Sensitivity of nontarget aquatic and terrestrial plants to metsulfuron-methyl exposure by foliar spray or irrigation

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ABSTRACT

Recently, metsulfuron-methyl (MSM) was approved for a Special Local Need (SLN, Section 24[c]) label in Louisiana and Texas to control giant salvinia (*Salvinia molesta* D.S. Mitchell) in public waterbodies. However, there is limited data on nontarget species response to MSM. Therefore, mesocosm trials were conducted to determine the sensitivity of nontarget aquatic species to foliar-applied MSM and the phytotoxic effects of MSM treated irrigation water on nontarget aquatic and terrestrial species. Foliar applications of MSM at 10.5 to 84.1 g ha^{-1} reduced giant blue iris (*Iris giganticaerulea* Small) dry weight $\geq$ 97% 7 wk after treatment (WAT). Broadleaf arrowhead (*Sagittaria latifolia* Willd.) and yellow water lily (*Nymphaea mexicana* Zucc.) showed little tolerance to MSM because biomass was reduced between 84 and 100% across all application rates. However, broadleaf cattail was the only species that demonstrated some level of tolerance to MSM with dose-response analysis revealing the effective dose to result in a 50% biomass reduction (ED_{50}) was 27.0 g ha^{-1}. Metsulfuron applied in irrigation water at concentrations up to 40 μg L^{-1} did not impact cherry tomato (*Solanum lycopersicum* L.) or vinca [*Catharanthus roseus* (L.) G. Don.] biomass. However, based on regression analysis, giant blue iris biomass was reduced 10 and 25% when irrigation water contained MSM at 13.8 and 37.6 μg L^{-1}, respectively. Additionally, soybean [*Glycine max* (L.) Merr.] biomass actually increased after irrigation with MSM at select concentrations. Based on these data, MSM in irrigation water at concentrations up to 40 μg L^{-1} should not cause biomass reductions in cherry tomato, vinca, and soybean, but should not be used to irrigate giant blue iris. Likewise, foliar applications of MSM should avoid contact with giant blue iris, broadleaf arrowhead, and yellow water lily.

Key words: dose-response, giant salvinia, native plant, phytotoxicity.

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INTRODUCTION

The invasive aquatic fern, giant salvinia (*Salvinia molesta* D.S. Mitchell) has continued to invade waterbodies across the southern United States since its introduction in 1995 (Johnson 1995). Giant salvinia exhibits a rapid growth rate and is capable of doubling its biomass in as few as 36 h under ideal growing conditions (Johnson et al. 2010). Due to its rapid growth rate, giant salvinia can quickly outcompete native vegetation and results in monotypic stands (Mitchell and Tur 1975). Infestations of giant salvinia can negatively impact wildlife habitat, water quality, transportation, irrigation, recreational activities, property values, mosquito control, and public health (Jacono 1999, Jacono and Pittman 2001, Nelson et al. 2001).

Currently, glyphosate and diquat are the most utilized herbicides in Louisiana for giant salvinia management (Mudge et al. 2016). Outdoor mesocosm trials demonstrated that glyphosate alone or in combination with diquat provided 95 to 99% control during the growing season (spring and summer); however, winter applications resulted in slightly reduced activity (Mudge et al. 2016, Mudge and Sartain 2018). Other herbicides including carfentrazone-ethyl, flumioxazin, bispyribac-sodium, fluridone, penoxsulam, and topramezone have demonstrated varying levels of control when applied alone or in combination with other chemistries (Glomski and Getsinger 2006, Mudge and Harms 2012, Mudge et al. 2012, Glomski and Mudge 2013, Mudge 2016, Mudge et al. 2016). Applications of the contact herbicides carfentrazone-ethyl and flumioxazin were shown to result in rapid chlorosis and necrosis within days after treatment (Nelson 2014). However, giant salvinia can form mats nearing 1 m thick (Thomas and Room 1986) and the contact herbicides only impact the outer layer while providing little control to protected plants found sheltered in dense infestations (Nelson et al. 2001, Glomski and Getsinger 2006, Richardson et al. 2008, Sartain 2018). Glyphosate is rapidly inactivated upon reaching the water column; thus, it is only effective if applied to foliage (Carlisle and Trevors 1988). The systemic herbicides fluridone, bispyribac-sodium, penoxsulam, and topramezone, which are absorbed by emergent and submersed fronds, can provide giant salvinia control, but injury symptoms are slow to develop (Mudge et al. 2012, Glomski and Mudge 2013, Nelson 2014, Mudge 2016). Consequently, there is a need for additional herbicide options for giant salvinia to provide selective, expedient control that reduces selection pressure on currently utilized herbicide modes of action (Sartain and Mudge 2018a).

Metsulfuron-methyl (MSM) is an acetolactate synthase (ALS)-inhibiting herbicide registered for use in wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), pastures, turf, right-of-way, and industrial sites to control dicotyledonous weeds, brush, and deciduous trees (Shaner 2014, Bayer 2019a) at 4.2 to 168.2 g ha^{-1}. Previous research that showed foliar-applied MSM provided at least 98% control of giant salvinia at 21.1 to 84.1 g ha^{-1} resulted in the recently approved SLN labels in Texas and Louisiana for use of MSM to control giant salvinia in public waters (Sartain and Mudge 2018a, Alligare 2019, Alligare 2020, Bayer 2020). As the use of this herbicide in aquatic sites potentially increases, it is important to determine the effects of foliar applied MSM and potential irrigated water containing MSM on common nontarget species that occur in or near areas where giant salvinia has infested. In Florida, MSM can be applied in select aquatic environments to control old world climbing fern [*Lygodium microphyllum* (Cav.) R. Br.] and other emergent species including pickerelweed (*Pontederia* spp.), arrowhead (*Sagittaria* spp.), smartweed (*Polygonum* spp.), and willow (*Salix* spp.) in dewatered zones of lakes (Bayer 2019b,c) under the authority of a SLN label. However, MSM has a broad herbicidal activity, spanning several plant families including the Fabaceae, Asteraceae, Polygonaceae, Amaranthaceae, Chenopodiaceae, and even members of the Poaceae (Bayer. 2019a, USEPA 2019). Consequently, some nontarget emergent species might be sensitive to MSM.

The primary purpose of aquatic weed management is to control growth of invasive plant species while maintaining a diversity of native species (Mudge and Haller 2010). Native aquatic plants can improve water clarity and quality, provide valuable fish and wildlife habitat, reduce sediment resuspension, and help prevent the spread of invasive plants (Savino and Stein 1982, Heitmeyer and Vohs 1984, Smart 1995, Dibble et al. 1996). However, glyphosate and diquat, the current standard practice for giant salvinia management, are largely nonselective (Van et al. 1986, Shaner 2014). Previous research demonstrated that MSM had minimal effects (i.e., injury or reductions in biomass) on the aquatic plants sand cordgrass (*Spartina bakeri* Merr.), soft rush (*Juncus effusus* L.), maidencane (*Panicum hemitomon* Schult.), sawgrass (*Cladium jamaicense* Crantz.), and buttonbush (*Cephalanthus occidentalis* L.) at foliar rates up to 168 g ha^{-1} (Langeland and Link 2006, Hutchinson and Langeland 2008). However, some species are sensitive to MSM. Hutchinson and Langeland (2008) and Chiconela et al. (2004) reported that foliar applications of MSM (70 to 168 g ha^{-1}) resulted in 90 to 100% reductions in biomass of lizard's tail (*Saururus cernuus* L.), golden canna (*Canna flaccida* Salisb.), fireflag (*Thalia geniculata* L.), swamp fern (*Blechnum serrulatum* Rich.), pickerelweed (*Pontederia cordata* L.), and arrowhead (*Sagittaria lancifolia* L.). Although information regarding the sensitivity of some aquatic plants to MSM is available, little is known of the susceptibility of nontarget species common to Louisiana and Texas.

Homeowners, commercial nurseries, and farmers commonly source irrigation water from nearby waterbodies (Hodges and Haydu 2006). Nontarget terrestrial species can be negatively impacted if irrigation water containing low concentrations of herbicides are used for nontarget plant species (Mudge and Haller 2009). However, the response of nontarget species to irrigation water with low levels of MSM has not been investigated. The U.S. Environmental Protection Agency (USEPA) evaluates the impacts and risks associated with aquatic herbicides in water and can impose water use restrictions on treated water to protect human health and the environment. Tolerances of MSM on certain food crops have been established by the USEPA by determining the maximum amount of pesticide residue that can remain in or on a treated food commodity to ensure food safety (USEPA 2017), but no such tolerances are required for ornamental plants (nonfood crops). Therefore, when water treated with an aquatic herbicide is used for irrigation of both food and nonfood crops and herbicide residues remain, plant phytotoxicity is of concern (Mudge and Haller 2009). With the recent SLN registration of MSM in Louisiana and Texas, it is important to determine the impact of this new technology on species outside of giant salvinia. Therefore, small-scale research was conducted to 1) determine the sensitivity of nontarget aquatic species to foliar applied MSM and 2) determine the phytotoxic effects of MSM treated irrigation water on nontarget aquatic and terrestrial species.

MATERIALS AND METHODS

Outdoor mesocosm experiments were conducted in the spring and summer of 2019 at the Louisiana State University (LSU) Aquaculture Research Facility in Baton Rouge, LA, to determine the sensitivity of nontarget aquatic plants giant blue iris (*Iris giganticaerulea* Small), broadleaf arrowhead (*Sagittaria latifolia* Willd.), yellow water lily (*Nymphaea mexicana* Zucc.), and broadleaf cattail (*Typha latifolia* L.) to foliar applications of MSM. In addition, outdoor mesocosm trials were conducted in April and June 2019 to evaluate the susceptibility of the nontarget aquatic giant blue iris and terrestrial plants 'Sun Gold' cherry tomato (*Solanum lycopersicum* L.), 'Pacifica Cherry Halo' vinca [*Catharanthus roseus* (L.) G. Don.], and 'Asgrow® 5535'[1] glyphosate-resistant soybean [*Glycine max* (L.) Merr.] to MSM in irrigation water. All species evaluated reflect those commonly found in Louisiana and Texas.

Foliar application experiment

Giant blue iris plants were purchased from a commercial nursery[2]. At the time of purchase, plants were approximately 25 cm tall growing in 2.5-L, high-density polyethylene (HDPE) pots (14.0 cm diam by 16.4 cm height) and the plants remained in the original containers for the duration of the trial. Each pot contained three to four iris rhizomes growing in an in-house pine bark potting media, and the pots were top-dressed upon arrival with a slow-release fertilizer[3] (15–9–12) at a rate of 2 g kg^{-1} soil. Plants were selected on the basis of uniform height to minimize variation. Pots were transferred to trays (69 by 53 by 16 cm) maintained with 15 cm of municipal water (pH 8.0) from the bottom of the tray and allowed to acclimate for 2 wk before herbicide treatment. At the time of treatment, plants were approximately 33 cm tall and actively growing with no floral production.

Broadleaf arrowhead (30 to 35 cm tall) and yellow water lily (40 to 45 cm tall) were purchased as bare-root plants from a commercial nursery[4] and transferred into 2.5 L HDPE pots upon arrival. Cattail (whole plants with rhizomes, 117 to 127 cm tall) were collected from ponds at the LSU Aquaculture Research Facility and transferred into 14-L pots to accommodate their substantial rhizome biomass. All pots contained topsoil[5] and slow-release fertilizer at a rate of 2 g kg^{-1} soil. After transplanting, a 2.5-cm layer of masonry sand was added to the top of each pot to limit nutrient exchange and/or suspension of organic matter to the water column. Pots were then placed in 1,135-L tanks filled with pond water (pH 8.5) to a depth of 10 cm for broadleaf arrowhead and cattail, and a water depth of 45 cm for yellow water lily. As broadleaf arrowhead and cattail elongated, water level was increased slowly until a final depth of 45 cm was achieved. All three species were allowed to acclimate to their new environment for 6 wk before being individually transferred to 76-L HDPE containers (49.5 cm diam by 58.4 cm height) filled to 45 cm with pond water for the experimentation phase of the trial.

Experiments were set up as a completely randomized design with five replications for iris, four replications for cattail and broadleaf arrowhead, and three replications for yellow water lily due to plant availability. Treatments consisted of MSM[6] at 10.5, 21.1, 42.1, and 84.1 g ha^{-1} plus a nontreated control (NTC) for each species. Applications were made to the foliage of all species using a CO_2-pressurized sprayer calibrated to deliver 935 L ha^{-1} through a single 80-0067 nozzle[7] at 138 kPa. All treatments included a nonionic surfactant[8] at 0.25% v v^{-1}. Additionally, a shielding device was used to minimize herbicide drift to adjacent plants.

Experiments were conducted in April and repeated in May of 2019. Biomass were collected pretreatment from extra pots (3 to 5 replicates depending on the species; see replicate information above) as a reference to monitor plant growth throughout experiments. At 7 wk after treatment (WAT), all viable aboveground biomass for all plant species were harvested and dried in an oven (65 C) to constant weight. Biomass data from each trial were subjected to an ANOVA using SAS®[9] version 9.4 to test for main effects interactions. Interactions between experimental run and MSM dose were not detected for all species ($P > 0.05$). Therefore, data were pooled across experimental runs. Initially, biomass data were fitted to the four-parameter log-logistic model under the *DRC* package in R (version 0.98.1091, R Core Team 2019.):

$$y = c + (d - c)/1 + \exp\left[b\left(\log(x) - \log(e)\right)\right] \qquad [1]$$

where c is the lower limit, d is the upper limit, b is the slope at the inflection point, e is the dose for 50% reduction in biomass, y is the response (biomass in grams), and x is the dose (MSM g ha^{-1}) (Ritz et al. 2015). Additionally, doses required to cause 10 and 25% reductions in biomass were estimated using the *ED* function in *DRC* (Knezevic et al. 2007). Lack-of-fit tests at the 95% level comparing ANOVA to the regression model indicated giant blue iris, broadleaf arrowhead, and yellow water lily data were not appropriately described by the log-logistic model (Ritz and Streibig 2005). Therefore, means for those species were separated using Fisher's protected LSD test ($\alpha = 0.05$).

Irrigation experiment

Giant blue iris plants were cultivated and maintained in the same manner as in the foliar application experiment. Cherry tomato and vinca were obtained as 5-cm-tall seedlings and soybean was started from seed. Cherry tomato and vinca plants were immediately transplanted into 2.5 L HDPE pots filled with topsoil and slow-release fertilizer at 2 g kg^{-1} soil. Likewise, three soybean seeds per pot were planted in fertilizer-amended pots and thinned to two plants pot^{-1} after emergence. When irrigation treatments were applied, cherry tomato and vinca plants were actively growing, beginning to flower, and relatively uniform in size and biomass. Soybeans were treated when all plants reached the V5 to V6 growth stage (vegetative growth with 5 to 6 unfolded trifoliate leaves) (Fehr and Caviness 1977). Cherry tomato, vinca, and soybean plants remained in outdoor mesocosms under full sunlight for the duration of experiments and were irrigated with 1.27 cm of municipal water daily using an overhead sprinkler system on an automatic timer.

Experiments were set up as a completely randomized design with five replications and the trials were conducted in April and June of 2019. Biomass from five extra replicates were collected pretreatment as a reference to monitor plant growth throughout experiments. Treatments consisted of a single overhead irrigation event of MSM-treated municipal water at concentrations of 1, 2.5, 5, 10, 20, and 40 μg L^{-1} plus a NTC for reference. The concentrations utilized in this research correspond with doses evaluated in concurrent giant salvinia efficacy trials (Prevost 2019). Treatments were applied with a watering can with enough solution to deliver the equivalent of 1.27 cm of irrigation solution to each experimental unit, which was sufficient to cover the plants and saturate the soil. At 24 h after treatment, the previous irrigation schedule resumed with water containing no herbicide for the remainder of the trial.

Five mature fruit from each cherry tomato replicate were harvested and weighed fresh immediately at 4 and 5 WAT. Additionally, all viable aboveground biomass were harvested for giant blue iris at 7 WAT and at 6 WAT for cherry tomato, vinca, and soybean plants. Biomass were then dried to a constant weight in an oven (65 C) for 7 d and weighed. All data were first subjected to an ANOVA. No interactions were detected between MSM concentration and experimental run for any data set ($P > 0.05$); therefore, data were pooled across experimental runs. Several regression models were evaluated; however, cherry tomato and vinca were highly tolerant to irrigation treatments and data could not be regressed. Conversely, giant blue iris data was fit to the two-parameter exponential decay model under the *DRC* package:

Table 1. The effect of foliar-applied metsulfuron-methyl (MSM) on the dry biomass of three nontarget aquatic plant species grown in mesocosms 7 wk after treatment from experiments conducted in Louisiana in 2019[1].

	Dry Biomass, g (SE)[2]		
MSM Rate, g ha^{-1}	Giant Blue Iris	Broadleaf Arrowhead	Yellow Water Lily
0	31.5 (1.8) a	14.4 (1.5) a	23.7 (1.5) a
10.5	0.7 (0.5) b	0.0 (0.0) b	3.7 (0.6) b
21.1	0.2 (0.2) b	0.0 (0.0) b	3.0 (0.4) b
42.1	0.3 (0.2) b	0.0 (0.0) b	3.1 (0.5) b
84.1	0.8 (0.4) b	0.0 (0.0) b	2.9 (0.7) b

[1]Pretrial dry-weight biomass [g (SE)]: giant blue iris, 12.1 (0.8); broadleaf arrowhead, 11.3 (1.2); yellow water lily, 22.7 (1.1).
[2]Means within a column followed by the same letter are not different based on Fisher's protected LSD test ($\alpha = 0.05$; $n = 10$).

$$y = d^{-x/e} \quad [2]$$

where y is the response (biomass in grams), x is MSM concentration (µg L^{-1}), d is the upper limit, and e is the steepness of decay. In addition, MSM concentrations required to cause 10 and 25% reduction in biomass were estimated. Soybean exhibited a triphasic response to MSM concentrations and required nonparametric local regression (loess) analysis under the *stats* and *ggplot2* packages (Wickham 2016, R Core Team 2019). The soybean loess curve was also fitted with a 95% confidence band and minimum and maximum responses were estimated.

RESULTS AND DISCUSSION

Foliar application experiment

Giant blue iris, broadleaf arrowhead, and yellow water lily were all highly sensitive to foliar applications of MSM (Table 1). By 7 WAT, dry biomass of giant blue iris was reduced 97 to 99% regardless of MSM rate. Similarly, broadleaf arrowhead biomass was reduced 100% from all rates, and yellow water lily biomass was reduced by at least 84% when compared to the NTC (Table 1). Interestingly, giant blue iris, broadleaf arrowhead, and yellow water lily all were highly sensitive to MSM even at the lowest evaluated rate (10.5 g ha^{-1}) with no difference in response among rates.

Broadleaf cattail was the only species in foliar application experiments with great enough tolerance to MSM to exhibit a dose response that allowed regression modeling (Figure 1). Regression analysis revealed that the effective dose to result in 50% reduction in biomass (ED_{50}) was 27.0 g ha^{-1}. Likewise, ED_{10} and ED_{25} values were 17.2 and 21.5 g ha^{-1}, respectively. These results support the use of MSM for the control of giant salvinia in areas containing desirable broadleaf cattail because giant salvinia has been shown to be controlled at rates as low as 21.2 g ha^{-1} (Sartain and Mudge 2018a). In the event of broadleaf cattail exposure to the effective dose required to control giant salvinia, it is expected that minimal injury (~25% reduction in biomass) will occur. However, if cattail is exposed to MSM rates of 27 g ha^{-1} or greater, noticeable loss is likely to occur.

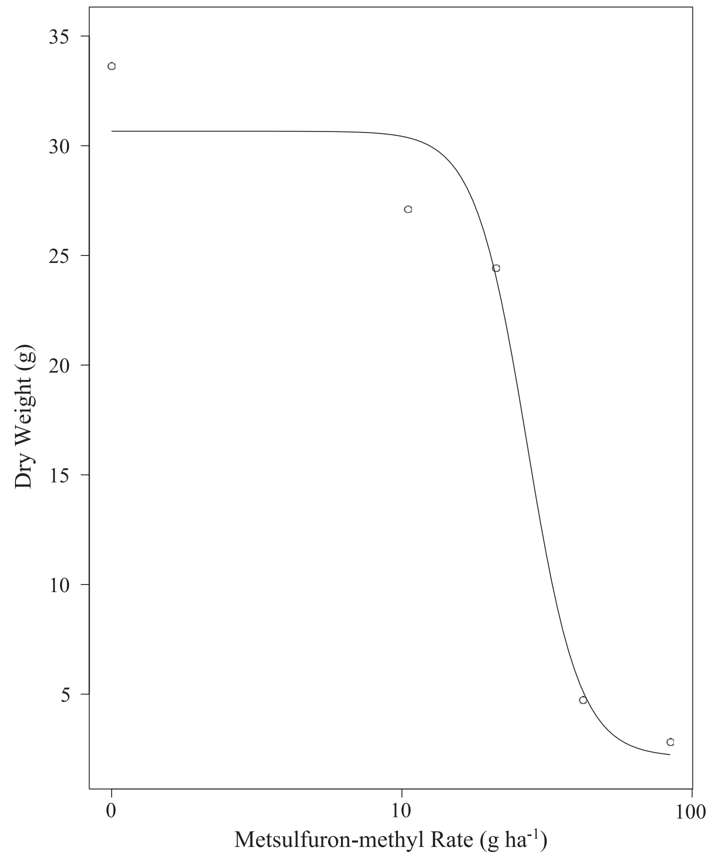

Figure 1. Four-parameter regression model of broadleaf cattail dry weight response 7 wk after treatment with foliar doses of metsulfuron-methyl from mesocosm experiments. Four-parameter regression model: $y = c + (d - c)/1 + \exp[b(\log(x) - \log e)]$, where y is the response (plant dry weight in grams), c is the lower limit, d is the upper limit, b is the slope, x is metsulfuron-methyl dose (g ha^{-1}), and e is the dose require to reduced dry weight 50% (equivalent to ED_{50}). Regression parameters and estimates followed by standard error (SE): b, 4.8 (3.6); c, 2.1 (4.1); d, 30.7 (2.9); e, 27.0 g ha^{-1} (5.0); $ED_{10} = 17.2$ g ha^{-1} (5.2); $ED_{25} = 21.5$ g ha^{-1} (4.1). Pretreatment dry biomass [g (SE)]: 21.4 (2.6).

Although giant salvinia infestations typically exist as a monoculture (Mitchell 1978), it is important to understand the effect of any herbicide application on other species that might be growing in the vicinity. Overall, most of the evaluated species were negatively impacted by low use rates (0.25 times the labeled rate) of MSM (Alligare 2019, Bayer 2020). Prevost (2019) estimated an LD_{90} (lethal dose to control 90% of the test population) of 3.83 g ha^{-1} for giant salvinia. Thus, the lowest use rate (21.1 g ha^{-1}) would be highly efficacious against the target plant, but also injurious or lethal to the nontarget species evaluated in this research. Therefore, applicators should avoid these species if possible while treating giant salvinia, because these species would be negatively impacted when exposed to MSM. At the foliar use rate of 21.1 to 42.1 g ha^{-1} approved by the SLN label in Louisiana and Texas, the results generated under mesocosm conditions suggest that giant blue iris, broadleaf arrowhead, yellow water lily, and broadleaf cattail would be significantly injured or killed. Consequently, future research should investigate the impact of foliar applications on other key nontarget emergent and floating species, especially trees

Table 2. The effect of a single overhead irrigation with 1.27 cm water containing metsulfuron-methyl (MSM) on cherry tomato fruit fresh biomass, and tomato and vinca plant dry biomass 6 wk after treatment (WAT) from experiments conducted in a mesocosm in Louisiana in 2019.

MSM Concentration ($\mu g\ L^{-1}$)	Tomato Fruit Fresh Biomass, g (SE)[1]		Dry Biomass[1,2], g (SE)	
	4 WAT	5 WAT	Tomato	Vinca
0	10.0 (0.9) a[a]	11.8 (0.8) a	18.8 (0.6) a	6.8 (0.5) a
1	10.5 (1.2) a	11.8 (0.8) a	18.8 (0.8) a	5.5 (0.6) a
2.5	13.0 (1.5) a	14.1 (0.8) a	18.5 (0.9) a	5.3 (0.4) a
5	10.3 (0.9) a	11.7 (1.3) a	18.0 (0.9) a	6.1 (0.8) a
10	12.1 (1.8) a	14.1 (0.7) a	20.1 (0.8) a	6.3 (0.6) a
20	12.3 (0.7) a	13.5 (0.8) a	19.5 (1.0) a	6.2 (0.4) a
40	12.2 (1.6) a	12.5 (1.0) a	18.1 (0.8) a	5.9 (0.6) a

[1]Means within a column followed by the same letter are not significantly different based on Fisher's Protected LSD test ($P < 0.05$; $n = 10$).
[2]Pretreatment dry weight biomass [g (SE)] of plants: cherry tomato, 2.3 (0.2); vinca, 1.2 (0.1).

such as bald cypress [*Taxodium distichum* (L.) Rich.], which are very ecologically important (Samuelson and Hogan 2003) to the freshwater systems that giant salvinia commonly inhabit. The impact of foliar applied MSM to bald cypress should be investigated when the nontarget tree is actively growing and dormant, similar to previous research that investigated simulated aerial applications of diquat, glyphosate, and flumioxazin to trees that were void of all leaves (Sartain and Mudge 2018b).

Irrigation experiment

Tomato fruit biomass, tomato plant biomass, and vinca plant biomass were not affected by a single exposure to MSM via overhead irrigation (Table 2). After treatments were administered, these species continued to grow with no adverse effects or noticeable symptoms. Conversely, giant blue iris biomass declined with increasing MSM concentrations (Figure 2). Based on regression results, the concentrations required to reduce giant blue iris biomass 10 and 25% were 13.8 and 37.6 $\mu g\ L^{-1}$, respectively.

Uniquely, soybean exhibited a positive response to MSM irrigation water at some concentrations (Figure 3). Loess modeling indicated that soybean biomass increased from irrigation with MSM concentrations of 1.3 to 10.4, 16.5 to 23.5, and 32.5 to 38.3 $\mu g\ L^{-1}$. All other concentration ranges resulted in biomass similar to the NTC. At the time of harvest (6 WAT), all plants were healthy and producing seed pods. Several hormesis models were evaluated in an effort to describe the positive effect observed from soybean response to MSM in irrigation water; however, model fit was poor due to the lack of biomass reduction at higher concentrations (Figure 3).

These data provide evidence that the varieties of tomato, vinca, and soybean evaluated in this research were not negatively impacted by a single overhead irrigation water containing MSM at concentrations ranging from 1 to 40 $\mu g\ L^{-1}$. The plants in these research trials were relatively young at the time of treatment and it is speculated that mature plants will also likely be tolerant. It should also be noted that

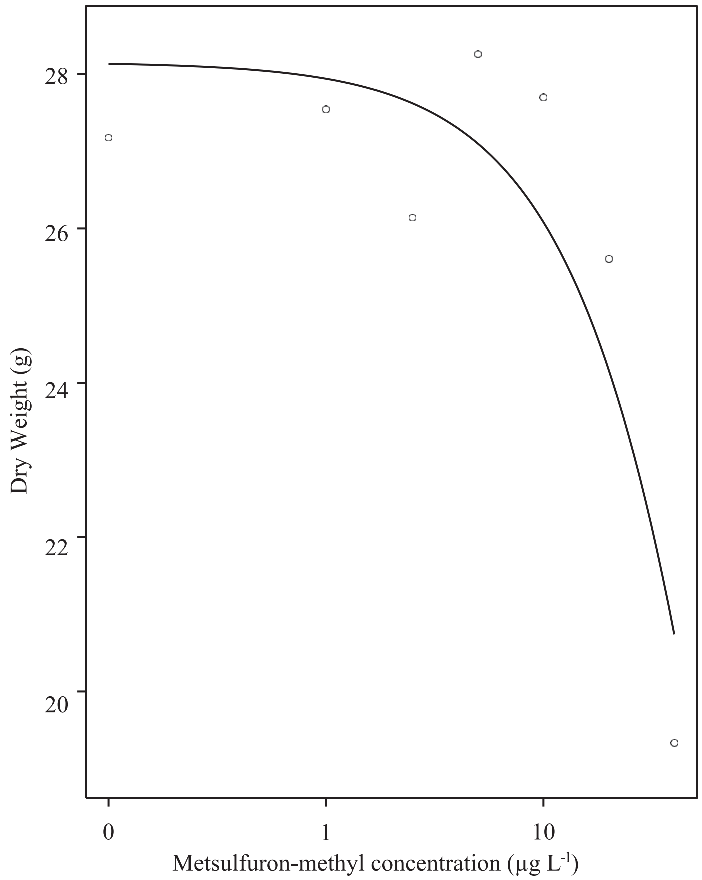

Figure 2. Exponential decay regression model of giant blue iris dry weight response 7 wk after treatment with a single overhead irrigation event (1.27 cm) with water containing metsulfuron-methyl at 0, 1, 2.5, 5, 10, 20, or 40 μg L^{-1} from mesocosm experiments. Two-parameter exponential decay model: $y = d^{-x/e}$, where *y* is the response (dry weight in grams), *x* is metsulfuron-methyl concentration ($\mu g\ L^{-1}$), *d* is the upper limit, and *e* is the steepness of decay. Regression parameters and estimates followed by standard error (SE): *d*, 28.2 (1.2); *e*, 130.9 (47.7); $EC_{10} = 13.8\ \mu g\ L^{-1}$ (5.0); $EC_{25} = 37.6\ \mu g\ L^{-1}$ (13.7).

in the MSM foliar nontarget trial, iris was highly sensitive to MSM applied to the foliage at rates as low as 10.5 g ha^{-1} (Table 1). Future small-scale research should investigate the impact of MSM in irrigation water on other nonaquatic species, as well as the impact of sequential/repeat irrigation events with herbicide-treated water on the species evaluated in the current research.

Nontarget plant damage is an important consideration when using any herbicide, terrestrial or aquatic (Mudge and Haller 2010). Because homeowners, plant nurseries, and commercial farmers commonly utilize nearby surface waters for irrigation (Hodges and Haydu 2006), it is important to consider the effect of using water that has been recently treated with an aquatic herbicide. Sulfonylurea herbicides, such as MSM, are degraded at faster rates by acid hydrolysis, which increases at lower pH levels (Grey and McCullough 2012). Metsulfuron half-life ranges from 4 to 9.6 d at pH 5.2 and 116 d at pH 7.1 (National Center for Biotechnology Information 2019). Because giant salvinia thrives at a pH $<$ 7.5 (Cary and Weerts 1984) and has the ability to decrease

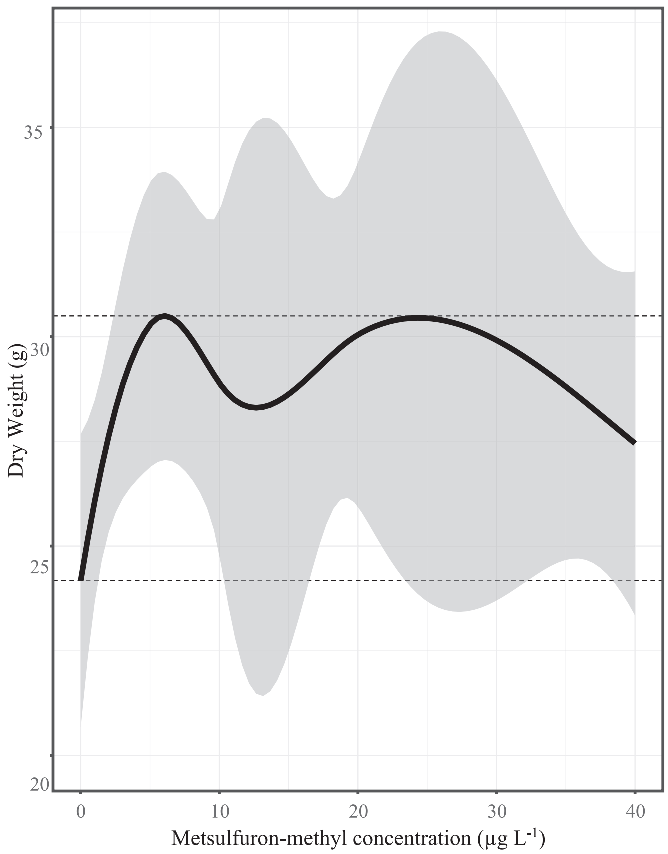

Figure 3. Nonparametric local regression of soybean dry weight response 7 wk after treatment with a single overhead irrigation event (1.27 cm ha^{-1}) with water containing metsulfuron-methyl at 0, 1, 2.5, 5, 10, 20, or 40 µg L^{-1} from mesocosm experiments conducted in Louisiana in 2019. Horizontal dotted lines represent minimum (24.2 g, 0 µg L^{-1}) and maximum (30.5 g, 2.3 µg L^{-1}) of the curve. Solid band depicts 95% confidence intervals.

the pH over time, metsulfuron should degrade quicker in waterbodies throughout Louisiana and Texas. In addition, MSM exhibits a low toxicity profile to animals and aquatic organisms (Shaner 2014).

Currently, MSM aquatic use is granted under a SLN label in Louisiana and Texas and can only be applied by federal and state agencies to control giant salvinia in public waters (i.e., freshwater sloughs, marshes, lakes, and other quiescent systems; Alligare 2019, Bayer 2020). Under this label, treated water from the application area may not be used for irrigation purposes and herbicide cannot be applied within 402 m of any functioning potable water intake (Alligare 2019, Bayer 2020). This research will assist in determining if irrigation restrictions for MSM can be altered or removed in the future. Metsulfuron is highly active on the floating fern giant salvinia at low-use rates (Prevost 2019), but this research has also demonstrated the ALS herbicide is also highly injurious and nonselective to several nontarget species that might be present when foliar applications are administered. Therefore, MSM could alter the native aquatic plant community and should be further evaluated against other species before a Section 3 aquatic label is pursued in the future.

SOURCES OF MATERIALS

[1]Asgrow®glyphosate-resistant soybean, Bayer Crop Science, 800 N. Lindbergh Blvd., St. Louis, MO 63141.

[2]Giant blue iris plants, Bracy's Nursery, LLC., 64624 Dummyline Rd., Amite City, LA 70422.

[3]Osmocote®, The Scotts Company, P.O. Box 606, Marysville, OH 43040.

[4]Broadleaf arrowhead and yellow water lily plants, Aquatic Plants of Florida, Inc., 8120 Blaikie Ct., Sarasota, FL. 34240.

[5]Timberline Top Soil, Oldcastle® Lawn & Garden, Inc., 900 Ashwood Pkwy., Atlanta, GA 30338.

[6]PRO MSM 60®, Alligare, LLC, 13 N. 8th Street, Opelika, AL 36801.

[7]Single 80-0067 nozzle, TeeJet®, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60187.

[8]Non-ionic surfactant, Surf-AC® 910, Drexel Chemical Company, P.O. Box 13327, Memphis, TN 38113.

[9]SAS® software version 9.4, SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513.

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