Weed Technology

www.cambridge.org/wet

Giant reed (*Arundo donax*) responses to herbicides in a greenhouse study

Mingyang Liu[1,4], Andrew Hulting[2] and Carol Mallory-Smith[3]

[1]Former Graduate student, Oregon State University, Corvallis, OR, USA; [2]Associate Professor, Oregon State University, Corvallis, OR, USA; [3]Professor Emeritus, Oregon State University, Corvallis, OR, USA and [4]Assistant Professor, Weifang Engineering Vocational College, Qingzhoushi, China

Research Article

Cite this article: Liu M, Hulting A, Mallory-Smith C (2020) Giant reed (*Arundo donax*) responses to herbicides in a greenhouse study. Weed Technol. **34**: 824–829. doi: 10.1017/wet.2020.66

Received: 12 February 2020
Revised: 9 May 2020
Accepted: 12 June 2020
First published online: 22 June 2020

Associate Editor:
Daniel Stephenson, Louisana State University Agricultural Center

Nomenclature:
Giant reed, *Arundo donax* L.; acetochlor; atrazine; dimethenamid-p; flufenacet; mesotrione

Keywords:
giant reed; biofuel crops; chemical control; invasive species

Author for correspondence:
Mingyang Liu, Assistant Professor, Weifang Engineering Vocational College, 8979 Yunmenshan Rd., Qingzhoushi, China
Email: 2002-9-17@163.com

Abstract

Giant reed recently was promoted as a biofuel crop in Oregon. Because giant reed is a highly invasive plant in North American rivers, the planting of this species in Oregon is a cause for concern to scientists and local land managers. However, some growers in the area were interested in producing giant reed as a rotational crop. To find potential herbicides to control the giant reed or to control it as a volunteer, 13 foliar and 13 cut-and-spray herbicide treatments were preevaluated in greenhouse studies. We chose 10% and 85% reduction in aboveground biomass for either crop safety or control, respectively. When applied at the standard rates, acetochlor and dimethenamid-p reduced aboveground dry biomass of the crop by 10% or less. Acetochlor+atrazine, atrazine, flufenacet, and mesotrione reduced aboveground biomass of the crop by at least 85%, indicating that these compounds have the potential to serve as controls against giant reed.

Introduction

Giant reed is a tall, perennial herbaceous plant with large bamboo-like culms and robust rhizomes. It has been proposed as a good alternative for reducing the cost of bioenergy crop production due to its high productivity and low agronomic and energy inputs (Corno et al. 2014). Giant reed grows in many different ecosystems and soil types, preferentially along lakes, ponds, and rivers (Corno et al. 2014; Lewandowski et al. 2000). A 10-yr field experiment in central Italy indicated that aboveground dry biomass production of giant reed can reach 28.7 tons per hectare per year (Angelini et al. 2009). Another study in Italy reported that giant reed cultivation may produce the same amount of biomass at 25% of the cost on 64% of the area compared with traditional bioenergy crops (Corno et al. 2016). In order to meet federal and state rules, Portland General Electric (PGE) selected giant reed as one of the alternative fuels for its 585-megawatt coal-fired power plant in Boardman, Oregon (Morgan and Sytsma 2015). PGE contracted 120 ha of production in Morrow County, Oregon, and with plans to convert up to 36,500 irrigated hectares to giant reed production by 2020 (County Court of Morrow 2010; Lies 2011). However, weed management in giant reed production has not been well studied, and no herbicides have been registered for use against giant reed as a crop.

Growers and the public have both raised concerns about giant reed's invasive potential. Giant reed is an invasive weed in many tropical and cool-summer, temperate, Mediterranean-type environments in North America such as Mexico, Texas, California, and other parts of the southwestern United States (ODA 2011). The major concern is the plant's impact on water supplies and its possibility to change riparian landscapes because it consumes large amounts of water (Anonymous 2012; Oakins 2001). Previous studies have indicated that giant reed consumes three times more water than typical native species (Jackson et al. 2002; Oakins 2001). Other negative impacts of giant reed invasion may include dramatically altered ecological processes in riparian systems, water facility damage, and increased fire hazard (ODA 2011). In coastal California, the appearance of giant reed will increase the risk of wildfire because the large amount of biomass produced by giant reed can reduce the buffering capacity of riparian areas (Anonymous 2012). Giant reed can create large debris piles that threaten the structural integrity of bridges and other in-stream structures, which results in expensive removal and cleanup following flood events (ODA 2011; Seawright et al. 2009).

Previous studies of giant reed have mainly focused on biocontrol efforts, treating the plant as an invasive species in riparian zones over large areas (Jackson et al. 2002; Seawright et al. 2009). However, chemical control could be a more efficient method. Chemical control of giant reed depends on several factors, such as the presence or absence of native plants, the size of the stand, the amount of biomass left after control, the terrain conditions, and the season (Bell 1997; Martin et al. 2019). Foliar spray, cut-and-spray, and cut-resprout-spray are three common chemical methods used to control giant reed. Imazapyr and glyphosate also have been used to control giant reed (Jackson 1993; Martin et al. 2019; Morgan and Sytsma 2015;

Table 1. Herbicides used in the herbicide applications screening assay.

Herbicide	Description	Rate
		kg ai ha^{-1}
2,4-D amine	Weedar 64 (3.8 Lb/Gal EC)	0.13
		0.26
		0.52
Acetochlor+atrazine	Harness Xtra (6 Lb/Gal EC)	1.18
		2.36
		4.70
Bromoxynil+MCPA	Bronate Advance (5 Lb/Gal EC)	0.42
		0.84
		1.68
Bromoxynil+pyrasulfotole	Huskie (2.06 Lb/Gal EC)	0.14
		0.27
		0.54
Carfentrazone	Aim EC (2 Lb/Gal EC)	0.02
		0.04
		0.07
Chlorsulfuron	Telar XP (75% DF)	0.03
		0.05
		0.11
Dicamba	Clarity (4 Lb/Gal SC)	0.28
		0.56
		1.12
Dicamba+2,4-D amine	Latigo (4.2 Lb/Gal EC)	0.59
		1.18
		2.35
Dimethenamid-p	Outlook (6 Lb/Gal EC)	0.37
		0.74
		1.47
Fluroxypyr+bromoxynil	Starane NXT (2.913 Lb/Gal EC)	0.35
		0.70
		1.40
Mesotrione	Callisto (4 Lb/Gal SC)	0.11
		0.21
		0.42
Metsulfuron	Escort XP (60% WDG)	0.04
		0.08
		0.17
Thifensulfuron+tribenuron	Affinity BroadSpec (50% WDG)	0.02
		0.03
		0.06

[a]Abbreviations: DF, dry flowable; EC, emulsifiable concentrate; SC, suspension concentrate; WDG, wettable dispersible granules.

Santín-Montanyá et al. 2013). Generally, population expansion of giant reed occurs mainly through vegetative reproduction, either from underground rhizome extension of a colony or from stem fragments carried downstream (Bhanwra 1988; Else 1996; Johnson et al. 2006; Lewandowski et al. 2000). Thus, the Oregon Department of Agriculture (ODA 2011) recommended killing or removing the root-mass.

To determine potential herbicides for weed management in giant reed grown as a biofuel crop or to control giant reed, greenhouse studies were conducted to evaluate giant reed response to herbicides commonly used in Oregon. Herbicides were applied either as foliar or as cut-and-spray treatments.

Materials and Methods

General Procedures

The giant reed plants used in this study were provided by BOO-Shoot Gardens LLC, 1768 Dunbar Rd., Mount Vernon, WA 98273. Each giant reed plant was individually transplanted in to a 950-ml-square pot filled with potting mix (Sunshine Mix 1 Potting Mix, Sun Gro Horticulture, Bellevue, WA), and placed in the greenhouse. Greenhouse conditions included 25/20 C day/night temperatures with ambient sunlight plus grow lights providing 14 h of overhead light via 25 mW cm^{-2} per day. Herbicide treatments were applied using an experimental spray chamber equipped with TeeJet TP8004VS nozzles (TeeJet Technologies, Glendale Heights, IL) calibrated to deliver 187 L ha^{-1} at 276 kPa. Before herbicide application, the healthiest stem was kept on each plant, and other stems were cut at the soil level. A randomized complete block design with four blocks was used in both experiments. The treatments were applied when the mean plant height was between 40 and 50 cm. When treatments were applied, the height range of the plants was 32 to 61 cm. Giant reed plants were grouped into four blocks based on size. The plant height in the four blocks were ≤40 cm, 40–45 cm, 45–50 cm, and ≥50 cm, respectively. The studies were repeated.

Herbicides

Because no herbicides were registered for use against giant reed either as a crop or for control as a volunteer, herbicides were selected that growers in that area were using with rotational crops. The application rates were based on the highest recommended labeled rate for using in the rotational crops and on our field experience.

Experiment 1: Herbicide Screening Assays

Giant reed plants were sprayed with 13 different foliar applied herbicides (Table 1). Three rates, half of the labeled field rate (0.5×), the labeled field rate (1×), and two times the labeled field rate (2×), were used for each herbicide. A nonionic surfactant was added, if required by the label.

Before aboveground biomass harvest, the plant injury was visually rated on a score from 0 (no injury) to 100 (death). Depending on the mode of action of the different herbicides, injury symptoms, including leaf yellowing or purpling, leaf/stem twisting, and short or abnormal plant, were evaluated. At the same time, the number of stems with at least two leaves were counted as an indication of survival. The plant height was measured on the tallest stem of each plant and converted to percentage relative to the untreated controls. Aboveground biomass was harvested about 2.5 cm above the soil surface at 21 and 42 d after herbicide application. The 2.5 cm of stem was retained at the first harvest to ensure that the plant would regrow. A second harvest was conducted to examine the herbicide's influence on regrowth. At 42 d after herbicide application, belowground biomass was harvested. Roots were separated from soil by rinsing them under tap water. The biomass samples were oven-dried at 65 C for 72 h and weighed. The percent dry weight of the treated plants relative to the untreated control was calculated. The study was repeated.

Experiment 2: Herbicide Screening Assay with the Cut-and-Spray Method

In Experiment 2, herbicides were applied with a cut-and-spray treatment. The purpose of this study was to determine which herbicides could suppress giant reed regrowth after harvest. Giant reed plants were grown under the same conditions as in Experiment 1. When giant reed plant reached the same heights as in Experiment 1, the treatments were applied. Giant reed plants were cut 2.5 cm above the ground, before herbicides were applied. Herbicides at three rates, 0.5×, 1×, and 2×, were applied within 2 d after cutting (Table 2). Herbicide efficacy was estimated at 21 d after herbicide application. Measurements, including plant injury,

https://doi.org/10.1017/wet.2020.66 Published online by Cambridge University Press

Table 2. Herbicides used for the cut and spray assay.

Herbicide	Description	Rate
		kg ai ha^{-1}
2,4-D amine	Weedar 64 (3.8 Lb/Gal EC)	0.13
		0.26
		0.52
Acetochlor	Harness (7 Lb/Gal EC)	0.95
		1.91
		3.81
Acetochlor+atrazine	Harness Xtra (6 Lb/Gal EC)	1.18
		2.36
		4.70
Atrazine	Atazine (4 Lb/Gal EC)	1.12
		2.24
		4.48
Dimethenamid-p	Outlook (6 Lb/Gal EC)	0.37
		0.74
		1.47
Diuron	Diuron 4L (4 Lb/Gal EC)	0.90
		1.79
		3.59
Flufenacet	Define (60 % DF)	0.19
		0.38
		0.76
Flumioxazin	Chateau (51 % WDG)	0.21
		0.43
		0.85
Metribuzin	Metri DF (75 % DF)	0.42
		0.84
		1.68
Pendamethalin	Prowl H2O (3.6 lb/gal SC)	1.68
		3.36
		6.73
Pyroxasulfone	Zidua (85 % WDG)	0.05
		0.10
		0.20
S-metolachlor	Dual II Magnum (7.64 Lb/Gal EC)	0.53
		1.07
		2.13
Sulfentrazone	Spartan F4 (4 Lb/Gal EC)	0.21
		0.42
		0.84

[a]Abbreviations: DF, dry flowable; EC, emulsifiable concentrate; SC, suspension concentrate; WDG, wettable dispersible granules.

stem numbers, plant height, and aboveground and root dry biomass, were collected as described in Experiment 1. The study was repeated.

Analysis of variance was performed using R software, version 3.5.1. The herbicide effects and possible interaction with rates were tested for each measured parameter. The treatment means were separated using a Student's *t*-test at $P < 0.05$.

Results and Discussion

Normality of residuals and homogeneity of variance of the data were analyzed using R software, version 3.5.1. No significant differences were found among blocks or between replicated studies. Therefore, data for the same treatment were pooled across trials for further analysis.

Experiment 1: Herbicide Screening Assay with Foliar Application

Plant injury caused by herbicide treatment was found at the first harvest with 9 of the 13 herbicides applied at the 1× and 2× labeled rates (Table 3). Except for bromoxynil+MCPA, injury caused by these herbicides was observed on regrowth after the first harvest. Injury caused by dimethenamid-p at both harvests was observed only at the 2× rate. Injury caused by chlorsulfuron was observed at the second harvest.

The number of stems varied from one to five. At the first harvest, dicamba, dicamba+2,4-D-amine, and mesotrione application resulted in reduced stem numbers when applied at the 1× and 2× rates (Table 3). Fluroxypyr+bromoxynil and thifensulfuron-tribenuron application resulted in reduced stem numbers only when applied at the 1× rate. At the second harvest, giant reed plants treated with 1× and 2× rates of all herbicides except bromoxynil+ pyrasulfotole and carfentrazone had fewer stems than control plants. At the second harvest, bromoxynil+MCPA, dimethenamid-p, and thifensulfuron+ tribenuron applications resulted in reduced stem numbers only at the 2× rate.

The plant height of treated plants varied from 64% to 109% of that of controls. When applied at 1× and 2× rates, 2,4-D-amine, carfentrazone, chlorsulfuron, dicamba, dicamba+2,4-D-amine, fluroxypyr+bromoxynil, mesotrione, and metsulfuron applications resulted in reduced the plant height at both the first and second harvests, whereas acetochlor+atrazine caused a reduction in the height of regrowth. Dimethenamid-p caused a plant height reduction at both harvests but only at the 2× rate.

When sprayed at 1× or 2× rates, applications of 2,4-D amine, carfentrazone, dicamba, dicamba+2,4-D amine, fluroxypyr+ bromoxynil, and mesotrione resulted in reduced the aboveground biomass at both harvests. Acetochlor+atrazine, chlorsulfuron, and metsulfuron applications resulted in reduced aboveground biomass at the second harvest. Bromoxynil+ pyrasulfotole applied at the 2× rate resulted in reduced aboveground biomass of regrowth. However, application of the 2× rate of bromoxynil+ pyrasulfotole did not result in reduced aboveground biomass at the first harvest.

Application of the herbicides 2,4-D amine and mesotrione resulted in reduced root dry biomass when they were sprayed at all three rates. Fluroxypyr+bromoxynil and metsulfuron applications resulted in reduced root dry biomass only when they were sprayed at the 2× rate.

Experiment 2. Herbicide Screening Assay with the Cut-and-Spray Method

In Experiment 2, all plants were killed when they were treated with diuron, pyroxasulfone, and s-metolachlor at the 2× rate. Plant injury was observed with most herbicide except plants that had been treated with acetochlor and the lower rate of dimethenamid-p (Table 4).

Stem number varied from 0 to 2.1. Stem number was the least affected growth parameter in this study. Most herbicides caused injury to the plants but did not reduce the stem numbers, or they reduced the stem number only when used at the highest rate.

Herbicide effects on plant height and aboveground dry weight were similar to the plant injury data. Most injury eventually led to a reduction in plant height or aboveground dry weight. The only exception was plants that were treated with 0.5× pendimethalin, which caused a reduction in plant height but did not reduce aboveground dry weight.

The herbicides 2,4-D amine, acetochlor+atrazine, atrazine, diuron, and flufenacet used at all three rates resulted in reduced plant root growth, whereas pyroxasulfone, s-metolachlor, and

https://doi.org/10.1017/wet.2020.66 Published online by Cambridge University Press

Table 3. Plant response to foliar applications.

		First harvest				Second harvest				
Herbicide	Rate	pi[a,b]	sn	ph	adw	pi	sn	ph	adw	rdw
	kg ai ha^{-1}									
Control	0.00	0	2.0	100.0	100.0	0	2.0	100.0	100.0	100.0
2,4-D amine	0.13	33.8*[c]	1.6	94.8	64.9*	50.0*	1.0*	55.4*	24.9*	61.9*
	0.26	48.8*	1.8	89.6*	63.0*	50.0*	0.8*	47.4*	17.3*	54.9*
	0.52	62.5*	1.9	87.5*	58.4*	71.3*	0.8*	20.1*	12.2*	64.2*
Acetochlor+atrazine	1.18	20.0*	1.3	105.7	83.0	47.5*	1.8	56.3*	43.7*	74.2
	2.36	32.5*	2.0	97.4	80.1	67.5*	0.5*	15.7*	4.6*	81.3
	4.70	35.5*	1.9	106.3	103.0	100.0*	0.0*	0.0*	0.0*	80.2
Bromoxynil+MCPA	0.42	8.8	2.3	104.2	105.2	21.3	1.8	71.5	59.9*	82.6
	0.84	13.8*	1.8	96.6	92.8	6.3	2.0	86.7	79.8	91.2
	1.68	13.8*	1.7	102.6	83.4	15.0	1.4*	82.8	78.9	90.5
Bromoxynil+pyrasulfotole	0.14	10.0	2.1	108.6	120.4*	25.0	2.0	70.7	79.2	104.3
	0.27	15.0	1.8	104.4	105.3	6.3	2.1	86.8	83.2	83.3
	0.54	18.8	1.5	109.2	107.6	21.3	1.6	74.1	71.7*	89.7
Carfentrazone	0.02	27.5*	2.2	100.6	101.5	31.3	2.1	64.7*	68.6*	103.1
	0.04	28.8*	2.4	109.2	81.5*	35.0*	1.8	64.9*	70.5*	81.7
	0.07	31.3*	2.6	105.4	84.9*	32.5*	1.9	68.2*	71.0*	95.8
Chlorsulfuron	0.03	0	2.1	90.6	107.6	46.3*	1.4	55.7*	45.8*	100.1
	0.05	0	2.1	89.5	101.9	60.0*	1.0*	34.7*	30.1*	90.4
	0.11	3.8	1.6	80.1*	80.7*	83.8*	0.4*	16.7*	14.07*	106.0
Dicamba	0.28	8.8	2.3	81.1*	75.2*	55.0*	1.5*	36.2*	36.3*	103.2
	0.56	23.8*[c]	1.3*	71.5*	52.4*	57.5*	0.9*	43.8*	55.5*	89.8
	1.12	38.8*	1.0*	64.1*	41.1*	77.5*	1.5*	21.2*	21.0*	81.7
Dicamba+2,4-d amine	0.59	23.8*	1.6	71.9*	64.6*	46.3*	0.9*	62.2*	39.2*	104.4
	1.18	38.8*	1.4*	78.3*	46.6*	61.3*	1.0*	61.9*	31.6*	98.6
	2.35	52.5*	1.0*	73.7*	49.5*	81.3*	0.4*	25.7*	13.2*	79.8
Dimethenamid-p	0.37	10.0	2.0	108.6	101.5	12.5	1.8	80.7	57.4	108.1
	0.74	10.5	1.7	102.9	97.2	9.5	1.8	92.0	93.1	101.9
	1.47	17.8*	2.1	102.1	92.5	27.5*	1.5*	70.0*	53.7	75.6
Fluroxypyr+bromoxynil	0.35	12.5*	2.0	83.9*	66.7*	47.5*	1.1*	54.8*	44.1*	85.2
	0.70	10.0*	1.9	76.9*	63.7*	62.5*	0.6*	38.3*	24.1*	77.8
	1.40	33.8*	1.3*	74.9*	48.9*	100.0*	0.0*	0.0*	0.0*	54.2*
Mesotrione	0.11	21.3*	1.8	88.7	63.9*	81.3*	0.5*	28.0*	8.4*	62.6*
	0.21	40.0*	1.4*	81.3*	50.4*	95.0*	0.1*	7.2*	1.4*	62.2*
	0.42	55.0*	1.4*	77.8*	48.2*	100.0*	0.0*	0.0*	0.0*	69.1*
Metsulfuron	0.04	1.3	1.5*	79.4*	70.8*	45.0*	1.0*	62.7	45.4*	98.3
	0.08	5.0*	1.8	81.4*	85.1	50.0*	1.5*	51.5*	34.6*	99.3
	0.17	15.0*	1.9	83.1*	88.8	65.0*	1.0*	33.5*	14.3*	78.7*
Thifensulfuron+tribenuron	0.02	6.3	1.8	96.3	109.5	26.3*	2.1	76.9	86.0	103.3
	0.03	7.5	1.6	90.9	86.3	11.3	1.4	75.5	77.3	88.6
	0.06	3.8	1.5*	100.2	103.5	10.0	1.5*	80.8	77.3	105.3

[a]Abbreviations: adw, aboveground dry weight; pi, plant injury; ph, plant height; rdw, root dry weight; sn, stem number.
[b]Data for plant injury, plant height, aboveground dry weight, and root dry weight are presented as a percent of the untreated control plants.
[c]Asterisks (*) indicate significant difference from the control group using Student's *t*-test ($P \leq 0.05$).

sulfentrazone use resulted in reduced root growth only when applied at the highest rate.

In these studies, herbicides that caused less than 10% reduction in aboveground biomass were considered to be acceptable for weed control in giant reed production, and those that caused more than 85% reduction were considered to provide near-total giant reed control. Therefore, when dimethenamid-p was applied to giant reed foliage at the standard rate, plant injury was considered to be acceptable for its use to control weeds in giant reed production fields. Atrazine and mesotrione also provided control of giant reed. When sprayed after cutting, two herbicides, acetochlor and dimethenamid-p, are proposed for use to control weeds in giant reed fields, and atrazine and flufenacet for removing giant reed. Weed control after cutting may be needed because giant reed is grown as a perennial crop.

This study was conducted in a greenhouse, which is very different from field conditions. The pots we used in the greenhouse trials limited the development of the root/rhizomes, which are important to the establishment and spread of giant reed. Furthermore, as indicated in a study conducted by Boose and Holt (1999), environmental condition and application timing could be important factors in giant reed control. Herbicides used in this study need to be reevaluated under field conditions. However, the results are a starting point for choosing the most likely candidates for further study. The herbicides used in this study are commonly used to control weeds among other crops in the area. In further field trails, other herbicides such as glyphosate, should be included for evaluation preplant or postharvest. Field studies conducted by Martin et. al. (2019) indicated that glyphosate applied after stem cutting resulted in less giant reed control compared with multiple

https://doi.org/10.1017/wet.2020.66 Published online by Cambridge University Press

Table 4. Plant response to cut plus spray application.

Name	Rate	pi[a,b]	sn	ph	adw	rdw
	kg ai ha^{-1}					
Control	0	0	2.1	100	100.0	100.0
2,4-D amine	0.13	58.7*[c]	2.5	36.2*	45.0*	71.3*
	0.26	60.0*	1.6	51.8*	53.6*	58.1*
	0.52	90.0*	1.0*	27.0*	9.3*	40.6*
Acetochlor	0.95	13.7	2.1	88.1	110.0	104.3
	1.91	30.0	2.0	90.9	86.8	102.1
	3.81	28.7	2.0	85.5	97.2	98.8
Acetochlor-atrazine	1.18	83.7*	1.3	17.9*	12.7*	57.1*
	2.36	92.5*	0.6*	9.0*	2.4*	55.6*
	4.70	83.7*	1.1	13.8*	3.6*	44.9*
Atrazine	1.12	85.0*	1.3	14.2*	2.6*	46.0*
	2.24	97.5*	0.3*	2.4*	0.5*	49.2*
	4.48	83.7*	0.9*	7.5*	1.7*	49.9*
Dimethenamid-p	0.37	17.5	2.1	90.2	102.2	94.7
	0.74	26.2	1.8	84.2*	107.0	101.1
	1.47	42.5*	2.1	103.7	106.2	96.7
Diuron	0.90	85.0*	1.1	26.2*	16.2*	46.1*
	1.79	81.2*	1.0*	19.7*	18.4*	48.3*
	3.59	100.0*	0.0*	0.0*	0.0*	38.2*
Flufenacet	0.19	68.7*	1.8	19.0*	26.5*	76.4*
	0.38	81.2*	0.6*	11.8*	15.5*	70.1*
	0.76	87.5*	1.1	10.4*	14.3*	64.5*
Flumioxazin	0.21	66.2*	2.1	32.1*	41.0*	74.9
	0.43	82.5*	1.0*	17.6*	21.3*	60.0*
	0.85	91.2*	0.8*	7.9*	13.4*	66.6
Metribuzin	0.42	63.7*	1.8	29.2*	33.3*	80.8
	0.84	76.2*	1.3	27.5*	24.9*	85.3
	1.68	92.5*	0.5*	7.3*	7.4*	81.9
Pendamethalin	1.68	58.7*	1.6	29.2*	80.0	76.3
	3.36	62.5*	1.6	36.9*	38.1*	83.0
	6.73	75.0*	1.4	22.3*	26.9*	84.0
Pyroxasulfone	0.05	72.5*	1.9	17.1*	18.1*	82.4
	0.10	81.2*	1.5	15.0*	20.6*	79.5
	0.20	100.0*	0.0*	0.0*	0.0*	58.8*
S-metolachlor	0.53	68.7*	1.6	22.2*	26.0*	73.1
	1.07	83.7*	1.3	12.9*	16.9*	69.7
	2.13	100.0*	0.0*	0.0*	0.0*	48.1*
Sulfentrazone	0.21	78.7*	1.8	46.9*	54.8*	55.4
	0.42	65.0*	1.9	47.5*	77.1*	55.1
	0.84	90.0*	0.9	30.8*	14.1*	16.2*

[a]Abbreviations: adw, aboveground dry weight; pi, plant injury; ph, plant height; rdw, root dry weight; sn, stem number.
[b]Data for plant injury, plant height, aboveground dry weight, and root dry weight are presented as a percent of the untreated control plants.
[c]Asterisks (*) indicate significant difference from the control group using Student's *t*-test ($P \leq 0.05$).

glyphosate applications. Further studies should also be conducted to investigate the optimum application timing and doses of these herbicides.

Acknowledgments. This research received no specific grant from any funding agency, commercial or not-for-profit sectors. No conflicts of interest have been declared.

References

Angelini LG, Ceccarini L, Nasso NND, Bonari E (2009) Comparison of *Arundo donax* L. and *Miscanthus* × *giganteus* in a long-term field experiment in Central Italy: Analysis of productive characteristics and energy balance. Biomass Bioenergy 33:635–643

Anonymous (2012) Riparian invasive research laboratory: giant reed. http://rivrlab.msi.ucsb.edu/invasive-species/giant-reed. Accessed: March 15, 2019

Bell GP (1997) Ecology and management of *Arundo donax*, and approaches to riparian habitat restoration in southern California. Pages 103–113 *in* Brock JH, Wade M, Pysek P, Green D, eds. Plant Invasions: Studies from North America and Europe. Leiden, The Netherlands: Blackhuys Publishers

Bhanwra RK (1988) Embryology in relation to systematics of Gramineae. Ann Bot 62: 215–233

Boose AB, Holt JS (1999) Environmental effects on asexual reproduction in *Arundo donax*. Weed Res 39:117–127

County Court of Morrow (2010) *Arundo donax* growing conditions 2010. Morrow County, OR: County Court of Morrow. P 1

Corno L, Lonati S, Riva C, Pilu R, Adani F (2016) Giant cane (*Arundo donax* L.) can substitute traditional energy crops in producing energy by anaerobic digestion, reducing surface area and costs: a full-scale approach. Bioresource Technol 218:826–832

Corno L, Pilu R, Adani F (2014) *Arundo donax* L.: a non-food crop for bioenergy and bio-compound production. Biotechnol Adv 32:1535–1549

Else JA (1996) Post-flood establishment of native woody species and an exotic, *Arundo donax*, in a southern California riparian system. M.S. Thesis. San Diego, CA: San Diego State University

Jackson NE (1993) Control of *Arundo donax*, techniques and pilot project. Pages 27–33 *in* Jackson NE, Randsen P, Douthit S, eds. *Arundo donax* Workshop. Ontario, CA, November 1993

Jackson NE, Katagi W, Loper C (2002) Southern California integrated watershed program arundo removal protocol. Santa Ana Watershed Project Authority http://www.sawpa.org.Arundo.protocol.htm. Accessed: February 20, 2019

Johnson M, Dudley T, Burns C (2006) Seed production in *Arundo donax*. Cal-IPC News. 14:12–13

Lewandowski I, Clifton-Brown JC, Scurlock JM, Huisman W (2000) Miscanthus: European experience with a novel energy crop. Biomass Bioenergy 19: 209–227

Lies M (2011) Capital press: PGE looks to giant cane for fuel. https://www.capitalpress.com/state/oregon/pge-looks-to-giant-cane-for-fuel/article_7995a952-a274-5433-adad-ee4878d718d0.html. Accessed: June 13, 2019

Martin CS, Gourlie JA, Barroso J (2019) Control of volunteer giant reed (*Arundo donax*). Invasive Plant Sci Manag 12:43–50

Morgan V, Sytsma M (2015) Early Detection and Rapid Response Plan for Giant Reed (*Arundo donax* L.) in Oregon. Project report prepared for PGE. 44 p https://olis.leg.state.or.us/liz/2017R1/Downloads/CommitteeMeetingDocument/111207. Accessed: June 13, 2019

Oakins AJ (2001) An assessment and management protocol for *Arundo donax* in the Salinas Valley Watershed. Capstone Project. B.S. thesis. Seaside, CA: California State University. Pp 7–8

[ODA] Oregon Department of Agriculture (2011) Plant Pest Risk Assessment for Giant Reed *Arundo donax* L. http://library.state.or.us/repository/2011/201105031342272/index.pdf. Accessed: June 13, 2019

Santín-Montanyá MI, Jiménez J, Ocaña L, Sánchez FJ (2013) Effects of sprout cutting plus systemic herbicide application on the initial growth of giant reed. J Environ Sci Health B 48:285–290

Seawright EK, Rister ME, Lacewell RD, Sturdivant AW, Goolsby JA, Mccorkle DA (2009). Biological control of giant reed (*Arundo donax*): economic aspects. Pages 5–8 *in* Proceedings of Southern Agricultural Economics Association Annual Meeting. Atlanta, GA: Southern Agricultural Economics Association

https://doi.org/10.1017/wet.2020.66 Published online by Cambridge University Press