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Response of water hyacinth and nontarget emergent plants to foliar applications of bispyribac-sodium alone and combination treatments

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ABSTRACT

The recently registered aquatic herbicide bispyribac-sodium (hereafter referred to as bispyribac) is highly efficacious against several noxious aquatic plants including the floating plant water hyacinth [*Eichhornia crassipes* (Mart.) Solms]. Although this acetolactate synthase-inhibiting herbicide is effective at low foliar use rates against water hyacinth, the development of injury symptoms and speed of control is slow compared with the herbicides 2,4-D and diquat. Therefore, mesocosm research was conducted to determine if foliar-applied combinations of bispyribac and low rates of the contact herbicides carfentrazone, diquat, endothall, or flumioxazin could improve and increase the speed of control compared with bispyribac applied alone for water hyacinth control. All foliar bispyribac alone and combination treatments containing low rates of contact herbicides reduced water hyacinth dry weight 62 to 74% of the nontreated control 6 wk after treatment (WAT). All other treatments were similar except for the bispyribac plus diquat and bispyribac plus flumioxazin treatments. There was no efficacy advantage of adding a contact herbicide to the tank mix; however, the combination treatments produced faster visual markers and the treatments containing flumioxazin and carfentrazone resulted in no plant regrowth. In addition, the bispyribac combinations were tested for selectivity against the nontarget emergent plants maidencane (*Panicum hemitomon* Schult.), jointed spikerush [*Eleocharis interstincta* (Vahl) Roem & J.A. Schult], club-rush (*Eleocharis cellulosa* Torr.), giant bulrush [*Schoenoplectus californicus* (C.A. Mey) Palla], and soft-stem bulrush [*Schoenoplectus tabernaemontani* (C.C. Gmel.) Palla]. All bispyribac alone and combination treatments reduced jointed spikerush and soft-stem bulrush shoot dry weight 37 to 69% and 27 to 42%, respectively, 6 WAT. Despite reductions in jointed spikerush and soft-stem bulrush dry weight, all plants were recovering by the conclusion of the experiment. On the contrary, none of the treatments affected maidencane, club-rush, or giant bulrush. These results indicate that bispyribac alone or in combination with contact herbicides may be a suitable alternative for selectively managing water hyacinth.

Key words: acetolactate synthase inhibitors, carfentrazone-ethyl, chemical control, diquat, *Eichhornia crassipes*, *Eleocharis cellulose*, *Eleocharis interstincta*, endothall, flumioxazin, *Panicum hemitomon*, *Schoenoplectus californicus*, *Schoenoplectus tabernaemontani*, selectivity, tank mix.

INTRODUCTION

Water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes* L.) are widespread problems in waterways throughout Florida and other southern U.S. states. These floating invasive plants spread via vegetative reproduction, forming extensive free-floating mats that often interfere with navigation, hydroelectric generation, irrigation, and fishing as well as lowering 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 such as 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 2012b). 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 2012). Implementation of this strategy often requires that invasive floating plants be treated when they are intermixed in stands of native vegetation.

The herbicides diquat and 2,4-D are the most widely used for water hyacinth and water lettuce control. 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 (Mudge and Netherland 2014). These herbicides not only provide quick control, but offer rapid visual markers (hours to 1 d) that help distinguish treated versus untreated sites. Although these visual cues have been important to the maintenance control program, visual injury symptoms to nontarget vegetation is becoming increasingly scrutinized

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by stakeholder groups. Although 2,4-D and diquat have been the mainstays of floating plant management programs in Florida for the past several decades (University of Florida 2012a), increasing pressure from stakeholder groups regarding nontarget impacts on emergent plants have led to greater consideration of alternative herbicides. For example, the Florida Fish and Wildlife Conservation Commission (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).

Bispyribac was registered by the U.S. Environmental Protection Agency in 2011 as an aquatic herbicide for control of hydrilla and other invasive plants (Wisconsin Department of Natural Resources 2012). In addition, it is efficacious against the floating plant water hyacinth as a foliar and subsurface treatment (Glomski and Mudge 2013). Unfortunately, the slow activity of acetolactate synthase (ALS) inhibitors, including bispyribac, may be problematic for aquatic managers that have come to utilize visual markers (1 d after treatment [DAT]) and expect rapid control associated with 2,4-D and diquat treatments. Foliar applications of the ALS herbicides imazamox and penoxsulam required 1 wk to develop noticeable injury symptoms (Mudge and Netherland 2014). To determine if the slow activity of ALS herbicides can be increased against water lettuce and water hyacinth, Mudge and Netherland (2014) evaluated foliar-applied combinations of imazamox and penoxsulam plus the contact herbicides carfentrazone, diquat, endothall, and flumioxazin. All combinations of the ALS and contact herbicides resulted in faster injury symptoms to both species compared with imazamox and penoxsulam alone. However, only a limited number of the combination treatments provided greater control compared with imazamox or penoxsulam alone. In addition, Mudge and Netherland (2014) evaluated the selectivity of these treatments against the nontarget emergent species duck potato (*Sagittaria lancifolia* L.), jointed spikerush [*Eleocharis interstincta* (Vahl) Roem & J.A. Schult], club-rush (*Eleocharis cellulosa* Torr.), giant bulrush [*Schoenoplectus californicus* (C.A. Mey) Palla], and soft-stem bulrush [*Schoenoplectus tabernaemontani* (C.C. Gmel.) Palla]. Most of the treatments had minimal impacts on the nontarget plants.

The combination of ALS and protoporphyrinogen oxidase (PPO) herbicides has been recently implemented into control programs in Florida (J. M. Crossland, pers. comm., 2013). The operational use of penoxsulam plus flumioxazin has shown promise in selectively managing mixed populations of floating invasive and emergent nontarget plants. Although the PPO component provides rapid visual symptoms for water lettuce management, the development of visual injury symptoms on hyacinth remains slow and requires further investigation. Applying a combination of contact herbicides with bispyribac may increase the speed and/or efficacy of the herbicide treatment on water hyacinth, similar to previous research by Mudge and Netherland (2014). In addition, these herbicide treatments may be applied to areas where invasive target and nontarget aquatic plants are found in mixed populations. Therefore, mesocosm trials were conducted to determine the speed of initial injury symptoms, speed of control, and efficacy of bispyribac plus low doses of contact herbicides when applied to water hyacinth. In addition, research was conducted to determine the selectivity of these combination treatments against five key nontarget emergent species.

METHODS AND MATERIALS

Bispyribac foliar combinations versus water hyacinth

A greenhouse trial was conducted in January 2013 at the U.S. Army Engineer Research and Development Center (USAERDC) in Vicksburg, MS to determine the efficacy of bispyribac plus contact herbicides against water hyacinth. Three water hyacinth plants (25 to 30 cm in height) obtained from cultures maintained at USAERDC were placed in 28- to 76-L plastic containers (49.5 cm diameter by 58.4 cm height) in a greenhouse set at day/night temperatures of 34/25 C. The containers were filled with tap water that was amended with Miracle-Gro®[1] (36–6–6) fertilizer at a rate of 41.6 mg L^{-1}. The fertilizer was added to the experimental units every 4 wk throughout the course of the experiment.

Four weeks after study inception, water hyacinth plants received foliar applications of bispyribac[2] (56.1 g ai ha^{-1}) alone or in combination with carfentrazone[3] (16.6), diquat[4] (17.5), flumioxazin[5] (17.9), or endothall[6] (37.1 g ae ha^{-1}, and as dipotassium salt formulation) (Table 1). Bispyribac was applied at half maximum label rate, whereas the contact herbicides were applied at 2 to 8% of maximum rate. The purpose of this mixing was to determine if the low rate of any fast-acting contact herbicide could speed up and enhance visual injury as well as increase efficacy compared with bispyribac alone. In addition, if these low rates were efficacious against water hyacinth, nontarget injury may be at a minimum compared with higher use rates. A methylated vegetable oil plus organosilicone surfactant[7] (1% v/v) was included with all herbicide treatments. Herbicide treatments were applied to water hyacinth using a forced-air CO_2-powered sprayer calibrated to deliver 935 L ha^{-1} diluent through a single TeeJet®[8] 80-0067 nozzle. A nontreated control was included for comparison. This study was a completely randomized design and treatments were replicated four times. Visual estimates of water hyacinth injury on a scale of 0 to 100%, where 0 = no chlorosis/necrosis/growth regulation and 100 = plant death, were recorded every day for the first 2 wk and weekly thereafter to determine onset of symptoms and long-term effectiveness of herbicide treatments. Plant injury was not recorded until 10% was achieved. Ten percent injury was chosen as a conservative value and near the threshold where an untrained professional may detect adverse affects on plant growth. At 6 wk after treatment (WAT), all living water hyacinth biomass was harvested, dried to a constant weight (70 C for 1 wk), and recorded as dry weight. Dry weight data

Table 1. Number of days until at least 10% injury was present for water hyacinth and emergent nontarget aquatic plant species treated with foliar bispyribac alone and combination treatments.[1]

Treatment	Rate (g ai ha^{-1})	Water Hyacinth	Maidencane	Jointed Spikerush	Club-rush	Giant Bulrush	Soft-stem Bulrush
B[2,3]	56.1	5	5	10	14	N/A	14
B	112.1	N/A	5	10	14	6	14
B + C	56.1 + 16.6	1	5	14	14	N/A	6
B + E	56.1 + 37.1[4]	3	N/A	N/A	N/A	N/A	N/A
B + F	56.1 + 17.9	1	N/A	N/A	N/A	N/A	N/A
B + F	56.1 + 35.7	N/A	3	10	10	N/A	6
B + D	56.1 + 4.4	N/A	2	6	10	6	6
B + D	56.1 + 8.8	N/A	2	6	6	6	6
B + D	56.1 + 17.5	1	1	6	6	6	6

[1]Plant injury (chlorosis, necrosis, and growth regulation) was recorded daily for 2 wk and weekly thereafter. Plant injury was not recorded until 10% was achieved. Ten percent injury was chosen as a conservative value and near the threshold where an untrained professional may detect adverse affects on plant growth.
[2]Abbreviations: B, bispyribac; S, surfactant; C, carfentrazone; D, diquat; E, endothall; F, flumioxazin; N/A indicates that the herbicide treatment was not applied to the given plant species.
[3]A methylated vegetable oil plus organosilicone surfactant (1% v/v) was included with all herbicide treatments.
[4]Endothall applied as dipotassium salt formulation and in g ae ha^{-1}.

were subjected to ANOVA and means were separated using Fisher's Protected LSD test ($P = 0.05$).

Bispyribac foliar combinations versus nontarget emergent plants

An outdoor mesocosm study was conducted at the Louisiana State University (LSU) AgCenter Aquaculture Research Facility, in Baton Rouge, LA to evaluate the sensitivity of the nontarget emergent species maidencane (*Panicum hemitomon* Schult.), jointed spikerush, club-rush, giant bulrush, and soft-stem bulrush against foliar applications of bispyribac alone and in combination with contact herbicides. In July 2013, plants were purchased from a Florida plant nursery and shipped overnight to LSU. One healthy plant propagule (30 to 40 cm) of each species was planted in topsoil[9] in 3-L high-density polyethylene pots amended with Osmocote®[10] (19–6–12) fertilizer at a rate of 2 g kg^{-1} soil. The sediment surface was top-dressed with a 2-cm layer of masonry sand to reduce sediment and nutrient suspension in the water column. This study was a completely randomized design and treatments were replicated three times. One pot of each species (five total pots) was placed inside 76-L plastic containers cultured outdoors under full sunlight. To acclimate the plants, water level was maintained at 20 cm for 4 wk and raised to 38 cm for the remainder of the study. The plastic containers were placed inside larger plastic tanks (946 L) partially filled with water to help maintain a consistent water temperature.

Plants were cultured for 7 wk before foliar herbicide treatments were applied to the emergent nontarget plants. Plants received foliar applications (g ai ha^{-1}) of bispyribac alone (56.1 or 112.1) or in combination with carfentrazone (16.6), diquat (4.8, 8.8, or 17.5), or flumioxazin (35.7). A methylated vegetable oil plus organosilicone surfactant (1% v/v) was included with all herbicide treatments. The herbicides were applied using the same methods as the water hyacinth experiment. A nontreated control was included for comparison. Similar to the water hyacinth trial, visual estimates of plant injury were recorded every day for the first 2 wk and weekly thereafter to determine onset of symptoms and long-term injury of herbicide treatments. Six WAT, all live shoot tissue was harvested at the soil line, placed in a drying oven at 50 C for 1 wk, and weighed. All plant dry-weight data were subjected to a one-way ANOVA and when treatment differences were detected, means were separated using Fisher's Protected LSD test ($P = 0.05$).

RESULTS AND DISCUSSION

Bispyribac foliar combinations versus water hyacinth

Bispyribac (56.1 g ai ha^{-1}) applied alone as a foliar treatment required 5 d to develop injury symptoms (Table 1). Conversely, the addition of carfentrazone, diquat, endothall, or flumioxazin resulted in injury symptoms 1, 1, 3, and 1 DAT, respectively. Although bispyribac plus diquat injured water hyacinth more severely (32% injury) than the other alone or combination treatments 1 DAT (10% injury), the addition of flumioxazin (53% injury) to the tank mix was the most injurious 1 WAT, followed by bispyribac plus carfentrazone (44%), bispyribac plus diquat (32%), and bispyribac plus endothall (16%). The addition of carfentrazone, diquat, endothall, or flumioxazin to the tank mix was beneficial since bispyribac was slow to develop symptoms; however, if rapid next-day injury symptoms are not required for herbicide applicators, bispyribac alone can be an effective treatment without a tank-mix partner. Previous research (Mudge and Netherland 2014) found similar overall efficacy results on water hyacinth when carfentrazone or flumioxazin was mixed with the ALS herbicides imazamox or penoxsulam. Injury symptoms were not present until 7 to 10 DAT for water lettuce and water hyacinth treated with foliar applications of imazamox and penoxsulam, respectively. The addition of the PPO herbicides carfentrazone and flumioxazin resulted in injury 2 to 7 DAT.

Regrowth was noted 1 WAT for bispyribac plus diquat and at 5 WAT for the bispyribac alone and bispyribac plus endothall treatments, whereas no regrowth was observed for the treatments containing flumioxazin or carfentrazone. These data indicate that diquat at 17.5 g ai ha^{-1} may not be suitable when used in combination with bispyribac or that a lower diquat rate needs to be tested for better compatibility when treating water hyacinth. Wersal and Madsen (2010)

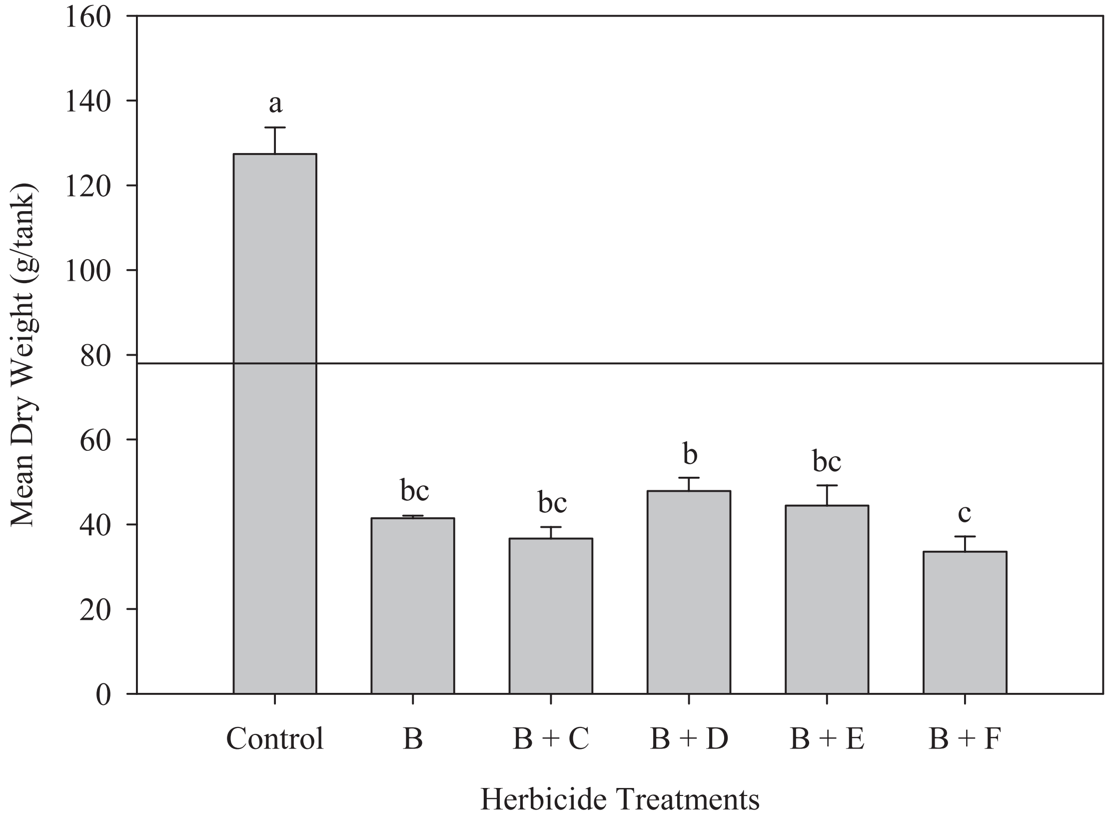

Figure 1. Effect of foliar (g ai ha^{-1}) bispyribac-sodium (B, 56.1) alone and in combination with carfentrazone (C, 16.6), endothall (E, 37.1 g ae ha^{-1}), flumioxazin (F, 17.9), or diquat (D, 17.5) on water hyacinth dry weight 6 wk after treatment. Endothall was applied as g ae ha^{-1}. A methylated vegetable oil plus organosilicone surfactant (1% v/v) was added to all treatments. Means with the same letter are not significant according to Fisher's Protected LSD test at $P = 0.05$; $n = 4$. Horizontal line represents pretreatment biomass.

demonstrated that the addition of 130.8 g ai ha^{-1} diquat (seven times greater rate than our rate) to penoxsulam reduced efficacy against water hyacinth and there was significant antagonism with the combination of these herbicides since the penoxsulam alone treatment was more efficacious than the penoxsulam plus diquat or diquat alone treatments.

All foliar bispyribac and combination treatments containing low rates of contact herbicides reduced water hyacinth dry weight 62 to 74% of the nontreated control 6 WAT (Figure 1). In addition, plant biomass was reduced below pretreatment level. All other treatments were statistically the same except for the bispyribac plus diquat treatment, which provided less control than the bispyribac plus flumioxazin treatment. On the basis of these results, there was no efficacy advantage of adding a contact herbicide to bispyribac; however, the low rates of contact herbicides did result in faster visual markers and no plant regrowth was noted when flumioxazin or carfentrazone were added to bispyribac.

Under greenhouse conditions, these plants were not subjected to wind/wave action; therefore, these results need to be verified in the field to determine if faster control will be achieved under natural conditions. These data indicate no compatibility issues when low rates of the contact herbicides carfentrazone, diquat, endothall, or flumioxazin were mixed with bispyribac. Also, the addition of the low rates of contact herbicides (2 to 8% of maximum rate) is more cost effective than mixing higher standard use rates. Research by Mudge and Haller (2012) demonstrated that flumioxazin at 1,144 g ai ha^{-1} provided $<$ 30% water hyacinth control. Conversely, water hyacinth control with carfentrazone calculated 90% effective concentration values were estimated to be 86.2 to 116.3 g ha^{-1} (Koschnick et al. 2004), which are five to seven times greater than the use rate in our research. On the basis of our research, the addition of low rates of contact herbicides to bispyribac can be efficacious compared with the higher flumioxazin (Mudge and Haller 2012) or carfentrazone (Koschnick et al. 2004) rates when applied alone.

In a mesocosm experiment, Glomski and Mudge (2013) demonstrated that bispyribac alone at 59 g ai ha^{-1} provided 98% water hyacinth control 8 WAT when applied as a foliar treatment. It is uncertain if additional water hyacinth control would have been achieved if our trial had been extended to 8 WAT, similar to the research conducted by Glomski and Mudge (2013). In addition, the current research was conducted in a greenhouse, whereas research by Glomski and Mudge (2013) was conducted in an outdoor mesocosm where natural conditions (wind, rain, insects, etc.) would have likely resulted in more rapid and increased control.

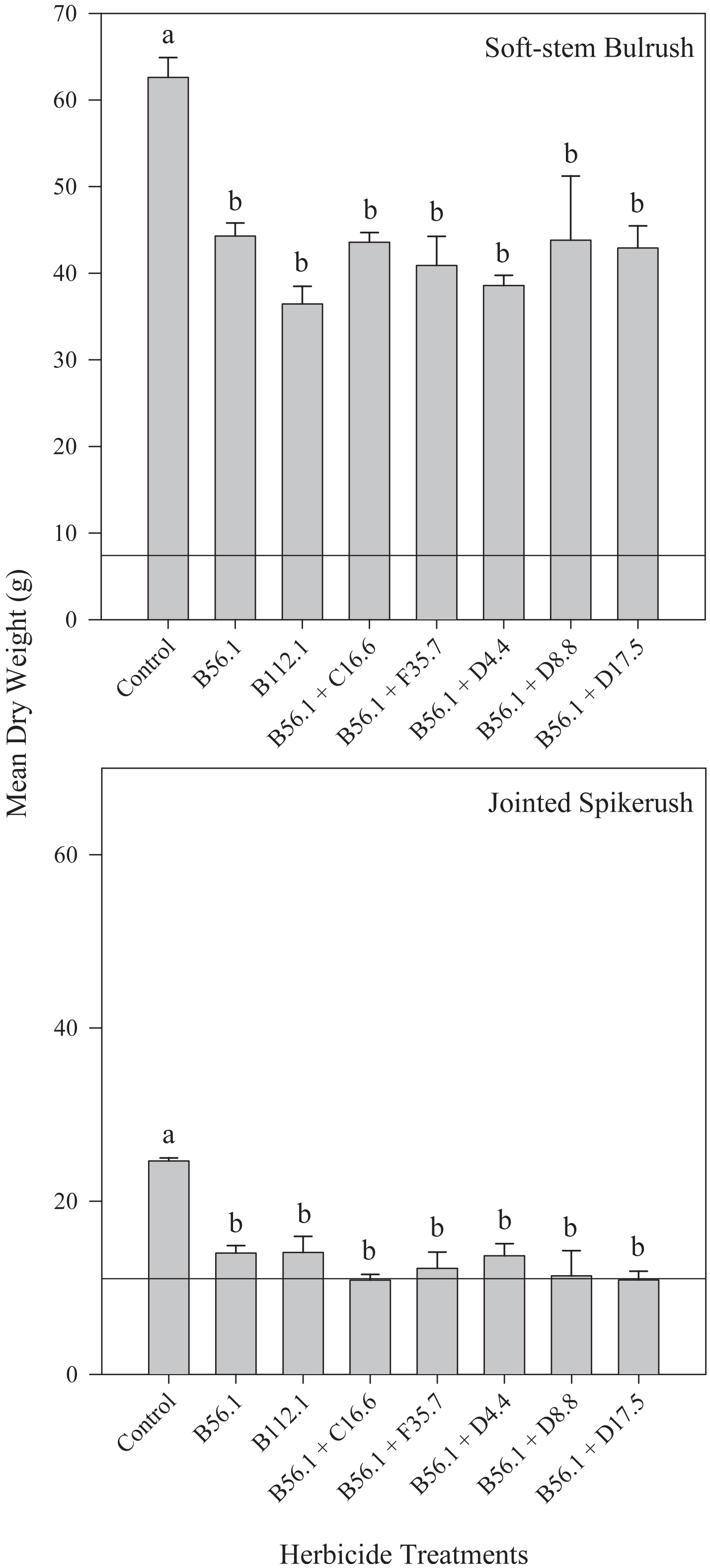

Figure 2. Effect of foliar bispyribac (B) alone and in combination with carfentrazone (C), flumioxazin (F), and diquat (D) on jointed spikerush and soft-stem bulrush shoot dry weight (mean ± standard error) 6 wk after treatment. Numbers behind herbicide abbreviations represent herbicide rates in g ai ha^{-1}. A methylated vegetable oil plus organosilicone surfactant (1% v/v) was added to all treatments. Means with the same letter are not significant according to Fisher's Protected LSD test at $P = 0.05$ for all species; $n = 3$. Horizontal line represents pretreatment biomass.

Bispyribac foliar combinations versus nontarget emergent plants

The bispyribac alone and combination treatments resulted in less severe injury symptoms and required a longer period of time to develop symptoms on nontarget emergent plants compared with water hyacinth (Table 1). All nontarget plants evaluated in this research were injured by all herbicide treatments within 14 DAT. Bispyribac at 56.1 or 112.1 g ai ha^{-1} resulted in less initial and long-term injury symptoms compared with bispyribac plus carfentrazone, flumioxazin, or diquat. Regardless of rate, bispyribac resulted in minimal chlorosis or necrosis. The prominent injury symptoms were growth regulation and stunting, which is common for susceptible plants treated with an ALS herbicide (Senseman 2007). Maidencane developed more intense and rapid injury symptoms (1 to 5 DAT) compared with the other nontarget species evaluated in the experiment; however, new leaves and shoots were observed 1 to 3 WAT. Injury was not noticeable until 6 to 14 DAT for jointed spikerush, club-rush, giant bulrush, and soft-stem bulrush. Although plant height data were not collected, most herbicide-treated plants were shorter in height compared with the nontreated control plants 6 WAT. Despite the initial injury symptoms (chlorosis and necrosis) and growth regulation, regrowth and the production of new shoots were observed from all herbicide-treated plants.

All bispyribac alone and combination treatments resulted in a decrease in shoot biomass for jointed spikerush (37 to 69%) and soft-stem bulrush (27 to 42%) (Figure 2). In addition, the bispyribac plus carfentrazone and bispyribac plus diquat (17.5 g ai ha^{-1}) treatments resulted in biomass reductions below pretreatment biomass level. Although the combination of bispyribac and flumioxazin resulted in a decrease in jointed spikerush and soft-stem bulrush biomass, flumioxazin was applied at a rate four times greater to the nontarget emergent species compared with water hyacinth; therefore, lower flumioxazin rates would likely provide more selectivity.

Even though all herbicide treatments resulted in injury symptoms within 1 to 14 DAT, none of the treatments had an impact on maidencane, club-rush, or giant bulrush dry weight (Figure 3). The lower diquat rates (4.4 and 8.8 g ai ha^{-1}) in combination with bispyribac were statistically the same as the higher diquat rate of 17.5 g ai ha^{-1} plus bispyribac for all nontarget emergent plants. The highest diquat rate plus bispyribac resulted in rapid injury but regrowth when applied to water hyacinth. Therefore, the lower rates of diquat should be tested against water hyacinth to determine if these treatments can provide not only rapid injury but long-term control without plant regrowth. Also, future research should evaluate lower and higher combination rates of contact herbicides against emergent nontarget plants and water hyacinth to determine optimal efficacy and selectivity spectrums. In addition, the bispyribac plus contact herbicide combination treatments should be tested for efficacy against water lettuce.

In previous mesocosm research (Mudge and Netherland 2014), the systemic herbicides penoxsulam and imazamox

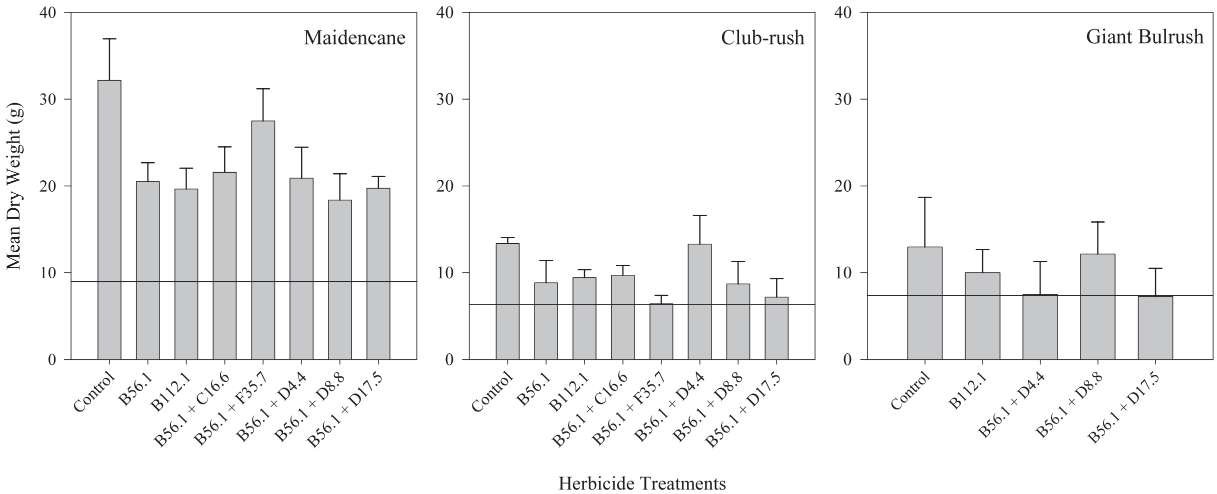

Figure 3. Effect of foliar bispyribac (B) alone and in combination with carfentrazone (C), flumioxazin (F), and diquat (D) on maidencane, club-rush, and giant bulrush shoot dry weight (mean ± standard error) 6 wk after treatment. Numbers behind herbicide abbreviations represent herbicide rates in g ai ha^{-1}. A methylated vegetable oil plus organosilicone surfactant (1% v/v) was added to all treatments. No significant differences were noted for all species; n = 3. Horizontal line represents pretreatment biomass.

applied alone or in combination with carfentrazone, diquat, endothall, or flumioxazin resulted in similar injury and biomass reductions when applied to jointed spikerush, club-rush, giant bulrush, and soft-stem bulrush. These data indicate that bispyribac alone at the maximum rate (112.1 g ai ha^{-1}) or half maximum rate (56.1) in combination with carfentrazone, diquat, endothall, or flumioxazin may be used operationally to selectively control water hyacinth. Bispyribac alone or combination treatments may be a viable alternative to 2,4-D or diquat if less injurious treatments are desired when controlling mixed populations of water hyacinth and emergent nontarget species.

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SOURCES OF MATERIALS

[1]Miracle-Gro® Lawn Fertilizer, The Scott's Co., P.O. Box 606, Marysville, OH 43040.

[2]Tradewind™ Herbicide, Valent USA Corp., P.O. Box 8025, Walnut Creek, CA 94596.

[3]Stingray™, FMC Corp., 1735 Market Street, Philadelphia, PA 19103.

[4]Reward® Landscape and Aquatic Herbicide, Syngenta Professional Products, P.O. Box 18300, Greensboro, NC 24719.

[5]Clipper™ Herbicide, Valent USA Corp., P.O. Box 8025, Walnut Creek, CA 94596.

[6]Aquathol® K, United Phosphorus, Inc., 630 Freedom Business Center, Suite 402, King of Prussia, PA 19406.

[7]Inergy®, Winfield Solutions, LLC, P.O. Box 64589, St. Paul, MN 55164.

[8]TeeJet® Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60187.

[9]Black Kow® Topsoil, Black Gold Compost Co., P.O. Box 190, Oxford, FL 34484.

[10]Osmocote®, The Scotts Co., P.O. Box 606, Marysville, OH 43040.

LITERATURE CITED

Florida Fish and Wildlife Conservation Commission. 2012. Aquatic Plant Permit Rules. http://myfwc.com/license/aquatic-plants/permit-rules/. Accessed April 17, 2013.

Glomski LM, Mudge CR. 2013. Effect of subsurface and foliar applications of bispyribac-sodium on water hyacinth, water lettuce, and giant salvinia. J. Aquat. Plant Manage. 51:62–65.

Harley KLS, Forno IW, Kassulke RC, Sands DPA. 1984. Biological control of water lettuce. J. Aquat. Plant Manage. 22:101–102.

Holm LG, Plucknett DL, Pancho JV, Herberger JP. 1977. The world's worst weeds: Distribution and biology. 18th ed. University Press Publications, Honolulu, HI. p. 609.

Koschnick TJ, Haller WT, Chen AW. 2004. Carfentrazone-ethyl pond dissipation and efficacy on floating plants. J. Aquat. Plant Manage. 42:103–108.

Mudge CR, Haller WT. 2012. Response of target and nontarget floating and emergent aquatic plants to flumioxazin. J. Aquat. Plant Manage. 50:111–116.

Mudge CR, and Netherland MD. 2014. Response of invasive floating plants and nontarget emergent plants to foliar applications of imazamox and penoxsulam. J. Aquat. Plant Manage. 52:1–7.

Owens CS, Madsen JD. 1995. Low temperature limits of water hyacinth. J. Aquat. Plant Manage. 33:63–68.

Senseman, SA (ed.). 2007. Herbicide handbook. 9th ed. Weed Science Society of America, Lawrence, KS. 458 p.

Schmitz DC, Schardt JD, Leslie AJ, Dray FA, Osborne JA, Nelson BV. 1993. The ecological impact and management history of three invasive alien aquatic plant species in Florida. Pages 173–194 *in* B.N. McKnight (ed.), Biological pollution. The control and impact of invasive exotic species. Indiana Academy of Science, Indianapolis, Indiana, 261 pp.

University of Florida. 2011. Plant Management in Florida Waters: 2,4-D Considerations. http://plants.ifas.ufl.edu/manage/developing-management-plans/herbicide-considerations/24-d-considerations. Accessed April 17, 2013.

University of Florida. 2012a. Plant Management in Florida Waters: Details about the Aquatic Herbicides Used in Florida. http://plants.ifas.ufl.edu/manage/control-methods/details-about-the-aquatic-herbicides-used-in-florida. Accessed August 5, 2013.

University of Florida. 2012b. Plant Management in Florida Waters: Maintenance Control Strategies. http://plants.ifas.ufl.edu/manage/developing-management-plans/maintenance-control-strategy. Accessed April 17, 2013.

Weldon LW, Blackburn RD. 1966. Waterlettuce—Nature, problem and control. Weeds 14:5–9.

Wersal RM, Madsen JD. 2010. Combinations of penoxsulam and diquat as foliar applications for control of water hyacinth and common salvinia: Evidence of herbicide antagonism. J. Aquat. Plant Manage. 48:21–25.

Wisconsin Department of Natural Resources. 2012. Bispyribac Sodium Chemical Fact Sheet. DNR PUB-WT-966. http://dnr.wi.gov/lakes/plants/factsheets/BispyribacSodiumFactsheet.pdf. Accessed October 25, 2013.