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Response of giant bulrush, water hyacinth, and water lettuce to foliar herbicide applications

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ABSTRACT

The aquatic herbicides 2,4-D (2,4-dichlorophenoxyacetic acid) and diquat (6,7-dihydrodipyrido[1,2-a : 2′,1′-c]pyrazinediium ion) are commonly used to control the invasive floating plants water hyacinth (*Eichhornia crassipes* [Mart.] Solms) and water lettuce (*Pistia stratiotes* L.). Despite the high level of efficacy and rapid injury markers from these foliar-applied herbicides, nontarget injury is common when these herbicides are applied to mixed populations of target and nontarget emergent plant species. Therefore, a series of trials were conducted to find additional herbicides that can selectively control water hyacinth and water lettuce. Giant bulrush (hard-stem bulrush, *Schoenoplectus californicus* [C.A. Mey] Palla) shoot biomass was not reduced by the aquatic herbicides flumioxazin (2-[7-fluoro-3,4-dihydro- 3-oxo-4-(2-propynyl)-2H-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1H-isoindole-1,3[2H]-dione), imazamox (2-[4,5-dihydro-4-methyl- 4-(1-methylethyl)-5-oxo-1 H-imidazol-2-yl]-5-[methoxymethyl]-3-pyridinecarboxylic acid), and penoxsulam (2-[2,2-difluoroethoxy]-N-(5,8-dimethoxy [1,2,4]triazolo[1,5- c] pyrimidin-2-yl)-6-[trifluoromethyl] benzenesulfonamide) 8 wk after treatment (WAT). Conversely, 2,4-D, diquat, glyphosate (N-[phosphonomethyl]glycine), triclopyr (3,5,6- trichloro-2-pyridinyloxyacetic acid), and 2,4-D plus diquat reduced plant dry weight 49 to 97%. In the water hyacinth screening trial, all herbicide treatments except flumioxazin resulted in 76 to 100% control. Water lettuce dry weight was reduced $\geq$ 61% by all foliar herbicide treatments, with the exception of 2,4-D and triclopyr. Although imazamox and penoxsulam were efficacious against the target species, noticeable injury symptoms were slow to develop (1 to 2 wk to occur), and the acetolactate synthase (ALS) herbicides were much slower in controlling the plants compared to other efficacious herbicides evaluated in the screening trial. These results indicate imazamox and penoxsulam may be suitable for selectively managing water hyacinth and water lettuce.

Key words: 2,4-D, chemical control, diquat, *Eichhornia crassipes*, flumioxazin, glyphosate, imazamox, penoxsulam, *Pistia stratiotes, Schoenoplectus californicus*, selectivity, triclopyr.

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INTRODUCTION

Water hyacinth and water lettuce are widespread problems in waterways and natural water bodies throughout Florida and along the Gulf Coast region. These floating invasive plants spread via seed germination and vegetative reproduction, forming extensive free-floating mats that often interfere with navigation, hydroelectric generation, irrigation, and recreation; they also lower the dissolved oxygen and pH of the water (Weldon and Blackburn 1966, Harley et al. 1984, Owens and Madsen 1995). The plants may also harbor mosquitoes, which are vectors for diseases like dengue fever, malaria, and encephalitis (Holm et al. 1977). Experience in Florida has demonstrated that consistent herbicide management to keep floating plants under maintenance control is the best available technology (Schmitz et al. 1993. University of Florida 2012). When these techniques are used in a coordinated manner, on a continuous or periodic basis, the target plant population is maintained at the lowest feasible level that funding and technology will permit (Florida Fish and Wildlife Conservation Commission [FFWCC] 2012).

The herbicides diquat and 2,4-D are the most widely used for water lettuce and water hyacinth control (Langeland et al. 2009). In addition, the nonselective products glyphosate and imazapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1- H -imidazol-2-yl]-3-pyridinecarboxylic acid), and the auxin mimic triclopyr are also recognized as efficacious against these floating invasive plants (Langeland et al. 2009). Aquatic herbicide applicators managing large water bodies in Florida have become accustomed to rapid symptoms and fast plant death associated with diquat and 2,4-D. These herbicides not only provide quick control, but offer rapid visual markers (hours to 1 d), which help distinguish treated vs. untreated sites. Although these visual cues have been important to the maintenance control program, significant visual injury symptoms to nontarget vegetation are increasingly becoming an issue with numerous stakeholder groups. Although 2,4-D and diquat have been the mainstays of floating plant maintenance control programs in Florida for the past several decades (J. M. Crossland, pers. comm. 2012) increasing pressure from stakeholder groups regarding nontarget impacts on emergent plants have led to greater consideration of alternate modes of action. For example, the FFWCC recommends not using 2,4-D when controlling mixed plant communities of water hyacinth and nontarget vegetation, because of significant injury or control of members of the bulrush (*Schoenoplectus* spp.) family (i.e., giant, soft-stem, and American bulrush) (University of Florida 2011). Emergent aquatic plants such as giant bulrush are native to Florida and the southeastern United States and

Table 1. Foliar herbicide treatments applied to giant bulrush, water hyacinth, and water lettuce.

Herbicide Treatment	Rate (g a.i. ha^{-1})[1]
Diquat + surfactant[2]	560.7 + 0.5% v/v
Diquat + surfactant	1,121.4 + 0.5 % v/v
Flumioxazin + surfactant	214.5 + 0.5% v/v
Flumioxazin + surfactant	428.9 + 0.5% v/v
Glyphosate + surfactant	2,242.8 + 0.5% v/v
Imazamox + surfactant	105.1 + 0.5% v/v
Imazamox + surfactant	210.2 + 0.5% v/v
Penoxsulam + surfactant	43.8 + 0.5% v/v
Penoxsulam + surfactant	87.6 + 0.5% v/v
Triclopyr + surfactant	841.0 + 0.5% v/v
Triclopyr + surfactant	1,682.0 + 0.5% v/v
2,4-D + surfactant	1,065.3 + 0.5% v/v
2,4-D + surfactant	2,130.6 + 0.5% v/v
2,4-D + Diquat + surfactant	1,065.3 + 560.7 + 0.5% v/v

[1]Glyphosate, triclopyr, and 2,4-D were applied as g ae ha^{-1}.
[2]Surfactant: methylated seed oil and emulsifiers.

have been planted in numerous water bodies (Denson and Langford 1982, Marburger et al. 1998, Mallison and Thompson 2010) to provide desirable habitat for fish (Holcomb and Wegener 1971) and wildlife (Marburger et al. 1998).

Recently, several new herbicides, including bispyribac-sodium, carfentrazone, flumioxazin, imazamox, and penoxsulam have received FIFRA-Section 3 registration by the U.S. Environmental Protection Agency (USEPA) for control of floating submersed, emergent, and floating weeds (Wersal and Madsen 2010, Wersal et al. 2010, Valent USA Corporation 2011, Vassios et al. 2011, Glomski and Mudge 2014). Most of these products have potential use on an operational level to control water hyacinth and water lettuce (Emerine et al. 2010, Wersal and Madsen 2010); however, their optimal use patterns and rates as well as selectivity to giant bulrush is unknown. Therefore, mesocosm trials were conducted to compare some of these recently and previously registered aquatic herbicides for selectivity against the nontarget emergent giant bulrush and efficacy against the floating weeds water hyacinth and water lettuce.

METHODS AND MATERIALS

The herbicide screening experiments were conducted at the University of Florida Center for Aquatic and Invasive Plants (UFCAIP) in Gainesville, FL in 2010. Giant bulrush plants were purchased from a Florida plant nursery. On April 28, 2010 and July 9, 2010, one healthy plant propagule (11.8 to 15.7 inches) of each species was planted in a mixture of 2 : 1 topsoil : masonry sand in 67.6 fluid ounces high-density polyethylene (HDPE) pots amended with Osmocote®[1] (15–9–12) fertilizer at a rate of 0.03 dry ounces per pound (0.03oz lb^{-1}) soil. The studies were established under a completely randomized design, and treatments were replicated four times. Two pots of giant bulrush were placed inside 95-L HDPE containers (57 cm diam by 46 cm height) cultured outdoors under 30% shade cloth. To acclimate the plants, water level was initially maintained at 10 cm for 2 wk and then raised to between 30 and 40 cm for the remainder of the study.

Simultaneously, five small water hyacinth and water lettuce plants were placed in separate 95-L containers containing well water amended with Osmocote fertilizer (15–9–12) at a rate 30 mg L^{-1}). An additional 10 mg L^{-1} of fertilizer was added to the experimental units every 2 wk throughout the course of the experiment. Giant bulrush, water hyacinth, and water lettuce were treated with foliar applications of diquat,[2] flumioxazin,[3] glyphosate,[4] imazamox,[5] penoxsulam,[6] triclopyr,[7] 2,4-D,[8] and 2,4-D plus diquat (Table 1). The initial and repeated experiments were treated 5 and 4 wk after planting, respectively. Plants were treated with two foliar rates of each herbicide, except glyphosate and 2,4-D plus diquat. The herbicides rates were chosen based on previous research or field activity on other target species. In addition, a nonionic surfactant[9] was added to all herbicide treatments. Herbicide treatments were applied to the plants with the use of a forced-air CO_2-powered sprayer at an equivalent of 100 gallons A^{-1}) diluent delivered through a single TeeJet®[10] 80-0067 nozzle at 25 psi. A nontreated control was treated with water and surfactant for comparison purposes. The initial study was treated on June 1, 2010 and harvested on July 29, 2010, and the repeated study was treated on August 2, 2010 and harvested on September 29, 2010. Visual injury was recorded 1, 3, and 6 wk after treatment (WAT) to determine the course of initial injury or recovery from herbicide treatments.

At 8 WAT, all healthy bulrush (shoot), water hyacinth, and water lettuce tissue was harvested, placed in a drying oven at 70 C for 1 wk, and weighed. All plant dry-weight data were normally distributed, but did not meet the assumption of equal variance. Therefore, data were analyzed via Kruskal-Wallis one-way analysis of variance (ANOVA) on ranks, and multiple comparisons were conducted via a Student-Newman-Keuls (SNK) method ($P = 0.05$). Differences between experimental runs were detected for all three species; therefore data were not pooled.

RESULTS AND DISCUSSION

The aquatic herbicides flumioxazin, imazamox, and penoxsulam did not reduce giant bulrush shoot biomass 8 WAT in the initial and repeated herbicide screening trials (Figure 1). In the initial trial, plants treated with the low rates of imazamox and flumioxazin as well as both rates of penoxsulam exhibited no visual injury throughout the course of the experiment (data not shown). Results were similar in the repeated experiment, with the exception of flumioxazin causing greater initial injury (significant spotting of shoot tissue) to giant bulrush. Injury symptoms were no longer evident by 6 WAT. The higher rates of imazamox and flumioxazin resulted in minor injury symptoms by 1 WAT, but injury was not detected 3 or 6 WAT in the first trial. Conversely, 2,4-D, diquat, glyphosate, triclopyr, and 2,4-D plus diquat reduced plant dry weight 49 to 97%. A rate response was evident with those herbicides tested at low and high rates. Giant bulrush biomass was reduced 2 to 4 times more at the higher application rates of 2,4-D, triclopyr, and diquat. All nonselective herbicide treatments

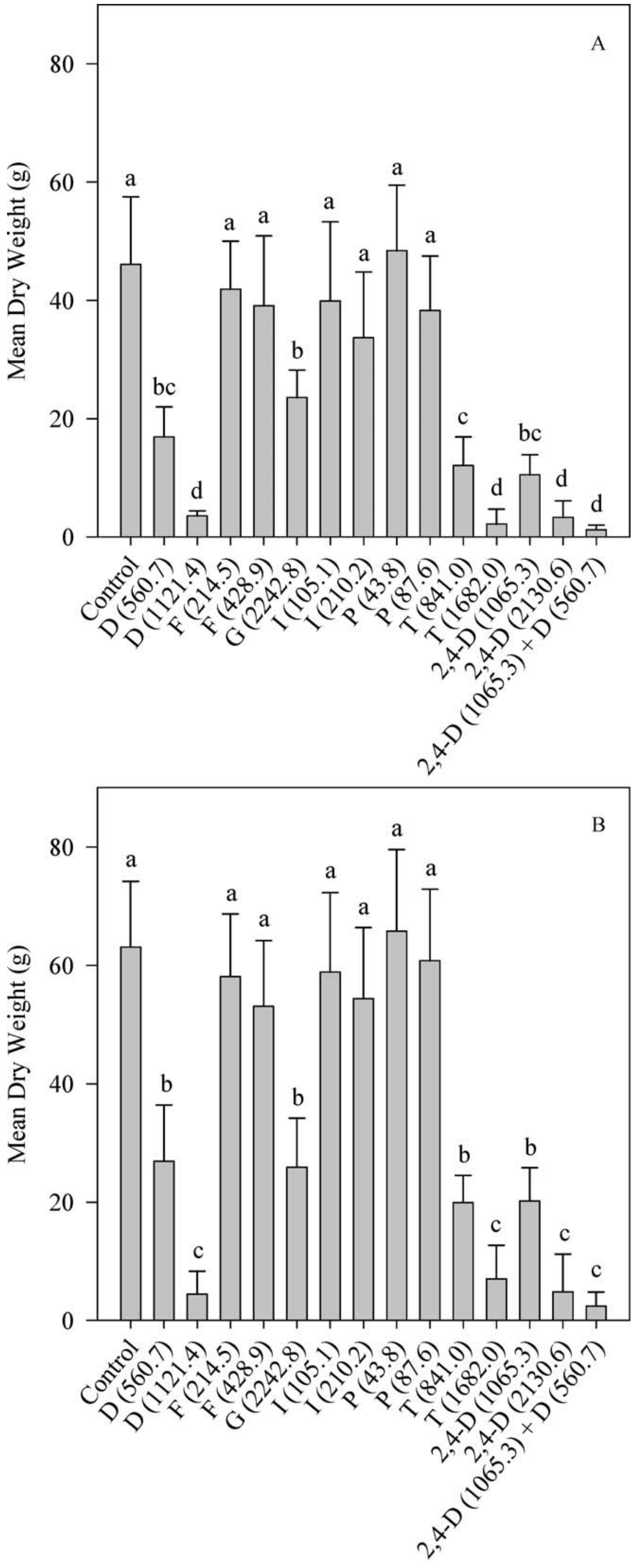

Figure 1. Effect of foliar herbicide applications of diquat (D), flumioxazin (F), glyphosate (G), imazamox (I), penoxsulam (P), triclopyr (T), 2,4-D, and 2,4-D plus diquat on giant bulrush dry weight 8 wk after treatment for the initial (A) and repeated (B) experiments. Numbers behind letters represent herbicide rates (g ai ha^{-1}). Glyphosate, triclopyr, and 2,4-D applied as g ae ha^{-1}). A methylated seed oil surfactant (0.5% v/v) was added to all treatments. Data were analyzed by Kruskal-Wallis one-way ANOVA on ranks and means separated by Student-Newman-Keuls (SNK) method; $n = 4$.

resulted in injury symptoms including chlorosis, necrosis, and rapid browning of tissue. Although some evidence of healthy recovery from the diquat and 2,4-D treated bulrush was evident at 6 WAT, the severe injury symptoms and reductions in biomass were a strong contrast to the flumioxazin, imazamox, and penoxsulam treatments.

All herbicide treatments except flumioxazin (214.5 and 428.9 g ai ha^{-1}) resulted in 76 to 100% and 89 to 100% water hyacinth control in the initial and repeated experiments, respectively (Figure 2). Similar results were noted when Wersal and Madsen (2010) reduced water hyacinth biomass > 90% by 10 WAT when penoxsulam was applied at rates as low as 24.5 g ai ha^{-1}. Also, previous research demonstrated flumioxazin applied at 1,144 g ai ha^{-1} was not efficacious against water hyacinth (Mudge and Haller 2012). The aquatic herbicides 2,4-D, triclopyr, and 2,4-D plus diquat in both experiments and diquat in the first experiment resulted in 100% control. Plants treated with the slow-acting ALS herbicides imazamox and penoxsulam exhibited minimum injury symptoms at 1 WAT, but severe injury was noted by 3 WAT. Previous research (Wersal and Madsen 2010) also noted slow development of water hyacinth injury symptoms from a low-dose stand-alone penoxsulam treatment, which only provided 20% visual injury 1 WAT. In our research, there was no noticeable rate response to imazamox or penoxsulam with regard to qualitative or quantitative data collected throughout the experiment. Minor to significant injury symptoms were noted with all other efficacious treatments within 1 WAT (data not shown).

Water lettuce dry weight was reduced ≥ 61% by all foliar herbicide treatments in both screening experiments with the exception of 2,4-D and triclopyr (Figure 3). The lack of control by these two herbicides was anticipated, because they are not recommended for control of water lettuce (Langeland et al. 2009). Both rates of diquat, flumioxazin, and 2,4-D plus diquat reduced plant dry weight ≥ 98% in the initial and repeated experiments. Similar to the water hyacinth experiment, imazamox and penoxsulam were efficacious against water lettuce. Also, the injury symptoms were slow to develop, but increased weekly.

In this screening experiment, imazamox and penoxsulam were considered selective against giant bulrush and efficacious on the floating weeds water hyacinth and water lettuce. These products alone may be viable alternatives to nonselective aquatic herbicides when mixed populations of giant bulrush and water hyacinth or water lettuce coexist. However, the biggest concern with the ALS herbicides was the slow development of injury symptoms and the speed of control compared to other herbicides evaluated in the screening trial. Aquatic applicators rely on fast-acting herbicides (i.e., 2,4-D and diquat) to provide visual markers

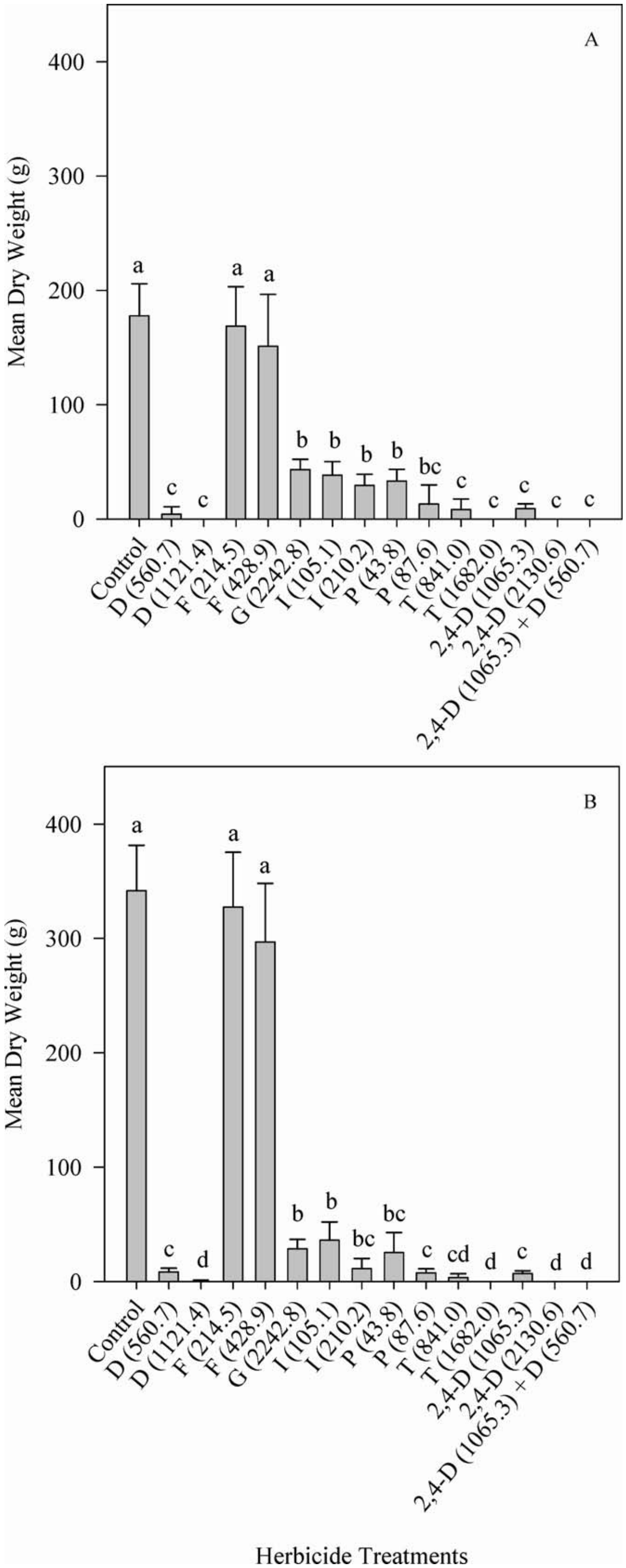

Figure 2. Effect of foliar herbicide applications of diquat (D), flumioxazin (F), glyphosate (G), imazamox (I), penoxsulam (P), triclopyr (T), 2,4-D, and 2,4-D plus diquat on water hyacinth dry weight 8 wk after treatment for the initial (A) and repeated (B) experiments. Numbers behind letters represent herbicide rates (g ai ha^{-1}). Glyphosate, triclopyr, and 2,4-D applied as

1 d after treatment (DAT) when treating water hyacinth or water lettuce. Despite the slow activity of the ALS inhibitors, imazamox and penoxsulam are relatively selective to emergent nontarget plants besides giant bulrush. Egyptian panicgrass (*Paspalidium geminatum* [Forssk.] Stapf) and maidencane (*Panicum hemitomon* Schult.) were highly tolerant to subsurface applications of penoxsulam (Koschnick et al. 2007). In the same research trial, soft-stem bulrush, maidencane, panicgrass, and sagittaria were marginally to highly tolerant to subsurface applications of imazamox.

Although the protoporphyrinogen oxidase (PPO) – inhibiting herbicide flumioxazin was noninjurious to giant bulrush and highly efficacious against water lettuce, it failed to reduce water hyacinth biomass at either foliar rate by 6 WAT. Field trials are currently underway to utilize foliar and subsurface applications of flumioxazin in mixed water lettuce and giant bulrush populations (M. D. Netherland, pers. obs.). All other herbicides were either nonselective or nonefficacious against the aquatic plants evaluated in the research. Additional aquatic herbicides including carfentrazone and bispyribac-sodium should be evaluated for selectivity and efficacy. The efficacy and low use rates permit imazamox and penoxsulam to be suitable candidates for selective floating plant management.

SOURCES OF MATERIALS

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

[2]Reward® Landscape and Aquatic Herbicide, Syngenta Professional Products, PO Box 18300, Greensboro, NC 24719.

[3]Clipper™ Herbicide, Valent USA Corporation, PO Box 8025, Walnut Creek, CA 94596.

[4]AquaPro® Herbicide, SePRO Corporation, 11550 North Meridian Street, Suite 600, Carmel, IN 46032.

[5]Clearcast®, SePRO Corporation, 11550 North Meridian Street, Suite 600, Carmel, IN 46032.

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

[7]Renovate® 3, SePRO Corporation, 11550 North Meridian Street, Suite 600, Carmel, IN 46032.

[8]Weedar® 64, Nufarm Inc., 150 Harvester Drive, Burr Ridge, IL 60527.

[9]Sun Wet™, Brewer International, PO Box 690037, Vero Beach, FL 32969.

[10]TeeJet®, Spraying Systems Co., PO Box 7900, Wheaton, IL 60187.

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g ae ha^{-1}. A methylated seed oil surfactant (0.5% v/v) was added to all treatments. Data were analyzed by Kruskal-Wallis one-way ANOVA on ranks and means separated by Student-Newman-Keuls (SNK) method; $n = 4$.

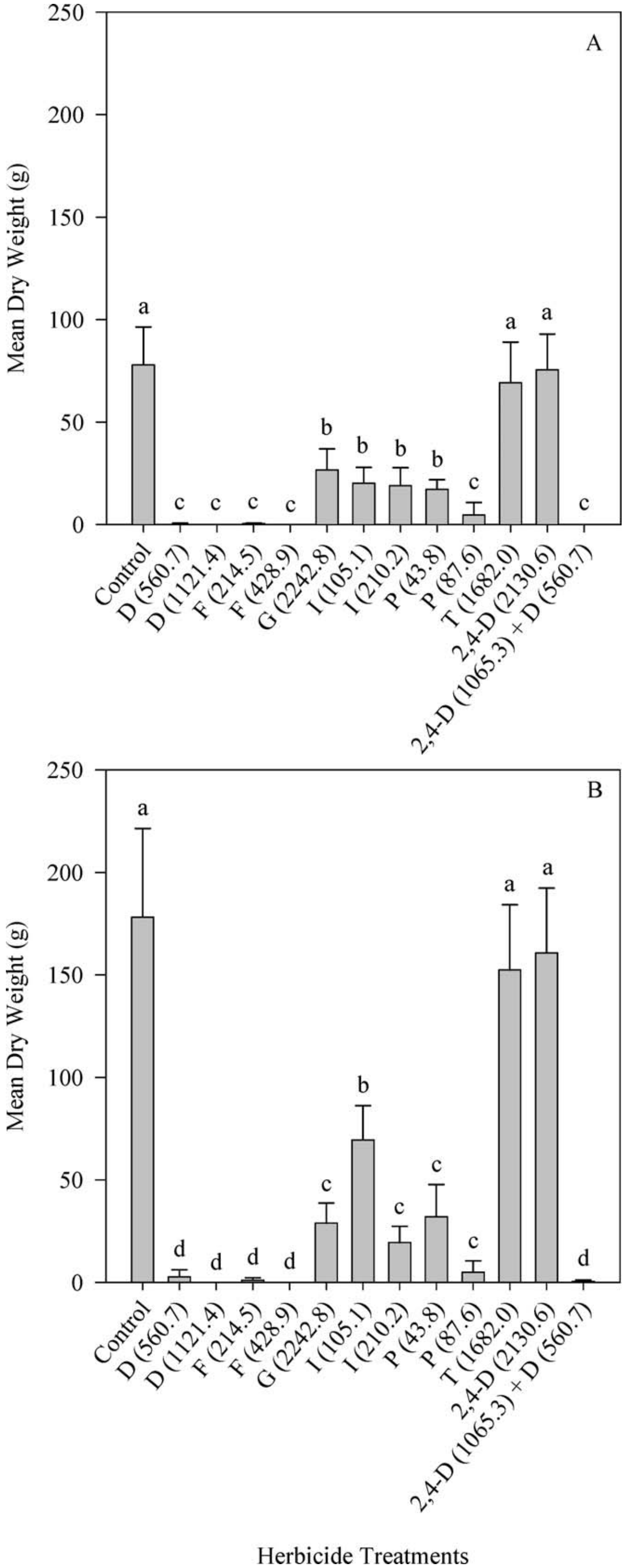

Figure 3. Effect of foliar herbicide applications of diquat (D), flumioxazin (F), glyphosate (G), imazamox (I), penoxsulam (P), triclopyr (T), 2,4-D, and 2,4-D plus diquat on water lettuce dry weight 8 wk after treatment for the initial (A) and repeated (B) experiments. Numbers behind letters represent herbicide rates (g ai ha^{-1}). Glyphosate, triclopyr, and 2,4-D applied as ← g ae ha^{-1}. A methylated seed oil surfactant (0.5% v/v) was added to all treatments. Data were analyzed by Kruskal-Wallis one-way ANOVA on ranks and means separated by Student-Newman-Keuls (SNK) method; $n = 4$.

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