J. Aquat. Plant Manage. 49: 111-113

NOTES

Giant reed (*Arundo donax* L.) response to glyphosate and imazapyr

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INTRODUCTION

Giant reed is an invasive plant of riparian ecosystems in many warm temperate and subtropical areas of the world (GISD 2007). In the United States, giant reed infestations occur in 25 states, those mostly below the 38th parallel (USDA 2009). In California, giant reed can infest all of the flood plain and is present in most of the coastal watersheds (Neill and Giessow 2001). Giant reed is listed as a noxious weed in California and Texas (CDFA 2009, Texas Department of Agriculture 2009).

Giant reed is not known to produce viable seed and spreads principally by rhizome movement, especially in flood events (Dudley 2000). Asexual reproduction and dispersal, however, has been successful in creating near monotypic stands of giant reed in many of the riparian ecosystems it has invaded (Bell 1997). The biological and physical effects of giant reed on invaded habitats include loss of wildlife habitat; decreased shading of streams, which in turn decreases reproductive potential for several aquatic fauna; loss of ground water from increased transpiration relative to native vegetation; changes in stream channel flows; increased debris flow during flood events; and increased wildfires (Bell 1997, Dudley 2000). In northern Mexico, giant reed invasion of the protected Cuatro Cienegas wetland is believed to have resulted in the extirpation of the Rio Salado darter (*Etheosoma segrex*), an endemic fish (Desert Fishes Council 2009).

Glyphosate (N-(phosphonomethy)glycine) has been widely used for giant reed control for nearly 2 decades (Jackson 1994, Bell 1997), while imazapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl) -5-oxo-1*H*-imidazol-2-yl]-3-pyridinecarboxylic acid) was first reported for giant reed control in 2005 (Neill 2006). The scientific literature, however, does not include reports of experiments that evaluate the effect of herbicide rate on control. Spencer et al. (2008) compared the response of giant reed to different glyphosate concentrations and found that the higher the concentration, the greater the control achieved, whereas trials with imazapyr have produced inconsistent results (Brenton 2003, Spencer et al. 2009). These experiments evaluated herbicide applications based on percent concentration, but the results did not provide information on rates. Applying herbicides based on concentration can lead to rather large and unintended differences in rate (Bell et al. 2008). Recent extension training on herbicide spray calibration has documented greater than 7-fold rate differences among individuals applying the same herbicide concentration (C.E. Bell, C.A. Wilen, and M.L. McGiffen, in preparation).

The objective of these experiments was to identify effective rates of 2 herbicides, glyphosate and imazapyr, applied alone and in combinations for control of giant reed in riparian habitats. Combinations of herbicide that lower the rate of each may provide control comparable to higher rates of either herbicide alone, reduce cost when one herbicide is more expensive, reduce soil residual compared to the full rate application, and help forestall herbicide resistance by attacking the weed with 2 or more herbicide modes of action.

MATERIALS AND METHODS

Giant reed control experiments were conducted on existing infestations within the floodplain of 3 rivers in southern California: along the San Gabriel River within the Whittier Narrows Dam (a flood control dam operated by the US Army Corps of Engineers) near the city of Montebello (hereafter Montebello); along the Santa Ana River within the Riverside County Hidden Valley Wildlife Area near Norco (hereafter Norco); and along the San Dieguito River within the San Dieguito River Park near Escondido (hereafter Escondido). All 3 experiments utilized a randomized complete block design with 4 replications. Blocks were used to minimize variation within a replication and to account for giant reed differences within the riverbed. Individual plot size varied between locations because of the nature of the existing giant reed populations. Herbicide treatments were applied at the Montebello location on 28 April 2006. Giant reed at this location had been pushed down with a bulldozer about 2 months prior and had regrown to a height of 2 to 3 m by the day of treatment. At this location, the giant reed infestation was in large but discrete populations, so individual treatment plots (2 by 5 m) were arranged side by side in blocks within a population. Weather on the day of treatment was 15 C, overcast with light winds of 0 to 3 kph. At the Norco location, herbicides were applied on 17 April 2008. Giant reed had been mowed

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about 6 weeks before and the plants had regrown to a height of 1.5 to 2 m on the day of treatment. The temperature was 24 C, the sky was clear, and the winds calm on the day of treatment. The giant reed infestation at Norco was also in large discrete populations, so individual treatment plots (2 by 6.5 m) were again arranged side by side within blocks within populations with no buffer between the plots. Giant reed was growing actively at the Montebello and Norco locations. The adjacent rivers were flowing freely from spring run-off, and we do not think that soil water was limiting when the herbicides were applied. Giant reed at the Escondido location was treated on 2 October 2008. The plants had not been mowed or otherwise disturbed. Leaves were slightly rolled and grayish, indicating some moisture stress because of the low river level and also because it had not rained since 15 April 2008. At Escondido, giant reed was present in discrete clumps of variable sizes along the riverbed, so clumps that were more than 2 m wide in two directions were used as individual plots. Plants were 2.5 to 4.5 m tall on the day of treatment, and the sky was clear, with light winds from 3 to 8 kph and a temperature of 30.5 C.

Herbicide rates were the same at all locations. These rates included the highest recommended label rate and half that rate for each herbicide applied alone (Imazapyr at 1.1 and 0.56 kg ae/ha, and glyphosate at 4.3 and 2.1 kg ae/ha, respectively). The combination treatments were additive mixtures of the half rate and one quarter rate of each herbicide. Non-ionic surfactant (NIS) at 0.25% v/v was added to all treatments at the Montebello and Norco locations. At the Escondido location, methylated seed oil surfactant[5] (MSO) at 1% v/v was used. Herbicide treatments were applied using a hand-held CO-pressured small-plot sprayer. At Montebello and Norco, herbicide treatments were applied over the top of the emerging shoots using a 2 m wide spray boom with 5 evenly spaced 8002vs flat fan nozzles. At the Escondido location, the giant reed plants were taller, and application was made by spraying up and down on the upper two-thirds of the plants from the side with a single 8004vs flat fan nozzle. The spray volume was 370 L/ha for the Montebello location, 470 L/ha at the Norco location, and 178 L/ha at Escondido.

Each experiment was visually evaluated for percent control where 0 equals no control or apparent injury and 100 equals dead plants. The Montebello experiment was visually evaluated at 2 and 13 months after treatment (MAT). The Norco location was evaluated at 3 and 12 MAT. Only the later evaluations are shown (Table 1). A single visual evaluation was made at the Escondido location at 6 MAT. We regard ratings of ≥85% as good and ≥95% as excellent.

These herbicides affect enzyme processes that influence growth, and ultimate perennial plant mortality typically does not occur the year of application (DiTomaso 2000). Therefore, quantitative data were taken after spring regrowth from rhizomes the calendar year following herbicide application when the plants were in the same phenolocical stage in all locations. To provide a buffer and avoid edge effects from adjacent plots, a 1 m^2 quadrat was established in the center of each plot in all 3 experiments for quantitative sampling. These samples included the number of living green shoots and the total fresh biomass of these shoots. These data were collected at the Montebello location on 17 May 2007 (13 MAT), at the Norco location on 23 June 2009 (14 MAT), and at the Escondido location on 17 June 2009 (9 MAT). Quantitative data were analyzed for differences between treatments using ANOVA (JMP 8.0, 2008). Because of a lack of homogeneity of variance between locations, data were not combined and are presented separately for each location. Where differences existed at the 5% confidence level, treatment means were compared using the Tukey-Kramer's Highly Significantly Difference test, also at the 5% confidence level.

Table 1. Visual evaluations of giant reed control following foliar applications of glyphosate and imazapyr, alone and in combination.

Treatment	Rate kg/ha	Montebello[a] 13 MAT[b]	Norco 12 MAT	Escondido 6 MAT
		Percent Control		
imazapyr	1.1	99	77	97
glyphosate	2.1	87	15	96
glyphosate	4.3	98	25	96
imazapyr + glyphosate	0.28 + 1.1	93	40	99
imazapyr + glyphosate	0.56 + 2.1	99	61	97
untreated control		0	0	0

[a]Montebello, San Gabriel River; Norco, Santa Ana River; Escondido, San Dieguito River.
[b]MAT = months after treatment; in spring the calendar year following application.
[c]Mean of 4 replications.

RESULTS AND DISCUSSION

Visual evaluations

At the Montebello and Norco locations there were no dead plants when visually evaluated the summer following herbicide application (2 and 3 MAT, respectively), but there were effects such as stunting and dead meristems indicating that the herbicides were having an effect on giant reed (data not shown). By the following year (13 MAT), however, all of the treatments at Montebello demonstrated good to excellent control compared to the untreated control (Table 1). The 12 MAT visual evaluations at Norco were relatively unchanged from those made at 3 MAT. Only the high rate of imazapyr (1.1 kg ae/ha) exhibited fair, but still unacceptable control (77%). All herbicide treatments resulted in excellent control at the Escondido location 6 MAT.

Quantitative data

All herbicide treatments at the Montebello and the Escondido locations reduced giant reed biomass and the number of green shoots compared to the untreated control (Table 2.). At Norco there were no differences between these treatments. The Escondido results are consistent with other sources that indicate that glyphosate and imazapyr are more effective when applied in fall as opposed to a spring application (Bell and Boutwell 1997, BASF 2004, Monsanto 2006).

The results at Montebello were very different than those at Norco, even though they were both applied in the spring under similar environmental conditions, possibly due to ade-

TABLE 2. GIANT REED NUMBER OF LIVING GREEN SHOOTS/M² AND BIOMASS (KG/M²).

		Number of Green Shoots			Biomass		
		Monte[a]	Norco	Escon	Monte	Norco	Escon
		Months After Treatment					
Treatment	Rate kg/ha	13	14	9	13	14	9
imazapyr	0.56	4.25 b[b]	16.33	1.0 b	0.45 b	5.36	0.23 b
imazapyr	1.1	4.00 b	14.00	1.0 b	0.83 b	4.60	0.28 b
glyphosate	2.1	6.00 b	14.00	11.0 b	1.75 b	6.60	1.08 b
glyphosate	4.3	0.75 b	12.00	16.0 b	0.16 b	3.63	0.78 b
imazapyr + glyphosate	0.28 + 1.1	4.25 b	7.00	0.0 b	1.06 b	3.30	0.00 b
imazapyr + glyphosate	0.56 + 2.1	5.75 b	10.25	7.25 b	0.41 b	3.63	0.60 b
untreated control		33.25 a	18.67	50.0 a	17.38 a	7.93	6.58 a

[a]Monte = Montebello, San Gabriel River; Norco, Santa Ana River; Escon = Escondido, San Dieguito River.
[b]Means in a column followed by the same letter are not different according to Tukey-Kramer's Highly Significant Difference Test (P = 0.05).

quate herbicide translocation within the plant. Both of these herbicides translocate in plants in phloem tissue and are not effective on perennial plants unless they reach the root system (DiTomaso 2000, BASF 2004, Monsanto 2006). Basipetal translocation does not occur until leaves reach full development (DiTomaso 2000). Stem growth when herbicides were applied at Montebello was about 30% higher than at Norco, which was probably sufficient for a shift from acropetal to basipetal phloem transport. This deduction, however, should be verified by further study before accurate recommendations can be made on when and how to use these herbicides in the spring for effective giant reed control.

While both imazapyr and glyphosate treatments worked well when applied alone, the combination treatments documented 2 of the 4 benefits discussed in the introduction, including (1) lowering overall cost when one of the herbicides, imazapyr in this case, is more expensive than the other, and (2) a shorter soil residual interval for imazapyr, which has been suspected of causing injury to native vegetation planted after treatment of giant reed (J. Giessow, pers. comm.). There were no differences in the level of control among these herbicide treatments at Montebello and Escondido, so land managers should be encouraged to use the lower rates.

ACKNOWLEDGEMENTS

I greatly appreciate the assistance of Nelroy Jackson, Gary Tanazaki, Ron Baxter, Ernie Klemm, Bill Neill, and Paul Webb in establishing and completing this research. Partial financial support for this research was provided by BASF Corporation.

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