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Efficacy of selected herbicides on Cuban bulrush [*Oxycaryum cubense* (Poepp. & Kunth) Lye]

JACKSON JABLONSKI, CANDICE PRINCE,* STEPHEN ENLOE, GREGORY MACDONALD, AND BENJAMIN SPERRY

ABSTRACT

Cuban bulrush (*Oxycaryum cubense*) (Poepp. & Kunth) Lye is an epiphytic perennial sedge that invades aquatic habitats in the southeastern United States. Its emergent and floating growth habit allows it to form tussocks that restrict waterway access for navigation and outcompete native plant species. It is primarily managed using herbicides, and there is a need to evaluate more active ingredients for Cuban bulrush control. Three groups of single or tank mix herbicide applications were evaluated for control of Cuban bulrush in a greenhouse setting Florida. In trial 1, we evaluated operational treatments currently used by state agencies in Florida (diquat, glyphosate, 2,4-D, glyphosate + flumioxazin, 2,4-D + diquat, and 2,4-D + glyphosate). In trial 2, we evaluated a recently registered synthetic auxin herbicide (florpyrauxifen-benzyl) alone or in combination with 2,4-D, imazamox, or flumioxazin. In trial 3, we evaluated several acetolactate synthase (ALS)-inhibitor herbicides (halosulfuron, imazapic, imazethapyr, bispyribac-sodium, imazapyr, and imazamox). Operational treatments and florpyrauxifen-benzyl combinations resulted in > 70% visual control 30 days after treatment (DAT) and > 90% biomass reduction of aboveground tissue 60 DAT. ALS-inhibiting herbicides resulted in slower symptom development, although there was limited regrowth (> 90% biomass reduction) 60 DAT for plants treated with imazapic, imazethapyr, imazamox, and imazapyr. Halosulfuron and bispyribac-sodium resulted in inconsistent levels of control between experimental runs. These small-scale results suggest that the current operational treatments as well as florpyrauxifen-benzyl combinations provide both fast and effective control of Cuban bulrush. Future work will focus on verifying these findings under operational field conditions.

Key words: aquatic sedge, chemical control, *Cyperus blepharoleptos*, greenhouse, selectivity.

INTRODUCTION

Cuban bulrush (*Oxycaryum cubense*) (Poepp. & Kunth) Lye is an emergent and floating aquatic sedge with uncertain nativity. It is also commonly referred to by the scientific name *Cyperus blepharoleptos* (Steud.) (GBIF 2022). Populations have been documented from South America and the Caribbean to tropical Africa (GBIF 2022). The first documented case in North America was in 1878 in Alabama (GBIF 2022). The earliest record of the species in Florida is from Glades County in 1945 (Wunderlin et al. 2020). Cuban bulrush is thought to have arrived in the United States via migratory birds or the unloading of ship ballasts (Watson and Madsen 2014). Today, vouchered plant specimens from wild populations have been documented in 28 counties across the state of Florida (Wunderlin et al. 2020). Two forms of the species have been recognized: forma cubense, with umbellate inflorescences, and forma paraguayense, with monocephalous inflorescences (Bryson et al. 2008). Forma paraguayense occurs in northwest Florida, southern Alabama, Mississippi, Louisiana, Georgia, South Carolina, southern Arkansas, and southeast Texas, while forma cubense occurs within peninsular Florida, Mississippi, and Louisiana (GBIF 2022).

Cuban bulrush grows aggressively, forming monotypic floating tussocks that can cover large areas of lakes to the exclusion of other aquatic plant species (Bryson et al. 1996). In addition to its impact on native plants, Cuban bulrush tussocks can block access points to waterbodies (i.e., docks and boat ramps) and shade out desirable submersed vegetation (Mallison et al. 2001). Water is often high in organic matter and low in dissolved oxygen below stands of floating aquatic species such as Cuban bulrush, contributing to poor fisheries habitat (Alam et al. 1996).

Cuban bulrush is difficult to manage because of its extensive stoloniferous growth below water. Several herbicides have been evaluated on Cuban bulrush, with triclopyr, diquat, and glyphosate resulting in greater than 85% biomass reductions, and carfentrazone, bispyribac-sodium, penoxsulam, imazamox, flumioxazin, and 2,4-D resulting in 80 to 84% biomass reduction when applied to plants in the preflowering stage (Watson and Madsen 2014). Currently, managers in Florida use flumioxazin, diquat, glyphosate, and 2,4-D with varying levels of control. Diquat and 2,4-D reportedly provide high levels of control one to 3 wk after treatment, while glyphosate can exhibit slower activity (FWC 2022). Although suppression of Cuban bulrush can be achieved using diquat, 2,4-D and glyphosate, multiple applications are required to control regrowth in the field (K. Gladding, pers. comm., 2020).

*First author: Graduate Student, Agronomy Department, University of Florida, Gainesville, FL 32653. Second author: Assistant Professor, Agronomy Department, Center for Aquatic and Invasive Plants, University of Florida, Gainesville, FL 32653. Third author: Professor, Agronomy Department, Center for Aquatic and Invasive Plants, University of Florida, Gainesville, FL 32653. Fourth author: Professor, Agronomy Department, University of Florida, Gainesville, FL 32611. Fifth author: Research Biologist, Environmental Laboratory, U.S. Army Engineer Research and Development Center, Gainesville, FL 32653. Corresponding author's E-mail: cprince14@ufl.edu. Accepted January 11, 2023.

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Table 1. The source of plant material, planting dates, and herbicide application dates for Cuban bulrush plants used for each trial. The percentage of plants that were flowering at the time of herbicide application is also included.

Trial	Run	Source	Planted	Treated	Flowering plants (%)
1	1	Cross Creek	3 October 2020	20 November 2020	100
	2	Cross Creek	3 October 2020	4 December 2020	100
2	1	Lake Tohopekaliga	9 February 2021	5 April 2021	0
	2	Lake Jackson	10 March 2021	5 May 2021	50
3	1	Lake Tohopekaliga	9 February 2021	14 April 2021	0
	2	Lake Jackson	10 March 2021	5 May 2021	50

In addition, both diquat and glyphosate have broad-spectrum activity and can result in nontarget damage to native species. There are often several other native and invasive hydrophytes within tussocks of Cuban bulrush, including important native species such as maidencane (*Panicum hemitomon* Shult.), water spider orchid (*Habenaria repens* Nutt.), and swamp loosestrife (*Decodon verticillatus* L.) (J. Jablonski, pers. obs., 2022). In areas with mixed stands of Cuban bulrush, herbicide options are needed to provide selectivity to these nontarget species. Florpyrauxifen-benzyl, a synthetic auxin herbicide that has recently been labeled for aquatic use, shows promising control and selectivity for a variety of aquatic species (Netherland and Richardson 2016, Enloe and Lauer 2017, Mudge et al. 2021), including several aquatic sedges (*Cyperus* spp.) (Miller and Norsworthy 2018). However, there is no published research confirming its efficacy on Cuban bulrush.

There are also several sedge-specific acetolactate synthase (ALS)-inhibiting herbicides registered for weed control in rice that may provide effective control of Cuban bulrush. These herbicides inhibit the synthesis of branched-chain amino acids (Duggleby et al. 2008). Several ALS-inhibitor herbicides, including halosulfuron, imazapic, and imazethapyr, have been evaluated for control on other sedges (*Cyperus* spp.) in aquatic environments and resulted in effective control (Jabran et al. 2012, Webster et al. 2014, Vitelli et al. 2021). Recent research has also found high efficacy of halosulfuoron, imazamox, and imazapyr on *Scleria lacustris*, another invasive aquatic sedge in the southeastern United States (Onisko 2020). Although halosulfuron, imazapic, and imazaethapyr are not currently registered for use in aquatic habitats, rice-labeled and aquatic-labeled herbicides share several aquatic toxicology requirements for registration. Establishing efficacy of these herbicides on key species such as Cuban bulrush may provide support for future aquatic registration. Here we investigated the relative efficacy of current operational treatments (glyphosate, 2,4-D, diquat, and flumioxazin), florpyrauxifen-benzyl combinations, and ALS-inhibiting herbicides on Cuban bulrush in the greenhouse. Results from this research will inform management of this species.

MATERIALS AND METHODS

Experiments were established at the University of Florida's Center for Aquatic and Invasive Plants (UF CAIP) in Gainesville, FL (29.424738N; 82.156820W) from 3 October 2020 to 5 May 2021. Cuban bulrush stolon cuttings (40 to 50 cm in length) were collected from Cross Creek (Alachua County, FL, 29.480338N; 82.163215W), Lake Tohopekaliga (Osceola County, FL, 28.287965N; 81.259517W), and Lake Jackson (Leon County, FL, 27.905576N; 81.166849W) (Table 1). Cuttings from Cross Creek were sourced from emergent plants rooted in the sediment along the shoreline, and cuttings from Lake Tohopekaliga in Cypress Cove and Lake Jackson were sourced from floating mats. Plant material was stored in a cooler until processing at UF CAIP.

Apical stolon segments (10 to 20 cm in length, one segment per pot) with attached leaves (10 to 15 cm in length) were planted in 3.7-L pots (16.2 cm diameter by 18.4 cm height) filled with commercial potting soil,[1] with slow-release fertilizer N-P-K, 15-9-12, at 10 g pot^{-1})[2] mixed into the top 1 to 2 cm of the pot. Stolon fragments were planted 1 to 2 cm into the soil. Twelve pots each were placed into single 80-L rectangular plastic bins (28 bins total, 86 cm by 56 cm by 20 cm) and subirrigated with 8 cm of standing well water. The soil was damp throughout the entire experiment to allow fertilizer capsule release.

Three treatment groups were evaluated. Herbicides for trial 1 were selected based on current operational treatments by the Florida Fish and Wildlife Conservation Commission for Cuban bulrush: diquat, glyphosate, 2,4-D, glyphosate + flumioxazin, 2,4-D + diquat, and 2,4-D + glyphosate (Table 2). Trial 2 included six herbicide treatments: florpyrauxifen-benzyl, florpyrauxifen-benzyl + 2,4-D, florpyrauxifen-benzyl + flumioxazin, and florpyrauxifen-benzyl + imazamox as well as 2,4-D and imazamox alone (Table 2). Trial 3 included six ALS-inhibiting herbicides: halosulfuron, imazapic, imazethapyr, bispyribac-sodium, imazapyr, and imazamox (Table 2). Each experiment also included a nontreated control for reference. There were four replicate pots per treatment, and each experiment was repeated twice.

Cuttings of the umbellate form (forma cubense) were collected from Cross Creek were used for trial 1; the first and second experimental runs were established on 20 November 2021 and 4 December 2021, respectively. Cuttings from Lake Tohopekaliga used for the first experimental run of experiments 2 and 3, which were established on 5 April 2021 and 14 April 2021, respectively. The second experimental runs for experiments 2 and 3 were established using cuttings from Lake Jackson on 5 May 2021. Plants were selected for experiments based on uniformity in height (~ 60 cm) and ramet number (~7 ramets per plant). All plants were well established at the time of treatment and were maintained in pots for at least 7 wk before herbicide treatment (Table 1). In trial 1, all plants were flowering at the time of treatment for both experimental runs (Table 1). No plants were flowering in the first experimental run, and

Table 2. Herbicides and foliar application rates evaluated against Cuban bulrush for each trial. Trials 1 and 3 included a nonionic surfactant (0.25% v v^{-1}). Trial 2 included a methylated seed oil (0.25% v v^{-1}). There were four replicate plants per treatment.

Experiment	Active ingredient	Rate (kg a.i. or a.e. ha^{-1})
1	Diquat[6]	1.12
	Glyphosate[7]	4.14
	2,4-D[8]	2.13
	Glyphosate + flumioxazin[9]	4.20 + 0.18
	2,4-D + diquat	1.9 + 0.20
	2,4-D + glyphosate	2.13 + 4.20
	Nontreated control	—
2	2,4-D	2.13
	Imazamox[10]	0.28
	Florpyrauxifen-benzyl[11]	0.03
	Florpyrauxifen-benzyl + 2,4-D	0.03 + 2.12
	Florpyrauxifen-benzyl + flumioxazin	0.03 + 0.21
	Florpyrauxifen-benzyl + imazamox	0.03 + 0.28
	Nontreated control	—
3	Halosulfuron[12]	0.06
	Imazapic[13]	0.094
	Imazethapyr[14]	0.09
	Bispyribac-sodium[15]	0.06
	Imazapyr[16]	0.75
	Imazamox	0.25
	Nontreated control	—

50% of plants were flowering in the second experimental run for experiments 2 and 3. No plants had produced seeds at the time of treatment.

Foliar herbicide applications were made using a CO_2-powered backpack sprayer calibrated to 935 L ha^{-1} with a two-nozzle[3] boom at 276 kPa. Trial 1 treatments included a nonionic surfactant[4] at 0.25% v v^{-1}, and all trial 2 and trial 3 treatments included a methylated seed oil[5] at 1% v v^{-1}. Surfactant type was selected based on label recommendations. Plants were removed from the greenhouse for herbicide application and allowed to dry completely (1 h) before they were moved back into bins. Water in the plastic bins was completely exchanged 4 h and 72 h after treatment to reduce herbicide leaching and uptake through the water column. Plants were visually evaluated for control (0 to 100%), and aboveground biomass was harvested 30 days after treatment (DAT). Aboveground and belowground biomass was then harvested 60 DAT to allow for plant regrowth. All harvested biomass was dried in a forced-air oven at 65 C for 72 h before measurement.

Biomass data were used to calculate percent biomass reduction (BR) using the following equation:

$$BR\% = 100 \times \frac{\text{untreated plants} - \text{treated plants}}{\text{untreated plants}}. \quad [1]$$

The experiment was established as a completely randomized design. Data for each experiment were analyzed using one-way analysis of variance (ANOVA) in RStudio (RStudio Team 2020) and evaluated for model assumptions of normality and homogeneity of variance. Means were separated via Tukey's honestly significant difference (HSD) test ($P \leq 0.05$) using the agricolae package (de Mendiburu and Yaseen 2020) in R. Due to statistical differences, experimental runs were analyzed separately.

RESULTS AND DISCUSSION

Trial 1

In the first experimental run, all foliar applied treatments resulted in > 80% control 30 DAT (Figure 1A). There were no differences between herbicide treatments; however, all herbicides resulted in greater visual control than the nontreated controls. All treatments resulted in at least 28% reduction of aboveground biomass by 30 DAT, although there were no differences between herbicide active ingredient (Figure 1B). There was no regrowth of aboveground tissue of treated plants by 60 DAT regardless of herbicide (Figure 1C). All herbicides resulted in at least 45% reductions in belowground biomass 60 DAT (Figure 1D). Diquat alone or in combination with 2,4-D resulted in greater reductions in belowground biomass than 2,4-D alone or in combination with glyphosate. Plants treated with glyphosate or glyphosate + flumioxazin showed intermediate reductions in belowground biomass (63 and 67%, respectively) that were not different than any other treatment (Figure 1D).

In the second experimental run, all herbicides resulted in > 75% visual control 30 DAT (Figure 2A). There were differences between treatments, with 2,4-D resulting in 15% less control than diquat, 2,4-D + diquat, and 2,4-D + glyphosate, but similar control to glyphosate. There were no differences in control between glyphosate (96%) or any other herbicide. Diquat resulted in 36% greater aboveground biomass reduction than glyphosate + flumioxazin 30 DAT; all other treatments resulted in intermediate levels of biomass reduction (Figure 2B). By 60 DAT, there was no regrowth of aboveground biomass regardless of herbicide (Figure 2C). In addition, all herbicides resulted in > 70% reduction in belowground biomass compared to the nontreated controls (Figure 2D).

Watson and Madsen (2014) evaluated the efficacy of 10 herbicides on mixed biotypes of Cuban bulrush and found >85% reductions in biomass when plants were treated with diquat, 2,4-D, or glyphosate. Plants in their study were established as floating mats in mesocosms filled with water, while in our experiment, plants were established in substrate to mimic infestations that we have observed on the banks of canals and lakes in Florida (C. Prince, pers. obs., 2020). The combined results of our study and of Watson and Madsen (2014) suggest that the current operational treatments used on Cuban bulrush may be equally effective regardless of its growth habit.

In addition, Cuban bulrush often grows in mixed populations with other invasive floating aquatic plants, such as water hyacinth (*Eichhornia crassipes* Mart.) water lettuce (*Pistia stratiotes* L.), and giant salvinia (*Salvinia molesta* D. S. Mitchell) (McFarland et al. 2004, Bryson et al. 2008). In these situations, tank mixes of 2,4-D and diquat may allow managers to effectively control multiple species at the same time. However, more research is needed to evaluate the efficacy of these operational treatments on Cuban bulrush under field conditions.

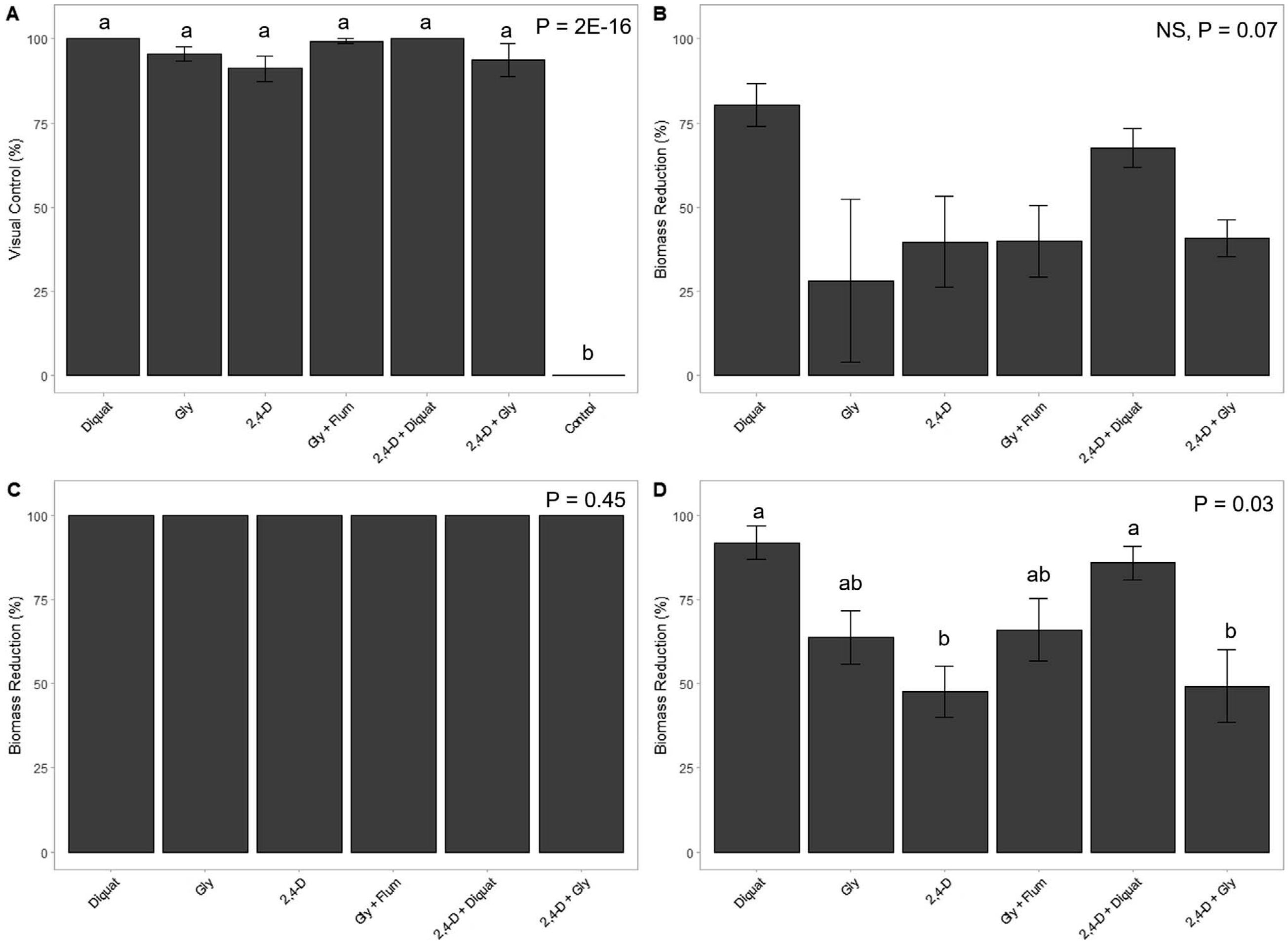

Figure 1. The response of Cuban bulrush (mean ± standard error) to trial 1 herbicide applications ($n = 4$) in the first experimental run. Visual evaluations (A) were made of control 30 days after treatment (DAT) with diquat, gly (gly), 2,4-D, glyphosate + flumioxazin (gly + flum), 2,4-D + diquat, and 2,4-D + gly. Aboveground biomass (B) was also harvested and used to calculate biomass reductions (%) compared to the nontreated control (average biomass of 6.7 g). Aboveground (C) and belowground (D) biomass reductions were also calculated 60 DAT. The average above- and belowground biomass for nontreated control 60 DAT plants was 0.2 and 4.8 g, respectively. P values from a one-way analysis of variance are displayed on each graph. Letters denote mean separation between treatments as determined by Tukey's HSD ($P \leq 0.05$); columns sharing a letter are not significantly different from each other.

Trial 2

In the first experimental run, all herbicides except imazamox (66%) resulted in > 80% visual control 30 DAT when applied to the foliage of the emergent aquatic species (Figure 3A). Florpyrauxifen-benzyl resulted in high levels of control when applied alone (96%) or in combination with 2,4-D (98%) and flumioxazin (92%); however, when applied in combination with imazamox it resulted in less control (88%) than all treatments except for imazamox alone. Similar to trial 1, 2,4-D resulted in high levels of control (92%) when applied alone (Figure 3A). All treatments resulted in greater control than the nontreated control. All treatments resulted in at least 55% aboveground biomass reductions 30 DAT except for imaxamox (22%), although there were no differences between treatments (Figure 3B). By 60 DAT, no regrowth of aboveground tissues was observed regardless of treatment (Figure 3C). Reductions in belowground biomass were minimal (< 50%) across all treatments, with no differences between herbicides (Figure 3D).

Similarly, in the second experimental run, all herbicides resulted in high levels of control (> 80%) 30 DAT except for imazamox (68%) (Figure 4A). All herbicide treatments resulted in greater control than the nontreated controls. Reductions in aboveground biomass were relatively low (average of 27% across treatments) 30 DAT, with no differences between herbicide treatments (Figure 4B). There was no regrowth of aboveground biomass by 60 DAT, except for plants treated with 2,4-D and imazamox, which had 94 and 97% biomass reductions, respectively (Figure 4C). There were no differences in aboveground or belowground biomass reductions between treatments (Figure 4C and Figure 4D, respectively).

These results suggest that florpyrauxifen-benzyl, either alone or in combination with 2,4-D, imazamox, or flumioxazin, may be viable alternatives to the standard operational treatments currently used by managers on Cuban bulrush. However, although plants treated with imazamox did not recover by 60 DAT, they were slower to develop symptoms compared to the other herbicides used

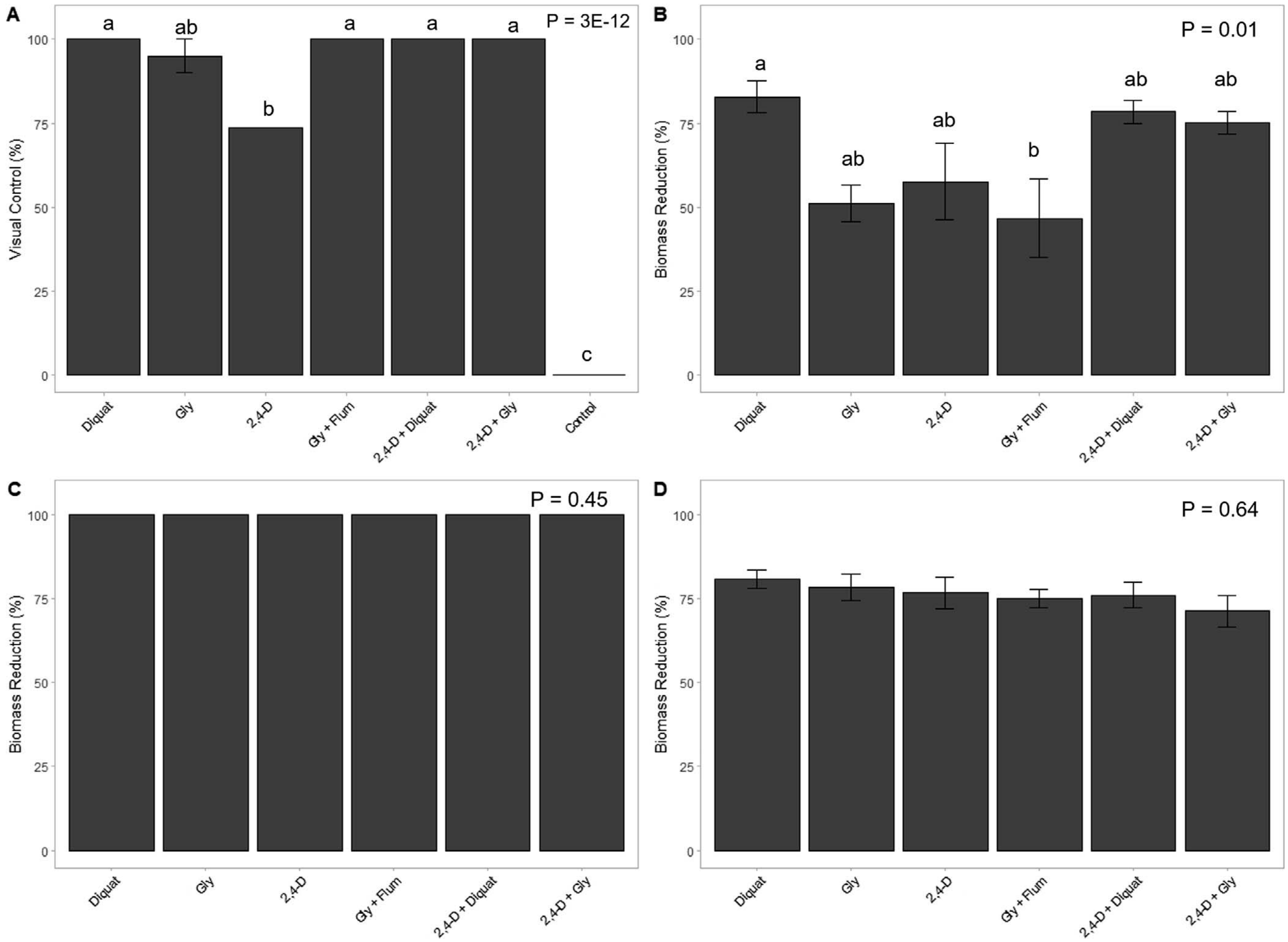

Figure 2. The response of Cuban bulrush (mean ± standard error) to trial 1 herbicide applications ($n = 4$) in the second experimental run. Visual evaluations (A) were made of control 30 days after treatment (DAT) with diquat, glyphosate (gly), 2,4-D, gly + flumioxazin (gly + flum), 2,4-D + diquat, and 2,4-D + gly. Aboveground biomass (B) was also harvested and used to calculate biomass reductions (%) compared to the nontreated control (average biomass of 6.7 g). Aboveground (C) and belowground (D) biomass reductions were also calculated 60 DAT. The average above- and belowground biomass for nontreated control 60 DAT plants was 0.2 and 4.8 g, respectively. *P* values from a one-way analysis of variance are displayed on each graph. Letters denote mean separation between treatments as determined by Tukey's HSD ($P \leq 0.05$); columns sharing a letter are not significantly different from each other.

in this experiment. This may be a consideration for managers who rely on early detection of control for follow-up treatments. More research is needed to evaluate the efficacy of florpyrauxifen-benzyl on Cuban bulrush under field conditions and in different growth habits (i.e., floating vs. rooted in substrate). In addition, research is needed to evaluate selectivity of the auxin mimic towards key nontarget species in a field setting.

Trial 3

In the first experimental run, minimal control ($\leq$ 60%) was observed across treatments applied to the foliage of Cuban bulrush (Figure 5A). Less visual control was noted when plants were treated with bispyribac-sodium (23%) compared to those treated with halosulfuron (52%), imazapic (54%), and imazapyr (60%). Bispyribac-sodium resulted in less control than all other herbicides except imazamox (40%) but was still different than the nontreated control (Figure 5A). Aboveground biomass reduction was low (average 40%) across treatments 30 DAT, with no differences detected between treatments (Figure 5B). In contrast, aboveground biomass reduction was high (> 90%) by 60 DAT for all herbicides except bispyribac-sodium, which possessed high variability (Figure 5C). Belowground biomass was also highly variable for bispyribac-sodium 60 DAT, with no differences between treatments (Figure 5D).

Visual control was low (< 20%) across all treatments in the second experimental run, with no differences between treatments (Figure 6A). Percent biomass reduction of aboveground biomass 30 DAT was also relatively low and similar across all treatments (average control 54%) (Figure 6B). By 60 DAT, there were high reductions in aboveground biomass (> 95%) for plants treated with imazapic, imazethapyr, imazapyr, and imazamox (Figure 6C). Halosulfuron

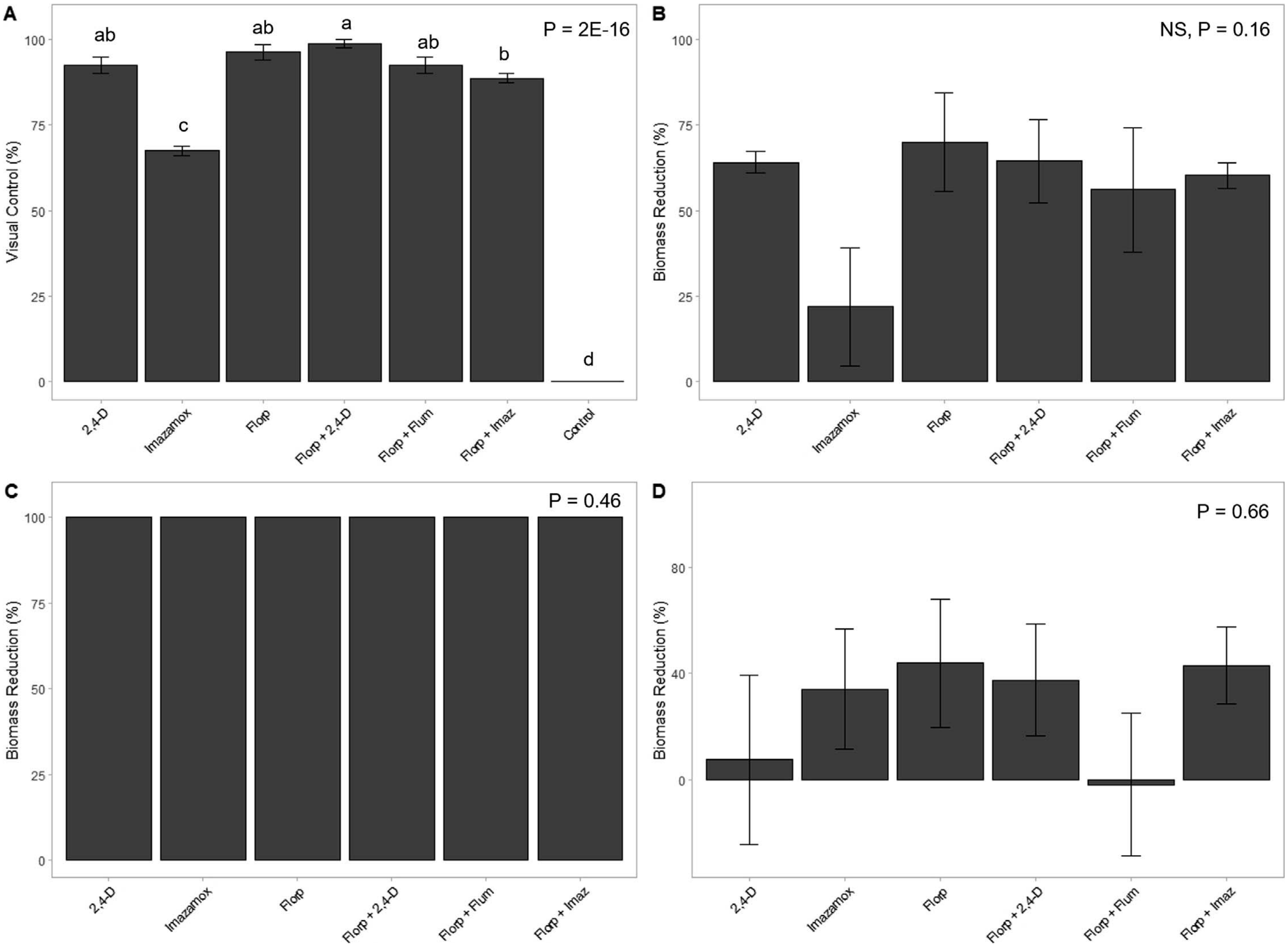

Figure 3. The response of Cuban bulrush (mean ± standard error) to trial 2 herbicide applications ($n = 4$) in the first experimental run. Visual evaluations (A) were made of control 30 days after treatment (DAT) with 2,4-D, imazamox, florpyrauxifen-benzyl (florp), florp + 2,4-D, florp + flumioxazin (flum), and florp + imazamox (imaz). Aboveground biomass (B) was also harvested and used to calculate biomass reductions (%) compared to the nontreated control (average biomass of 6.7 g). Aboveground (C) and belowground (D) biomass reductions were also calculated 60 DAT. The average above- and belowground biomass for nontreated control 60 DAT plants was 0.2 and 4.8 g, respectively. *P* values from a one-way analysis of variance are displayed on each graph. Letters denote mean separation between treatments as determined by Tukey's HSD ($P \leq 0.05$); columns sharing a letter are not significantly different from each other.

and bispyribac-sodium resulted in the lowest reductions of aboveground biomass (Figure 6C). Reduction of belowground biomass was relatively low and similar across all treatments 60 DAT (Figure 6D).

The ALS-inhibitor herbicides in this study were slower to develop symptoms than the operational herbicides used in trial 1 or the florpyrauxifen-benzyl combinations used in trial 2. However, several ALS-inhibitors (imazapic, imazethapyr, imazapyr, and imazamox) resulted in high reductions of aboveground biomass by 60 DAT and may provide adequate long-term control in the field. Bispyribac-sodium resulted in relatively poor control, particularly compared to the results of Watson and Madsen (2014). Differences between these studies may be due to differences in growing conditions (i.e., floating mats vs. rooted in substrate), the age of the plants, or the number of plants in the postflowering stage. In addition, although halosulfuron has provided high levels of control of other aquatic sedge species (Onisko 2020), results were variable on Cuban bulrush.

Imazapic and imazethapyr provided high levels of control on Cuban bulrush in both experimental runs of trial 3. Although these herbicides do not currently have labels for use in aquatic habitats, they are widely used for weed control in rice production. Additional research is needed to evaluate their efficacy on other invasive aquatic species (as well as nontarget native plants) to determine their suitability for use in aquatic ecosystems. In addition, research is needed to explore tank mix options using trial 3 herbicides.

We found differences between experimental runs in all three trials in this study. This may be due to using

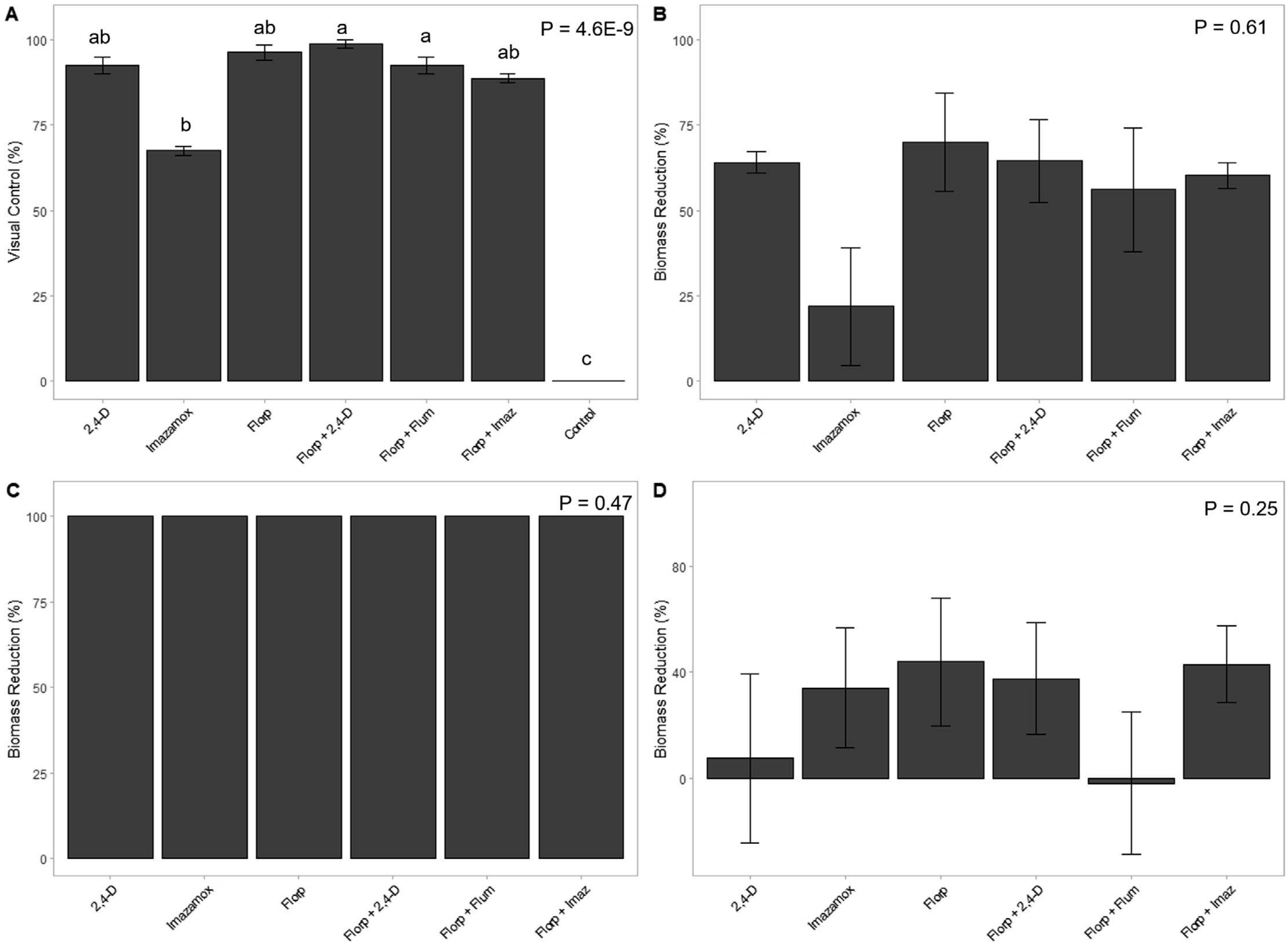

Figure 4. The response of Cuban bulrush (mean ± standard error) to trial 2 herbicide applications (n = 4) in the second experimental run. Visual evaluations (A) were made of control 30 days after treatment (DAT) with 2,4-D, imazamox, florpyrauxifen-benzyl (florp), florp + 2,4-D, florp + flumioxazin (flum), and florp + imazamox (imaz). Aboveground biomass (B) was also harvested and used to calculate biomass reductions (%) compared to the nontreated control (average biomass of 6.7 g). Aboveground (C) and belowground (D) biomass reductions were also calculated 60 DAT. The average above- and belowground biomass for nontreated control 60 DAT plants was 0.2 and 4.8 g, respectively. P values from a one-way analysis of variance are displayed on each graph. Letters denote mean separation between treatments as determined by Tukey's HSD ($P \leq 0.05$); columns sharing a letter are not significantly different from each other.

different sources of plant material, or the proportion of plants that were flowering (Table 1). Watson and Madsen (2014) found that Cuban bulrush was less susceptible to herbicide application in the postflowering stage. All plants were flowering at time of treatment in each experimental run for trial 1 of our study. However, there were differences in flowering between experimental runs for trials 2 and 3 (Table 1). There were no flowering plants at time of treatment in the first experimental run, compared to 50% of plants that were flowering in the second experimental run for both trials. This may account for the differences that we observed between experimental runs. However, trial 2 herbicides still resulted in high biomass reductions 60 DAT in the second experimental run (Figure 4C), suggesting that they provide adequate control of Cuban bulrush plants in the flowering stage. In addition, only halosulfuron and bispyribac-sodium resulted in poorer control of aboveground biomass 60 DAT in the second experimental run of trial 3 (Figure 6C); it is possible that these herbicides are less effective on postflowering plants than the other ALS-inhibiting herbicides included in this trial. However, more research is needed to experimentally evaluate this.

Based on the overall results of this study, managers are likely to see high control of Cuban bulrush using most of the trial 1 and trial 2 herbicides. Although several of the trial 3 herbicides resulted in high control, they were slower to act on Cuban bulrush and may not be suitable for applications on floating mats, where rapid development of symptoms is necessary for applicators to distinguish between treated and nontreated areas. Our results were similar to those found in other studies with ALS-inhibiting herbicides that were slow to develop symptoms and control (Willey et al. 2014, Mudge and Netherland 2015).

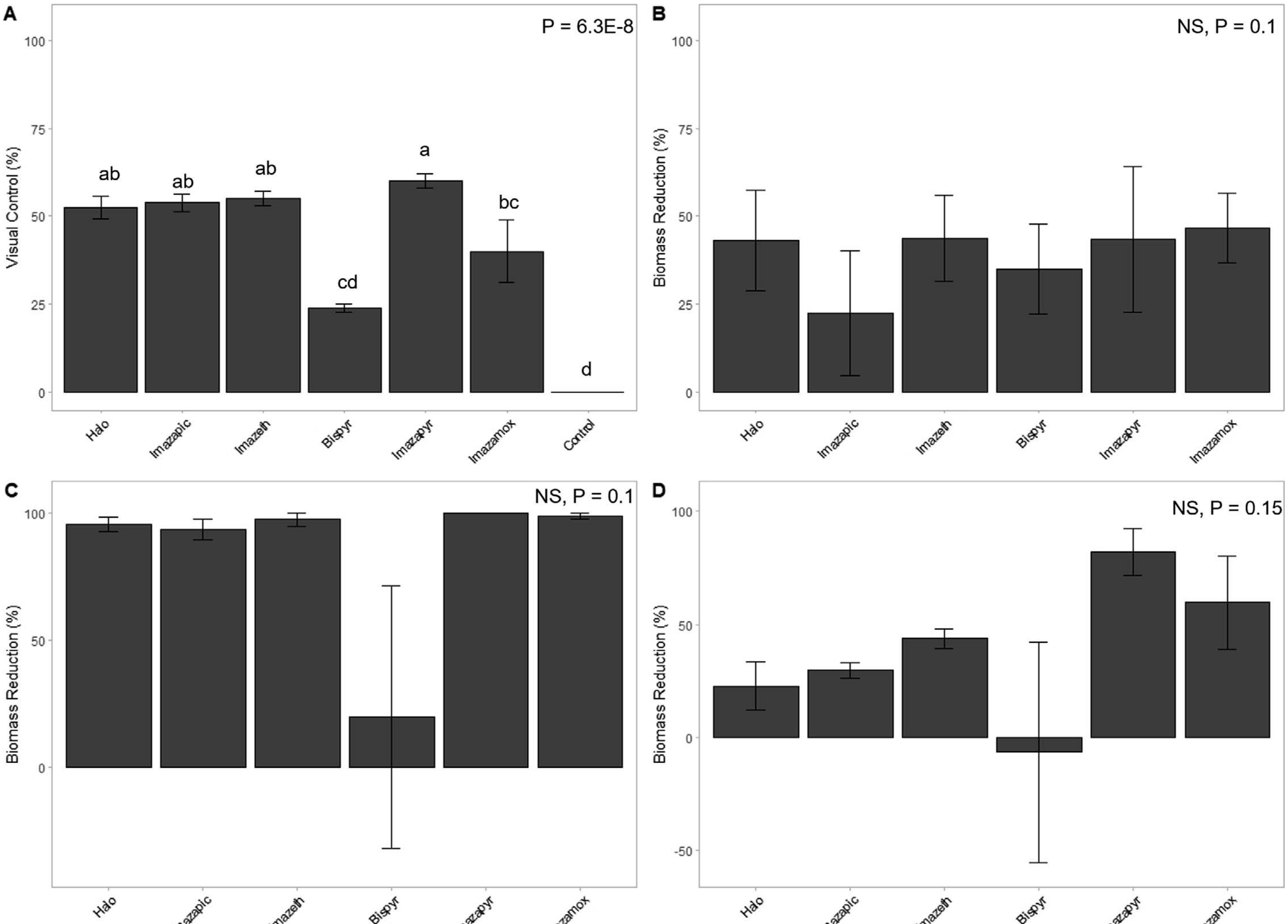

Figure 5. The response of Cuban bulrush (mean ± standard error) to trial 3 herbicide applications ($n = 4$) in the first experimental run. Visual evaluations (A) were made of control 30 days after treatment (DAT) with halosulfuron (halo), imazapic, imazethapyr (imazeth), bispyribac-sodium, imazapyr, and imazamox. Aboveground biomass (B) was also harvested and used to calculate biomass reductions (%) compared to the nontreated control (average biomass of 6.7 g). Aboveground (C) and belowground (D) biomass reductions were also calculated 60 DAT. The average above- and belowground biomass for nontreated control 60 DAT plants was 0.2 and 4.8 g, respectively. *P* values from a one-way analysis of variance are displayed on each graph. Letters denote mean separation between treatments as determined by Tukey's HSD ($P \leq 0.05$); columns sharing a letter are not significantly different from each other.

Cuban bulrush exhibits different growth habits in field and greenhouse environments. For example, tussock thickness in the field can exceed 75 cm (J. Jablonski, pers. obs., 2022), providing dormant stolons an opportunity to avoid herbicide exposure and regrow. Plant density may affect the success of chemical control, as well as histosol thickness of Cuban bulrush tussocks. Future work should examine herbicide applications at higher infestation levels with more biomass. In addition, our research was conducted in the greenhouse on plants that were rooted in substrate. This research needs to be repeated in the field, as well as with floating plants, in order to develop management recommendations and assess nontarget effects on native species.

SOURCES OF MATERIALS

[1]Pro-Line C25, Jolly Gardener, Poland, ME 04274.
[2]Osmocote Plus®, The Scotts Company, Marysville, OH 43040.
[3]Tee-Jet 11004 SV, Tee-Jet Technologies, Tifton, GA 31794.
[4]Induce, Helena Chemical, Collierville, TN 38027.
[5]Sun Wet, Brewer International, Vero Beach, FL 32969.
[6]Tribune, Syngenta Crop Protection, Greensboro, NC 24719.
[7]RoundUp Custom, Bayer Environmental Science, Cary, NC 27513.
[8]Weed Rhap A-4D, Helena Chemical, Collierville, TN 38027.
[9]Clipper SC, Nufarm Americas, Alsip, AL 60803.
[10]Clearcast, SePRO, Carmel, IN 46032.
[11]ProcellaCOR SC, SePRO, Carmel, IN 46032.
[12]Sedgehammer, Gowan, Yuma, AZ 85366.
[13]Plateau, BASF, Durham, NC 27709.

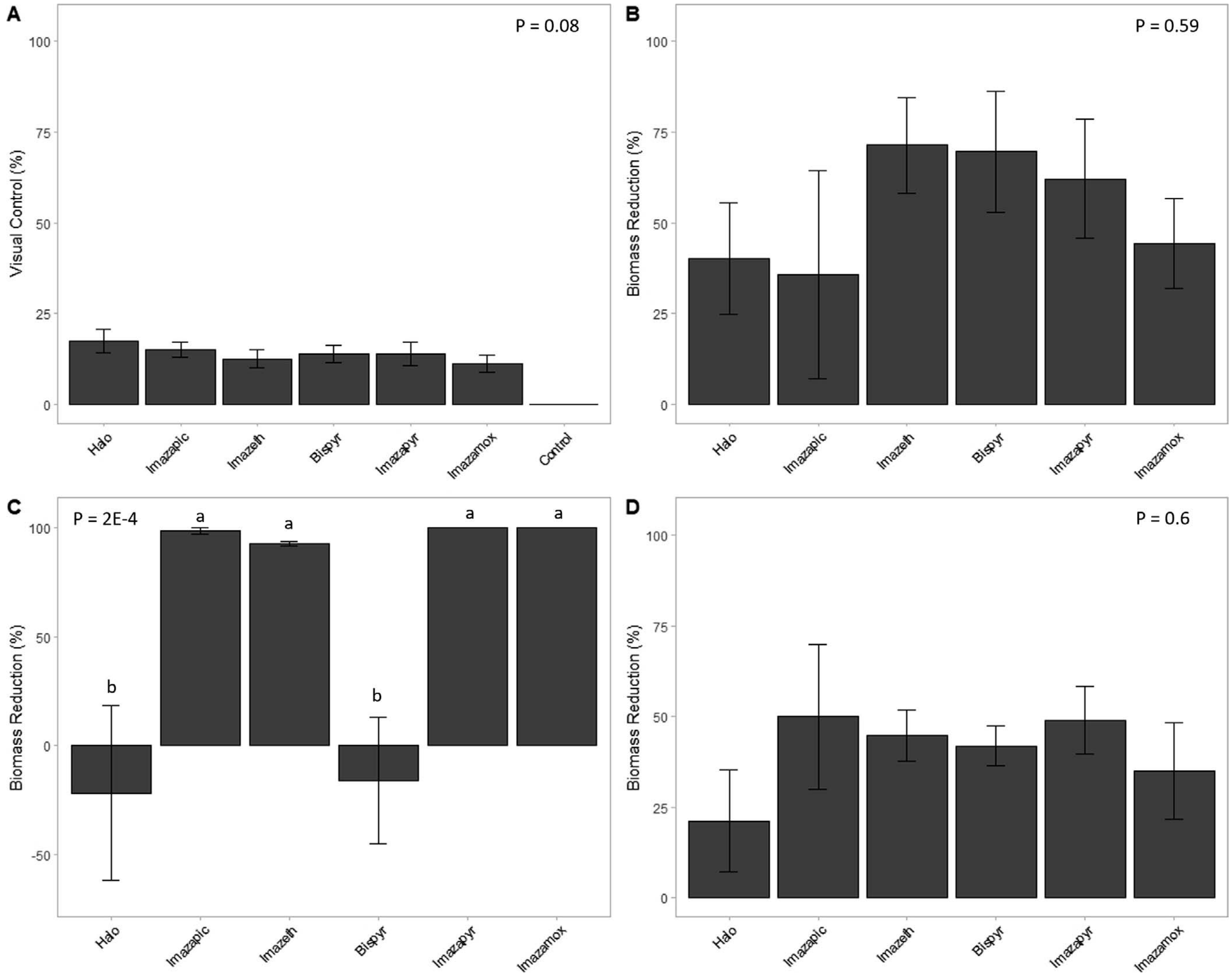

Figure 6. The response of Cuban bulrush (mean ± standard error) to trial 3 herbicide applications ($n = 4$) in the second experimental run. Visual evaluations (A) were made of control 30 days after treatment (DAT) with halosulfuron (halo), imazapic, imazethapyr (imazeth), bispyribac-sodium, imazapyr, and imazamox. Aboveground biomass (B) was also harvested and used to calculate biomass reductions (%) compared to the nontreated control (average biomass of 6.7 g). Aboveground (C) and belowground (D) biomass reductions were also calculated 60 DAT. The average above- and belowground biomass for nontreated control 60 DAT plants was 0.2 and 4.8 g, respectively. *P* values from a one-way analysis of variance are displayed on each graph. Letters denote mean separation between treatments as determined by Tukey's HSD ($P \leq 0.05$); columns sharing a letter are not significantly different from each other.

[14]Pursuit, BASF, Durham, NC 27709.

[15]Tradewind, Valent, San Ramon, CA 94583.

[16]Alligare Imazapyr 4 SL, Alligare, Opelika, AL 36801.

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