dichloro-5-[4-(difluromethyl)-4,5-dihydro-3-methyl-5-oxo-1*H*-1,2,4-triazol-1-yl]-4-fluorobenzenepropanic acid) and flumioxazin (2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2*H*-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1*H*-isoindole-1,3(2*H*)-dione) also did not reduce CFH dry weight biomass below pretreatment levels (Willey 2012). To date, no research has examined the efficacy of foliar applications of the protox inhibitors for the control of CFH. Foliar applications of the protox inhibitors were not evaluated by Willey (2012). Therefore, the objective of this study was to determine the efficacy of carfentrazone-ethyl

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Table 1. Weekly (weeks after treatment [WAT]) mean percent control ratings (± standard error [SE]) on crested floating heart treated with (G) glyphosate, (F) flumioxazin, (CE) Carfentrazone-ethyl, or a combination of F + G or CE + G. Means sharing the same letter in a column do not significantly differ from each other (Student-Neuman-Keuls [SNK]; $P \leq 0.001$).

Treatment (kg ai ha^{-1})	Percent control, WAT					
	1	2	3	4	5	6
Control	0.0 ± 0.0 c	0.0 ± 0.0 d	0.0 ± 0.0 c	0.0 ± 0.0 d	0.0 ± 0.0 c	0.0 ± 0.0 c
6.05 G	4.0 ± 1.0 bc	6.7 ± 1.7 d	6.7 ± 3.3 c	26.7 ± 11.7 cd	41.7 ± 21.7 b	45.0 ± 22.5 b
0.43 F	73.3 ± 12.0 a	85.0 ± 2.9 b	96.0 ± 1.0 a	95.0 ± 0.0 a	88.3 ± 1.7 a	51.7 ± 19.7 b
0.11 F + 3.03 G	83.3 ± 4.4 a	83.3 ± 3.3 b	90.0 ± 2.9 a	86.7 ± 3.3 a	96.0 ± 1.0 a	96.0 ± 1.0 a
0.22 F + 3.03 G	86.7 ± 6.0 a	88.3 ± 3.3 b	94.3 ± 2.3 a	95.0 ± 2.9 a	98.3 ± 0.3 a	97.7 ± 1.5 a
0.43 F + 6.05 G	93.3 ± 1.7 a	98.7 ± 0.7 a	99.3 ± 0.7 a	100.0 ± 0.0 a	100.0 ± 0.0 a	100.0 ± 0.0 a
0.22 CE	11.7 ± 1.7 bc	4.0 ± 1.0 d	3.3 ± 1.7 c	0.0 ± 0.0 d	0.0 ± 0.0 c	0.0 ± 0.0 c
0.06 CE + 3.03 G	10.0 ± 2.9 bc	10.0 ± 2.9 d	13.3 ± 3.3 c	40.0 ± 10.0 c	71.7 ± 6.0 a	75.0 ± 12.6 ab
0.11 CE + 3.03 G	10.0 ± 0.0 bc	10.0 ± 2.9 d	11.7 ± 1.7 c	26.7 ± 6.7 c	70.0 ± 5.8 a	80.0 ± 0.0 ab
0.22 CE + 6.05 G	25.0 ± 7.6 b	20.0 ± 5.0 c	25.0 ± 7.6 b	66.7 ± 6.7 b	73.3 ± 7.3 a	85.0 ± 2.9 ab

and flumioxazin applied via foliar application, alone and in combination with glyphosate on CFH.

MATERIALS AND METHODS

This study was conducted in 76-L outdoor tanks at the U.S. Army Engineer Research and Development Center's Lewisville Aquatic Ecosystem Research Facility. One CFH ramet was planted into a 1-L pot filled with top soil[1] amended with 3 g L^{-1} Osmocote[2] (16–8–12) and 2.5 g L^{-1} sulfur.[3] One pot of CFH was placed into each tank, and tanks were filled with Lake Lewisville water. Plants were allowed to establish for 8 wk and covered 100% of the water surface prior to treatment. On August 22, 2012, tanks were treated with 6.05 kg ai ha^{-1} glyphosate[4] (G), 0.43 flumioxazin[5] (F), 0.11 F + 3.03 G, 0.22 F + 3.03 G, 0.43 F + 6.05 G, 0.22 carfentrazone-ethyl[6] (CE), 0.06 CE + 3.03 G, 0.11 CE + 3.03 G, or 0.22 CE + 6.05 G. A nonionic surfactant[7] was added at a rate of 0.5% v/v. Foliar treatments were applied using a carbon dioxide- (CO_2) pressurized sprayer[8] equipped with a hand-held, single-nozzle spray header calibrated to deliver a spray volume of 934 L ha^{-1}. Treatments were replicated three times and included an untreated control. Weekly percent control ratings were recorded and at 6 wk after treatment (WAT), all viable biomass was harvested and dried at 65 C to a constant weight. Biomass and percent control rating data were subjected to one-way analysis of variance (ANOVA) with means compared via the Student–Newman–Keuls method (SNK; $P \leq 0.001$).

RESULTS AND DISCUSSION

At 1 WAT, visual percent control ratings ranged from 73 to 93% for flumioxazin alone and all flumioxazin + glyphosate combinations (Table 1). Flumioxazin alone provided 96 percent control at 3 WAT followed by a gradual decrease in percent control due to regrowth through 6 WAT. However, percent control ratings on the flumioxazin + glyphosate treatments increased weekly throughout the course of the study and ranged from 96 to 100% at 6 WAT. Percent control for carfentrazone-ethyl alone was similar to the untreated control throughout the study whereas the carfentrazone-ethyl + glyphosate treatments gradually increased through 6 WAT. At 6 WAT, the carfentrazone-ethyl + glyphosate treatments ranged from 75 to 85% control. Glyphosate control was significantly greater than the untreated control at 6 WAT but control was only 45%.

At 6 WAT, all herbicide treatments, except carfentrazone-ethyl alone, significantly reduced CFH biomass compared to the untreated control (Figure 1). Biomass reduction ranged from 78 to 100% for flumioxazin alone and the flumioxazin + glyphosate combinations and 48 to 67% for the carfentrazone-ethyl + glyphosate combinations. Although not statistically different than the other treatments, the 0.43 F + 6.05 G treatment had no viable shoot or root biomass remaining at the time of harvest. All other treatments had viable biomass present at 6 WAT, indicating that CFH would recover from these treatments.

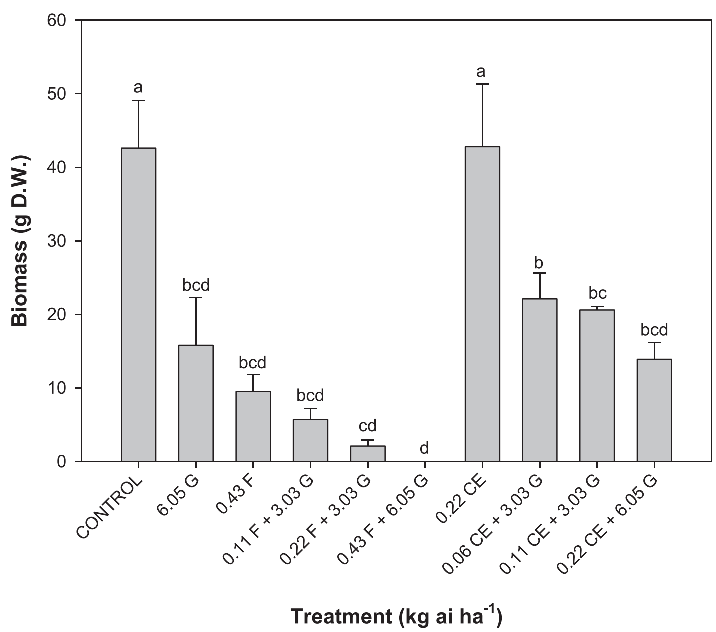

Figure 1. Response of crested floating heart biomass (mean ± standard error [SE]) to (G) glyphosate, (F) flumioxazin, (CE) carfentrazone-ethyl, or a combination of F + G or CE + G 6 wk after treatment. Bars sharing the same letter do not significantly differ from each other (Student–Neuman–Keuls [SNK]; $P \leq 0.001$).

Protox inhibitor + glyphosate combinations have been used for a number of years to control weeds in nursery production, landscape maintenance, and cotton fields (Culpepper et al. 2004, Culpepper et al. 2005, Williams and Miller 2007, Wehtje et al. 2010). Although CFH control wasn't significantly improved by mixing glyphosate with flumioxazin, control was improved by adding glyphosate to carfentrazone. The fact that all biomass, including root, was completely eliminated by 6 WAT at the highest flumioxazin + glyphosate treatment is a good indication that this treatment might be a suitable option for controlling CFH in the field. Future research should focus on the efficacy of protox + glyphosate combinations on CFH in the field and whether these combinations can result in long-term control.

SOURCES OF MATERIALS

[1]Hapi-Gro top soil, Hope Agri Products Inc., 2600-20 Old Hwy. 29 S, Hope, AR 71801.

[2]Osmocote®, The Scotts Company, PO Box 606 Marysville, OH 43040.

[3]Soil Acidifier, Bonide Products, Inc., 6301 Sutliff Rd., Oriskany, NY 13424.

[4]AquaPro®, SePRO Corporation, 11550 N. Meridian St., Ste 600, Carmel, IN 46032.

[5]Clipper®, Valent USA Corporation, 1735 Market St., Philadelphia, PA 19103.

[6]Stingray™, FMC Corporation, 1735 Market St., Philadelphia, PA 19103.

[7]Thoroughbred®, Winfield Solutions LLC, PO Box 64589, St. Paul, MN 55164.

[8]Bellspray Inc, 419 Hwy. 104, Opelousas, LA 70570.

ACKNOWLEDGEMENTS

Support for this research was provided by the Florida Fish and Wildlife Commission, Invasive Plant Management Section. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. Permission was granted by the Chief of Engineers to publish this information.

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