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The effect of herbicide and growth stage on Cuban club-rush (*Oxycaryum cubense*) control

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ABSTRACT

Cuban club-rush [*Oxycaryum cubense* (Poepp. & Kunth) Lye] is a floating, epiphytic, perennial aquatic plant from South America and the West Indies that has spread to the southeastern United States. To date, there are no published studies documenting management techniques for Cuban club-rush. The objectives of this study were to determine the efficacy of 10 aquatic-labeled herbicides for Cuban club-rush management, and to determine whether there is a difference in efficacy between preflowering and postflowering herbicide applications. Foliar applications of glyphosate [*N*-(phosphonomethyl)glycine; 4.54 kg ae ha^{-1}], carfentrazone, [X,2-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1*H*-1,2,4-triazol-1-yl]-4-fluorobenzenpropanoic acid; 0.22 kg ai ha^{-1}], 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; 0.42 kg ai ha^{-1}], 2,4-D [3,4-dichlorophenoxyacetic acid; 4.26 kg ae ha^{-1}], triclopyr [[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid; 6.72 kg ae ha^{-1}], imazamox [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid; 0.56 kg ai ha^{-1}], imazapyr [(±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-pyridinecarboxylic acid; 1.68 kg ai ha^{-1}], penoxsulam [2-(2,2-difluoroethoxy)-*N*-(5,8-dimethoxy[1,2,4]triazolo[1,5-*c*]pyrimidin-2-yl)-6-(trifluoromethyl)benzenesulfonamide; 0.10 kg ai ha^{-1}], bispyribac-sodium [2,6-bis[(4,6-dimethoxy-2-pyrimidinyl)oxy]benzoic acid, sodium salt; 0.448 kg ai ha^{-1}], and diquat 6,7-dihydrodipyrido[1,2-α:2′,1′-*c*]pyrazinediium ion; 4.48 kg ai ha^{-1}] were applied to Cuban club-rush grown in 151-L tanks fitted with a plastic mesh fence to simulate the epiphytic growth pattern of Cuban club-rush. Each herbicide and an untreated reference were replicated four times for a total of 44 tanks per study. A significant interaction between herbicide and growth stage was detected ($P = 0.0048$). Mean biomass of Cuban club-rush that was treated preflowering was lower than that of the plants treated with postflowering applications. All herbicides applied preflowering achieved > 80% biomass reduction. For the postflowering application, > 80% biomass reduction was achieved only by glyphosate, diquat, and triclopyr. Future studies should assess herbicide tank mixes and the effects of biomass mat thickness on Cuban club-rush control.

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INTRODUCTION

Cuban club-rush [*Oxycaryum cubense* (Poepp. & Kunth) Lye] is an aquatic, invasive plant that is spreading in the southeastern United States. It is an emergent, rhizomatous, perennial epiphyte with triangular stems that grow 0.3 to 0.9 m tall (Godfrey and Wooten 1979, Robles et al. 2007, Bryson et al. 2008). Two forms of Cuban club-rush are found in the United States that can be differentiated by their inflorescence features. *Oxycaryum cubense* forma *cubense* has an umbellate inflorescence, whereas *O. cubense* forma *paraguayense* has monocephalous inflorescence (Barros 1960). The root and rhizomes of Cuban club-rush intertwine with the roots of other plants to create dense, floating mats. It is often found in association with plants such as waterhyacinth [*Eichhornia crassipes* (Mart.) Solms], water fern (*Salvinia minima* Baker), hydrilla [*Hydrilla verticillata* (L. f.) Royle], floating pennywort (*Hydrocotyle ranunculoides* L. f.), angelstem primrose-willow [*Ludwigia leptocarpa* (Nutt.) H. Hara], parrotfeather [*Myriophyllum aquaticum* (Vell.) Verdc.], Eurasian watermilfoil (*Myriophyllum spicatum* L.), American pondweed (*Potamogeton nodosus* Poir.), marsh mermaidweed (*Proserpinaca palustris* L.), and humped bladderwort (*Utricularia gibba* L.) (Bryson and Carter 2008).

Cuban club-rush is adapted to dispersal by water (Haines and Lye 1983). It reproduces via buoyant, vegetative fragments that break from the floating mats and by achenes, which have a spongy, suberized pericarp allowing them to float (Haines and Lye 1983). Seed placement is important in the establishment of Cuban club-rush because germination in the leaf axils of waterhyacinth has been observed (Tur 1971).

Cuban club-rush is thought to be native to South America and the West Indies. It was likely introduced into the United States by migratory birds or ship ballast from those areas (Bryson et al. 1996). Cuban club-rush is now found throughout Central America, tropical Africa, and the southeastern United States, including Florida (Anderson 2007), southern Georgia (Bryson et al. 1996), Alabama (Lelong 1988), Louisiana (Thomas and Allen 1993), coastal Texas (Turner et al. 2003), and Mississippi (Cox et al. 2010). Bryson and Carter (2008) suggest that the sporadic distribution of Cuban club-rush in North America could be due to a lag phase or the low fertility of achenes.

The highly aggressive nature of Cuban club-rush allows it to exclude other vegetation, including the ability to outcompete and overtake waterhyacinth (Robles et al.

2007). In many countries, the greatest problem associated with Cuban club-rush is the extensive, floating mats that it forms. These mats block access points to waterways, impede recreation and navigation, and create poor fisheries habitat because the water below the mats is often low in dissolved oxygen and high in organic matter (Mallison et al. 2001). To date, there are no published studies, to our knowledge, documenting effective management techniques for control of Cuban club-rush.

For many areas of the southeastern United States, Cuban club-rush is not widespread, so there is a greater opportunity for preventing new invasions and possibly eradicating new, smaller populations. As part of the early detection and rapid response strategy, tools to control those small populations are needed. An important part of effective control involves implementing the management technique when success is most probable, which often depends on the phenology of the plant (Madsen and Owens 1998). Management studies were conducted in a mesocosm to evaluate 10 foliar-active herbicides labeled for use in aquatic systems and applied to the foliage of Cuban club-rush at two different growth stages, i.e., before and after flowering. The objectives were to (1) identify the most efficacious herbicides for Cuban club-rush control, and (2) determine whether Cuban club-rush control is affected when herbicide application is made at the preflowering or postflowering stage.

MATERIALS AND METHODS

The studies were conducted in 2011 and 2012 at an outdoor mesocosm at the R. R. Foil Plant Science Research Center, Mississippi State University, Starkville, MS. For both 2011 and 2012, the preflowering study began in August and ended in October. In 2011, the preflowering study ran for 8 wk, whereas the 2012 study was harvested 9 wk after treatment (WAT). The 6-wk, postflowering study began in September and ended in November for both years.

Eighty-eight, 151-L tanks were set up and covered with plastic-mesh netting with 1.9-cm^2 openings. The tanks were filled with water and amended with 30 mg L^{-1} of 24–8–16 (N–P–K) fertilizer[1] and 0.5 ml L^{-1} of water dye[2] each week throughout the study (Cheshier et al. 2011). At the beginning of June for both years, Cuban club-rush was harvested from Ross Barnett Reservoir in Jackson, MS, and Columbus Lake in Columbus, MS, at heights ranging from 15.2 to 25.4 cm. Ten plants were inserted through the holes of the mesh netting. Because some of the earlier transplants died, several plantings were required before plants became established. The final planting occurred 4 wk before herbicide application.

Eleven treatments, which included 10 herbicides and an untreated reference, were assigned to the tanks in a completely randomized design. Each treatment was replicated four times for a total of 44 tanks per study. The 44 tanks used in the postflowering study were not sprayed during the preflowering study.

For both preflowering and postflowering studies, before treatment, Cuban club-rush was sampled by taking all of the plant biomass above and below the mesh within a 0.01 m^{-2} quadrat. Plants were dried at 70 C for at least 4 d and then weighed to assess the pretreatment biomass.

Foliar applications of the 10 herbicides were made to Cuban club-rush using a carbon dioxide (CO_2) pressurized sprayer at a spray volume of 468 L ha^{-1} with 0.1% v/v nonionic surfactant[3] added. Herbicides were applied at the maximum labeled rate, with the exception of flumioxazin, which was applied at one-tenth of the maximum rate due to a calculation error that was not discovered until the end of the 2011 study. Herbicides used included diquat[4] [6,7-dihydrodipyrido[1,2-α:2′,1′-*c*]pyrazinediium ion; 4.48 kg ai ha^{-1}], imazapyr[5] [(±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-pyridinecarboxylic acid; 1.68 kg ai ha^{-1}], imazamox[6] [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid; 0.56 kg ai ha^{-1}], glyphosate[7] [*N*-(phosphonomethyl)glycine; 4.54 kg ai ha^{-1}], penoxsulam[8] [2-(2,2-difluoroethoxy)-*N*-(5,8-dimethoxy[1,2,4]triazolo[1,5-*c*]pyrimidin-2-yl)-6-(trifluoromethyl)benzenesulfonamide; 0.10 kg ai ha^{-1}], 2,4-D[9] [3,4-dichlorophenoxyacetic acid; 4.26 kg ai ha^{-1}], triclopyr[10] [[(3,5,6-trichloro-2-pyridinyl)oxy]-acetic acid; 6.72 kg ai ha^{-1}], bispyribac-sodium[11] [2,6-bis[(4,6-dimethoxy-2-pyrimidinyl)oxy]benzoic acid, sodium salt; 0.448 kg ai ha^{-1}], flumioxazin[12] [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; 0.42 kg ai ha^{-1}], and carfentrazone[13] [X,2-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1*H*-1,2,4-triazol-1-yl]-4-fluorobenzenpropanoic acid; 0.22 kg ai ha^{-1}]. A plastic barrier was placed around the tanks during treatment to prevent herbicide spray drift.

Visual ratings to assess Cuban club-rush control were made each week after the initial treatment for the duration of each study. Cuban club-rush control was assessed on a scale of 0 to 100, where 0 is no control and 100 is complete plant mortality. At the end of each study, all of the living plant biomass above and below the mesh within a 0.01-m^{-2} quadrat was removed, oven-dried at 70 C, and weighed.

A mixed procedures model in SAS[14] statistical software, with year as a random effect, was used to evaluate the effects of herbicide, growth stage, and potential interactions between herbicide and growth stage on mean biomass reduction of Cuban club-rush (Littell et al. 2006). If a main effect was significant, means were separated by least-square means and grouped using the least-square differences procedure. No significant difference between years was detected; therefore, data were pooled. All analyses were conducted at a $P = 0.05$ level of significance in SAS. The visual ratings were not statistically analyzed but will be used in the discussion.

RESULTS AND DISCUSSION

A significant interaction between herbicide and growth stage was detected ($P = 0.0048$). Except for the postflowering application of carfentrazone, each herbicide achieved significant mean biomass reduction compared with the untreated reference at both growth stages at 8 and 9 WAT for the preflowering application and 6 WAT for the postflowering application (Figure 1). For imazapyr, imaza-

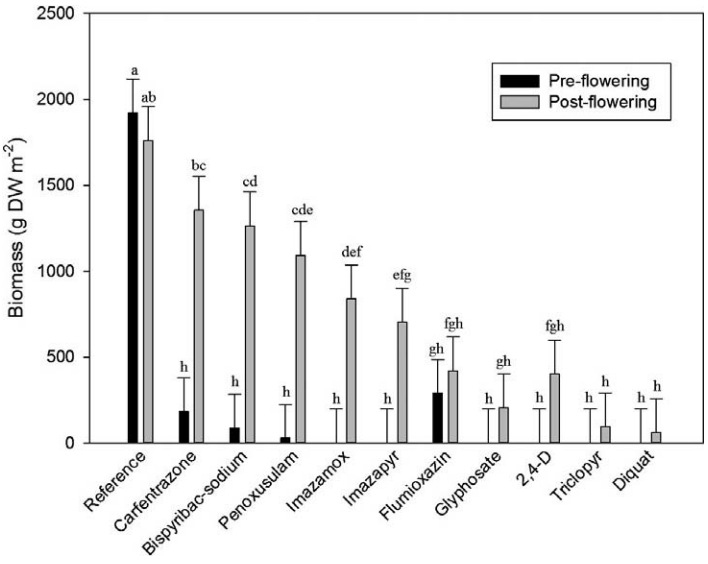

Figure 1. Mean (± 1 SE) Cuban club-rush biomass (g dry wt [DW] m^{-2}) harvested for the preflowering and postflowering studies combined for 2011 and 2012 from R. R. Foil Plant Science Research Center, Mississippi State University, Starkville, MS. Bars sharing the same letter are not significantly different at the $P = 0.05$ level of significance according to least-square means.

mox, penoxsulam, bispyribac-sodium, and carfentrazone, a significant difference in mean biomass reduction was detected between the two growth stages. All the herbicides applied to Cuban club-rush before inflorescence emergence reduced biomass $\geq 85\%$ by 8 and 9 WAT. For the postflowering application, only diquat, triclopyr, and glyphosate provided $\geq 85\%$ biomass reduction at 6 WAT.

Imazapyr, imazamox, penoxsulam, bispyribac-sodium are acetolactate synthase (ALS) inhibitors. ALS compounds inhibit the production of amino acids, which are necessary for protein production. As plants approach maturity and the onset of seed production, protein synthesis is already reduced, which may contribute to the reduced control observed between growth stages with application of the ALS inhibitors (Koschnick et al. 2007). Carfentrazone may not have been as effective during the postflowering application because of changes in the leaf composition from younger to mature leaves, thereby reducing herbicide-absorption rates. Koschnick et al. (2004) observed that younger leaves of waterhyacinth treated with carfentrazone showed injury, whereas more-mature leaves showed few symptoms.

Another possible explanation for the differences measured in control between growth stages could be due to differences in the amount of biomass present during the preflowering and postflowering herbicide applications. For these studies, the average biomass in the preflowering and postflowering tanks was 400 and 1,480 g dry wt (DW) m^{-2}, respectively. The greater amount of club-rush biomass during the postflowering herbicide application made it difficult to get complete coverage of all the plants growing in the tank.

The results of this study show that both preflowering and postflowering herbicide applications can effectively reduce Cuban club-rush biomass; however, the herbicide used should be dependent on the growth stage of the plant. For preflowering herbicide applications, all of the herbicides provided adequate control ($> 80\%$) of Cuban club-rush; however, for postflowering herbicide applications, Cuban club-rush treated with carfentrazone did not differ significantly from the untreated reference (Figure 1). Furthermore, triclopyr, diquat, and glyphosate were the only herbicides to achieve $\geq 85\%$ biomass reduction. Because this is the first documented study, to our knowledge, of herbicide activity on Cuban club-rush, this information will be useful for rapid response to new populations.

During the course of the study, we discovered that the two reservoirs from which we harvested the club-rush had the two different biotypes. The Ross Barnett Reservoir had *O. cubense* forma *cubense*, and Columbus Lake had *O. cubense* forma *paraguayense*. At the time of the first harvest, neither population had flowered, so the differences in the two forms were not known. Samples from the two populations were sent to Dr. Ryan Thum at Grand Valley State University (Allendale Charter Township, MI) for genetic analysis. Although more samples are needed, preliminary works suggests there may be a genetic difference between the two biotypes (R. Thum and T. Pashnick, unpub. data).

Future work on Cuban club-rush should include further genetic testing because herbicide efficacy may be different for the two biotypes. With the increasing issue of herbicide resistance, herbicide tank mixtures and various herbicide application rates should be evaluated as well. Because information is very limited on the growth and reproduction of Cuban club-rush, biological and ecological studies are necessary for better management of the species.

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SOURCES OF MATERIALS

[1]Miracle Gro Fertilizer, Scotts Company LLC, 14111 Scottslawn Road, Marysville, OH 43041.

[2]Aquashade, Arch Chemicals, Inc. W175 N 11163 Stonewood Drive, Suite 234, Germantown, WI 53022.

[3]Dyne-Amic, Helena Chemical Company, 225 Schilling Boulevard, Collierville, TN38017.

[4]Reward, Syngenta Crop Protection, Inc., P.O. Box 18300, Greensboro, NC 27419.

[5]Habitat, BASF Corporation, 26 Davis Drive, Research Triangle Park, NC 27709 (at the time of the study); now SePRO Corporation, 11550 North Meridian Street Suite 600. Carmel, IN 46032.

[6]Clearcast, BASF Corporation, 26 Davis Drive, Research Triangle Park, NC 27709 (at the time of the study); now SePRO Corporation, 11550 North Meridian Street Suite 600. Carmel, IN 46032.

[7]Rodeo, Dow AgroSciences LLC, 9330 Zionsville Road, Indianapolis, IN 46268.

[8]Galleon SC, SePRO Corporation, 11550 North Meridian Street Suite 600. Carmel, IN 46032.

[9]DMA IV-IVM, Dow AgroSciences LLC, 9330 Zionsville Road, Indianapolis, IN 46268.

[10]Renovate 3, SePRO Corporation, 11550 North Meridian Street Suite 600. Carmel, IN 46032.
[11]Tradewind, Valent U.S.A. Corporation, 1333 N California Blvd, Walnut Creek, CA 94596.
[12]Clipper, Valent U.S.A. Corporation, 1333 N California Blvd, Walnut Creek, CA 94596.
[13]Stingray, FMC Corporation, 1735 Market Street, Philadelphia, PA 19103
[14]SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513-2414.

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