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NOTE

Evaluation of six herbicides for the control of water primrose (*Ludwigia peploides* (Kunth) P.H. Raven spp. *glabrescens*)

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INTRODUCTION

Water primrose, *Ludwigia peploides* (Kunth) P.H. Raven ssp.*glabrescens* (Kuntze) P.H. Raven, is a perennial aquatic plant native to North America. It is an emergent macrophyte that grows on submersed or temporarily exposed soils and survives on anaerobic waterlogged soils (Rejmankova 1992). *Ludwigia* spp. are typically found along the margins of lakes, reservoirs, slow-moving river systems, and shallow water areas of floodplains and canals (Okada et al. 2009). *Ludwigia peploides* belongs to the evening primrose family (Onagraceae) and is made up of several subspecies; *L. peploides* (Kunth) P.H. Raven ssp. *montevidensis* (Spreng.) P.H. Raven, *L. peploides* (Kunth) P.H. Raven ssp. *peploides*, and *L. peploides* ssp. *glabrescens* (USDA 2014). They exhibit creeping growth characteristics and are sometimes classified as creeping emergent plants (Rejmankova 1992). Their growth characteristics consist of rooting in the substrate and producing long ascending stems that root and branch at the nodes (Rejmankova 1992, Okada et al. 2009). These long stems are also capable of producing adventitious roots, which are often not in direct contact with the substrate, and gather nutrients directly from the water (Sytsma 1989).

Ludwigia peploides can reproduce through vegetative and sexual propagules that are easily dispersed by water (Okada et al. 2009). Fruits containing sexually produced seeds, buoyant vegetative mats, and shoot fragments all facilitate new plant growth and are capable of being dispersed by water flow (Okada et al. 2009). *Ludwigia peploides* exhibits weedy characteristics and maintains positive relative growth rates even under crowded conditions (Rejmankova 1992). Daily crop growth rates in water primrose can be up to 40 to 50 $g\ m^{-2}\ d^{-1}$, which is similar to water hyacinth [*Eichhornia crassipes* (Mart.) Solms], oftentimes referred to as the world's worst aquatic weed (DeBusk et al. 1981, Reddy and DeBusk 1987). Erect emergent macrophytes (*Typha* spp., *Scirpus* spp., *Phragmites australis* Cav.) typically allocate a large proportion of biomass below ground, e.g., rhizomes, whereas creeping emergents, such as *Ludwigia* spp., allocate most of their biomass to aboveground structures that are photosynthetically active (leaves), which allows for increased relative growth rate when compared with erect emergent macrophytes (Rejmankova 1992).

These growth characteristics enable *Ludwigia* spp. to form dense floating mats and cause nuisance problems in water bodies of all sizes throughout the southeastern United States. Infestations can produce dense floating mats that can be a threat to public health by facilitating increased habitat for mosquito species that can carry West Nile Virus and other diseases (Sears and Meisler 2006). Extensive growth can also affect species diversity of other plant species, lower dissolved oxygen levels, and lead to increased flooding (Sears and Meisler 2006).

Several management techniques for controlling *Ludwigia* spp. are available. Biological control of large-flower primrose-willow, *Ludwigia.grandiflora* (Michx) Greuter and Burdet ssp. *grandiflora*, by the water primrose flea beetle (*Lysathia Altica ludoviciana* Fall) has been used in other countries and may be a potential control agent of *Ludwigia* ssp. in the southeastern United States (McGregor et al. 1996). Mechanical control of *L. grandiflora* (Michx) Grueter and Burdet ssp. *hexapetala* (Hook. and Arn) G.L. Nesom and Karteszin in California provided several years of control, but issues associated with cost, access, and disposal of plants are causes for concern (Meisler 2009). Currently, there is little information on chemical control of *L. peploides*. Moreira and others (1999) stated that contact herbicides were effective at controlling parrotfeather (*Myriophyllum aquaticum* Vell. Verdc.), a similar creeping emergent plant, but fast regrowth typically occurred and led to multiple applications. Therefore, systemic herbicides may be the best option for controlling *L. peploides*.

Triclopyr and 2,4-D are both systemic herbicides that belong to the synthetic auxin group of herbicides. Glyphosate is a systemic herbicide that disrupts enolypyruvyl shikimate-3-phosphate synthase, and has been used as a control option for many emergent aquatic species. Imazapyr and imazamox are both members of the imadizolinone chemical family and have been effective at controlling *M. aquaticum* and *Alternanthera. philoxeroides* (Mart.) Griseb. (Wersal and Madsen 2007, Hofstra and Champion 2010),

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Table 1. Mean aboveground biomass (g dry weight [DW] pot^{-1}) of *L. peploides* after a foliar herbicide application.

Weeks after Treatment (WAT; g DW pot $^{-1}$)					
Herbicide	Herbicide Rate (kg ai ha^{-1})	3 WAT	6 WAT	9 WAT	12 WAT
Reference	-	61.6 ± 6a[1]	67.5 ± 6a	64.8 ± 7a	83.4 ± 9a
2,4-D[2]	2.1	11.0 ± 2g	6.3 ± 1de	10.5 ± 2bcde	9.7 ± 3de
	4.3	12.9 ± 2g	7.0 ± 2de	6.1 ± 1de	11.5 ± 3de
Glyphosate[2]	2.1	29.8 ± 5cde	20.5 ± 4cd	19.5 ± 6bcd	35.4 ± 5c
	4.2	26.7 ± 5cdef	17.6 ± 4cde	18.8 ± 3bcde	26.3 ± 5cd
Imazamox	0. 6	37.2 ± 7bc	37.1 ± 11b	21.8 ± 4bc	59.7 ± 12b
	1.1	32.6 ± 4cd	26.9 ± 5bc	24.1 ± 4b	35.9 ± 6c
Imazapyr	0.8	23.1 ± 5defg	13.1 ± 3cde	16.5 ± 3bcde	18.3 ± 5cde
	1.7	18.0 ± 3efg	16.1 ± 3cde	11.3 ± 3bcde	20.5 ± 3cde
Penoxsulam	0.05	62.6 ± 10a	68.6 ± 5a	68.5 ± 8a	78.7 ± 12a
	0.1	49.5 ± 4ab	76.2 ± 8a	62.3 ± 13a	84.0 ± 5a
Triclopyr[2]	3.4	11.9 ± 2g	7.1 ± 2de	4.1 ± 1e	6.3 ± 2e
	6.7	14.1 ± 1fg	5.8 ± 1e	7.3 ± 2cde	9.0 ± 2de

[1]Means in a column followed by the same letter do not differ significantly at $P = 0.05$ level of significance according to least-squares mean separation from the untreated control. Analyses were conducted within weeks after treatment (±1 SE).
[2]Rate expressed in kg ae ha^{-1}.

but regrowth was evident in response to imazamox (Wersal and Madsen 2007). Penoxsulam, commonly used in rice production, is typically applied to water-seeded rice crops for broadleaf weed, sedge, grass, and aquatic plant control (Senseman 2007). Penoxsulam is listed to have moderate activity against *Ludwigia* spp. (Johnson et al. 2009).

To date, no published data have been available on the use of herbicides to control *L. peploides*. The objective of this study is to evaluate two use rates of 2,4-D, glyphosate, imazamox, imazapyr, penoxsulam, and triclopyr for the control of *L. peploides*.

MATERIALS AND METHODS

The study was conducted in an outdoor mesocosm facility at the R. R. Foil Plant Science Research Center, Mississippi State University, Starkville, Mississippi for 12 wk in 52 1,136-L tanks between August and November of 2009. The water in the tanks was maintained at approximately 18 inches throughout the study. It utilized a completely randomized design with two concentrations of 2,4-D[1] (2.1, 4.3 kg ai ha^{-1}), glyphosate[2] (2.1, 4.2 kg ai ha^{-1}), imazamox[3] (0.6, 1.1 kg ai ha^{-1}), imazapyr[4] (0.8, 1.7 kg ai ha^{-1}), penoxsulam[5] (0.05, 0.1 kg ai ha^{-1}), triclopyr[6] (3.4, 6.7 kg ai ha^{-1}), and an untreated reference, with four replicates per treatment. *Ludwigia peploides* ssp. *glabrescens* was collected locally from a small pond in Starkville, Mississippi. The collection was made to species and verified by a botanist in the Department of Plant and Soil Sciences at Mississippi State University (V. Maddox, pers. comm.). The identifying characteristic was that *L. peploides* ssp. *glabrescens* has a glabrous hypanthium, whereas some of the nonnatives or other subspecies typically have pubescence on the hypanthium. After plant collection and species verification, *L. peploides* specimens were separated into 20-cm apical shoots. Two apical shoots of *L. peploides* were then planted into 3.78-L plastic pots filled with a potting medium (a mixture of topsoil, loam, and masonry sand) and amended with 2 g L^{-1} of 19–6–12 Osmocote® fertilizer[7]. This planting methodology has worked well for other creeping perennial species (Wersal and Madsen 2010). A total of 12 planted pots was placed into each of the tanks and allowed to grow and begin creeping along the water surface before herbicide treatments.

After the acclimation period, plants were treated with foliar applications of 2,4-D, glyphosate, imazamox, imazapyr, penoxsulam, and triclopyr. Applications were made to *L. peploides* using a CO_2-pressurized backpack sprayer utilizing a single-nozzle boom equipped with an 8002 tip at a spray volume of 756 L ha^{-1}. A nonionic surfactant was added to the spray solution at a rate of 1% v:v. To prevent spray drift and cross-contamination, barriers were implemented during herbicide applications. Barriers consisted of a sheet being held at each end by one of two individuals. The sheet was wrapped around the rim of the tank held in place and foliar applications were made. At the time of treatment, plants had reached the water surface and had begun forming a "mat" in each tank.

Biomass samples were taken by removing plant material at the potting medium surface from three pots per tank. Samples were taken at 3, 6, 9, and 12 wk after treatment (WAT), dried at 70 C for at least 48 h, weighed, and compared with the untreated reference to assess herbicide efficacy. Aboveground biomass data (g dry weight [DW] pot^{-1}) were analyzed using a mixed procedures model in SAS[8] (Littell et al. 2006). If a significant treatment effect was observed these differences were then separated by the least-squares means method (Littell et al. 2006.) All analyses were conducted at $P < 0.05$ level of significance. In addition, aboveground biomass data (g DW pot $^{-1}$) were converted to a percentage of the reference to get a percent biomass reduction by the following equation:

$$\left(\frac{[\text{Reference Biomass} - \text{Treatment Biomass}]}{[\text{Reference Biomass}]}\right) \times 100 \quad [1]$$

RESULTS AND DISCUSSION

Three WAT all herbicides except penoxsulam significantly reduced biomass when compared with the untreated reference (Table 1). Six WAT, both rates of 2,4-D, triclopyr, and the lower rate of imazapyr had resulted in a > 80% reduction in plant biomass (Table 2). Both rates of 2, 4-D

TABLE 2. PERCENT CONTROL OF *LUDWIGIA PEPLOIDES* BASED ON BIOMASS RELATIVE TO THE UNTREATED REFERENCE AFTER HERBICIDE TREATMENT. A NEGATIVE NUMBER FOR PERCENT CONTROL INDICATES AN INCREASE IN BIOMASS RELATIVE TO THE UNTREATED REFERENCE.

		Weeks after Treatment (WAT; Percent Control)			
Herbicide	Herbicide Rate (kg ai ha^{-1})	3 WAT	6 WAT	9 WAT	12 WAT
2,4-D[1]	2.1	82	91	84	88
	4.3	79	90	91	87
Glyphosate[1]	2.1	52	70	70	58
	4.2	57	74	71	68
Imazamox	0. 6	40	45	66	28
	1.1	47	60	63	57
Imazapyr	0.8	63	81	75	74
	1.7	71	76	83	70
Penoxsulam	0.05	−2	−2	−6	−6
	0.1	20	−13	4	0
Triclopyr[1]	3.4	81	90	94	93
	6.7	77 %	91 %	89 %	89 %

[1]Rate expressed in kg ae ha^{-1}.

and triclopyr were able to maintain > 80% control throughout the 12-wk study period. Regrowth of *L. peploides* was observed 6 WAT in penoxsulam-treated tanks; at the end of the 12-wk study period neither the high nor the low rate of penoxsulam was able to provide a significant reduction in biomass compared with reference plants. Herbicide trials regarding weed control in rice fields resulted in penoxsulam providing poor to moderate broadleaf weed control when applied postemergence (Ottis et al. 2003). Both the high and low rates of imazapyr provided > 70% biomass reduction throughout the 12-wk study period when compared with the untreated reference (Table 2). Although penoxsulam, imazamox, and imazapyr all share similar modes of action (acetolactate synthase-inhibiting herbicides), they all produced different results in biomass reduction of *L. peploides*. Both rates of imazamox showed significantly different results after the 12-wk study period; the higher rate provided a 57% biomass reduction compared with 28% with the lower rate (Table 2). Similar results have been reported by Emerine et al. (2010), concluding that creeping water primrose biomass decreased with increasing rates of imazamox. Both imazapyr rates performed similarly 12 WAT, providing significant control and reducing water primrose biomass by > 70 %. Emerine et al. (2010) documented > 90% control of creeping water primrose, alligatorweed, and parrotfeather 5 WAT when treated with imazapyr (560 g ae ha^{-1}). Greater control with imazapyr applications by Emerine et al. (2010) may have been due to the use of a greenhouse as the study site.

The two rates of glyphosate did not significantly differ when compared after the 12-wk study period. Maximum biomass reduction after glyphosate applications was achieved 6 WAT (60 and 74%) and dry weight of *L. peploides* did not significantly differ among rates throughout the 12-wk study. Both auxin herbicides, 2,4-D and triclopyr, provided good control at the conclusion of the 12-wk study period. The two herbicides and the application rate at which each herbicide was applied did not significantly differ at the end of the study period. Both treatments provided > 75% control after the 3-wk sampling period and no regrowth of *L. peploides* was observed throughout the 12-wk study.

Results of this study indicate that the herbicides 2,4-D, triclopyr, imazapyr, glyphosate, and the 1.1 kg ai ha^{-1} rate of imazamox provide the best reduction of biomass in small populations of *L. peploides*. Lower rates of 2,4-D (2.1 kg ai ha^{-1}), triclopyr (3.4 kg ai ha^{-1}), imazapyr (0.8 kg ai ha^{-1}), and glyphosate (2.1 kg ai ha^{-1}) may be used since increased rates did not provide any additional biomass reduction throughout the study. Lower rates will also be more cost effective. Triclopyr and 2,4-D offers more selectivity than imazapyr and glyphosate because of their ability to control broadleaf vegetation and cause minimal impacts on grass species (Netherland 2008). Large dense stands of *Ludwigia* spp. may require increased rates to gain significant control. *Ludwigia* stands can produce stems in excess of 4 feet during optimal summertime conditions (Meisler 2009). Treatment efforts to control extremely dense stands of *Ludwigia* in California with glyphosate and triclopyr were unsuccessful at the rate and timing used, but may have been successful on less dense stands (Meisler 2009). Not all infestations are equal; site characteristics, access to nutrients, history/extent of the infestation, etc. all can affect the success of chemical management plans (Meisler 2009). This study indicates that 2,4-D, triclopyr, imazapyr, glyphosate, and the 1.1 kg ai ha^{-1} rate of imazamox are capable of reducing biomass in small stands of *L. peploides* by at least 50% and maintaining control for at least 12 wk. Since neither herbicide resulted in 100% control, regrowth may be present after 12 wk, and the utilization of a follow-up treatment with a different herbicidal chemistry may be beneficial for maintaining control. Future research addressing large-scale *Ludwigia* spp. treatments in field situations with varying rates and chemistries would offer insight into the best management practices for dealing with large stands of *Ludwigia* spp.

SOURCE OF MATERIALS

[1]Hardball®—2,4-dichlorophenoxyacetic acid 19.6%, Helena Chemical Co., 225 Schiling Boulevard, Suite 300 Collierville, TN 38017.

[2]Rodeo®—glyphosate: *N*-(phosphonomethyl)glycine isopropylamine salt 53.8%, Dow AgroSciences LLC, Indianapolis, IN 46268.

[3]Clearcast®—ammonium salt of imazamox 12.1%, SePro Corp., 11550 North Meridian Street, Suite 600, Carmel, IN 46032.

[4]Habitat®—Isopropylamine salt of imazapyr 28.7%, BASF Corp., 26 Davis Drive, Research Triangle Park, NC 27709.

[5]Galleon® SC—penoxsulam 21.7%, SePro Corp., 11550 North Meridian Street, Suite 600, Carmel, IN 46032.

[6]Renovate® 3—triclopyr 44.4%, SePro Corp. 11550 North Meridian Street, Suite 600, Carmel, IN 46032.

[7]Osmocote® Outdoor & Indoor Smart-Release® Plant Food, The Scotts Co., P.O. Box 606, Marysville, OH 43040.

[8]SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513-2414.

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