Weed Technology 2013 27:725–728

Poison Ivy (*Toxicodendron radican*) Control with Triclopyr and Metsulfuron, Applied Alone and in Tank Mixture

Glenn Wehtje, Charles H. Gilliam, and J. Scott McElroy*

Dermatitis from poison ivy is an important health problem, and considerable effort is devoted to the control of this virulent weed. Triclopyr, metsulfuron, and two fixed-ratio tank mixtures of triclopyr and metsulfuron were evaluated across a series of rates for poison ivy control. The objective was to test whether tank mixtures are more effective than triclopyr alone. Triclopyr, metsulfuron, and 9 : 1 and 8 : 2 (by weight) mixtures of these two herbicides, respectively, were applied at eight rates to 1-yr old, pot-grown poison ivy plants. Rates ranged in phytotoxicity from none to death. Percentage of control as determined from plant fresh weight reduction relative to a nontreated control was determined at 1 and 4 mo after treatment (MAT). Data were subjected to ANOVA followed by nonlinear regression. Rates required for 95% control at 1 MAT, control of regrowth at 4 MAT, and the costs of these treatments were determined for the herbicides applied alone and the mixtures. Triclopyr alone and metsulfuron alone were consistently the least and the most expensive treatments, respectively. The mixtures were intermediate to these extremes.

Nomenclature: Metsulfuron, triclopyr; poison ivy, *Toxicodendron radican* (L.) Kuntze.
Key words: Herbicide interactions, nonlinear regression, virulent weeds, weed control.

La dermatitis causada por *Toxicodendron radican* es un problema de salud importante, por lo que se dedican esfuerzos considerables para el control de esta virulenta maleza. Se evaluó triclopyr, metsulfuron, y dos mezclas en tanque en proporciones fijas de triclopyr y metsulfuron a lo largo de una serie de dosis para el control de *T. radican*. El objetivo fue probar si mezclas en tanque son más efectivas que triclopyr solo. Triclopyr, metsulfuron, y mezclas 9:1 y 8:2 (por peso) de estos dos herbicidas, respectivamente, fueron aplicados a ocho dosis, a plantas de *T. radican* de un año de dad, crecidas en macetas. La fitotoxicidad causada por las dosis varió de ninguna a muerte. El porcentaje de control, determinado a partir de la reducción en el peso fresco en relación al testigo sin tratar, fue determinado a 1 y 4 meses después del tratamiento (MAT). Los datos se analizaron con ANOVA y con regresiones no-lineales. Las dosis requeridas para controlar 95% a 1 MAT, control de rebrote a 4 MAT, y el costo de estos tratamientos fue determinado para los herbicidas aplicados solos y en mezcla. Triclopyr y metsulfuron solos fueron consistentemente los tratamientos menos y más costoso, respectivamente. Las mezclas fueron intermedias en relación a estos extremos.

Poison ivy is a high-climbing woody vine native to North America and prevalent in nearly all forested areas of the eastern United States and southeastern Canada (Miller and Miller 1999). It is also problematic in the landscape and forested sites in urban areas. Poison ivy produces clusters of flowers; the mature fruits are eaten, and the seeds spread, by birds (Miller and Miller 1999). Poison ivy sap contains urushiol, a yellowish, slightly volatile, oily allergen (Epstein and Byers 1981; Mitich 1995). Crushing or bruising of the foliage releases the sap, and when this sap contacts skin, it can result in skin dermatitis—that is, a blistering and painful rash. It is estimated that about 50% of the population is sensitive, and about 15% is extremely sensitive to poison ivy–based dermatitis. In this latter category, the amount of urushiol within a single poison ivy leaf is often sufficient to produce dermatitis (Epstein and Byers 1981). About two million cases of poison ivy–induced dermatitis occur annually in the United States. The leading cause of field injuries and workers' compensation claims among U.S. Forest Service personnel is dermatitis from poison ivy and similar virulent weeds such as poison oak (*Toxicodendron pubescens* P. Mill) and poison sumac [*Toxicodendron vernix* (L.) Kuntze] (Mitich 1995).

DOI: 10.1614/WT-D-13-00034.1

* Professor of Agronomy and Soils, Professor of Horticulture, and Associate Professor of Agronomy and Soils, respectively, Auburn University, Auburn, AL 36849. Corresponding author's E-mail:wehtjgr@auburn.edu

A survey of extension publications from across the United States revealed that, depending upon the situation, the following herbicides are recommended for poison ivy control: 2,4-D, mecoprop, dicamba, triclopyr, picloram, sulfometuron, and glyphosate, with glyphosate being the most commonly recommended. Very little research has been conducted on poison ivy control even though poison ivy–based dermatitis is a significant health problem. Yonce and Skroch (1989) evaluated glyphosate at 1.1 and 2.2 kg ha^{-1} (ae or ai not specified), applied at three different dates during the growing season for the control of native poison ivy stands at two locations in North Carolina. A single application of glyphosate at 2.2 kg ha^{-1}, applied at any time between mid-June and mid-August, controlled poison ivy approximately 87%. In previous research by Wehtje and Gilliam (2012) it was reported that both 2,4-D and triclopyr were more cost effective than either glyphosate alone or glyphosate tank-mixed with either 2,4-D or triclopyr.

There is no consensus among researchers as to the best method to evaluate herbicide mixtures. An excellent review of this topic has been published by Streibig and Jensen (2000). These authors suggested that an effective and logical method is to evaluate the mixture and the components of the mixture over a series of rates that progress from no phytotoxicity or marginal phytotoxicity to death. The mixture is held to a predetermined and constant ratio of the components.

https://doi.org/10.1614/WT-D-13-00034.1 Published online by Cambridge University Press

Through linear regression, nonlinear regression, or both an equally effective rate (e.g., the rate required for 95% control) for each herbicide and herbicide mixture can be then determined and its cost calculated. This approach was used in previous research focusing on 2,4-D, triclopyr (amine formulation), glyphosate, and mixtures thereof (Wehtje and Gilliam 2012). The same approach was chosen to evaluate and compare triclopyr and metsulfuron, and mixtures of these two components.

Weed control practitioners in central Alabama frequently recommend triclopyr, specifically the butoxyethyl ester formulation, for poison ivy control (James H. Miller, personal communication). In addition it is also commonly believed that tank-mixing this formulation of triclopyr with small amounts (i.e., $\leq$ 25% of the total herbicide amount) of metsulfuron is more effective than triclopyr alone. Poison ivy is not identified as a species controlled on the metsulfuron product label. Research evaluating metsulfuron alone and triclopyr plus metsulfuron tank mixtures for poison ivy control has not been published. The objective of this research was to evaluate and compare the cost efficacy of triclopyr, metsulfuron, and tank mixtures, and testing the hypothesis that mixtures are more cost effective than triclopyr applied alone.

Materials and Methods

Test Plant Production. Poison ivy was propagated and grown in a manner comparable to that used to commercially propagate container-grown landscape plants. Plants were propagated a year prior to the growing season in which the experiment was conducted. Poison ivy vines were collected from forested sites near the campus of Auburn University in late June through early July. Cuttings with aerial rootlets and two to four leaves were prepared from these vines. Cuttings were placed in 10-cm square plastic pots, filled with a 6 : 1 (v/v) pine bark–sand substrate. This substrate had been amended with a controlled-release granular fertilizer (Polyon® 17–6–12K, available from Harrell's Fertilizer, Inc., 203 West 4th St., Sylacauga, AL 35105), dolomitic limestone, and a micronutrient fertilizer (Micromax®, O. M. Scott Corp., 14111 Scotts Lawn Road, Marysville, OH 43401) at 8.3, 3.0, and 0.9 kg m^{-3}, respectively. Cuttings were maintained in a mist propagation bed for 8 wk. Cuttings with new growth were planted in 2.5-L plastic pots using soil (surface horizon, Pacolet sandy clay loam; 55% sand, 20% silt, and 18% clay) supplemented with composted hardwood sawdust at approximately 20% v/v. Plants were maintained in an outdoor area with natural shade. Plants were irrigated approximately 0.6 cm three times a week. Plants went dormant in the fall and were covered with polyethylene film during periods of extreme cold during the following winter. Plants resumed growth the following spring. Through this procedure a population of actively growing and established plants was obtained.

Experimental Procedures. Four herbicides or herbicide mixtures were included: 1) triclopyr (Remedy ® Ultra, 479 g ae L^{-1} butoxyethyl ester of triclopyr, Dow AgroSciences LLC, 9330 Zionsville Rd., Indianapolis, IN 46268) alone, 2) metsulfuron (Escort® XP, 0.6 kg ai kg^{-1} metsulfuron methyl, E. I. du Pont de Nemours and Co., 1007 Market St., Wilmington, DE 19898) alone, 3) a 9 : 1 (by weight) mixture of triclopyr plus metsulfuron, and 4) an 8 : 2 mixture of the same components. Weight of triclopyr was in acid equivalents, weight of metsulfuron was in active ingredient. Metsulfuron was applied at eight rates, ranging from 0.0027 to 0.07 kg ha^{-1}. Triclopyr and the two mixtures were also applied at eight rates, but ranging from 0.0040 to 0.22 kg ha^{-1}. A nontreated control was also included, resulting in a 33-treatment experiment. All herbicide-containing treatments included a nonionic adjuvant (Agri-Dex®, Helena Chemical Company, 225 Schilling Blvd., Suite 300, Collierville, TN 38017) at 0.25% v/v.

Treatments were applied during the first week of June using an enclosed-cabinet sprayer, calibrated to deliver 280 L ha^{-1} at 193 kPa. Plants were returned to the outdoor growing area immediately following treatment. Treated plants were not irrigated and were protected from rainfall for 72 h after treatment application. Treatments were applied to four single-pot replicates. A completely randomized design was used. Two identical experiments were conducted: one each in 2011 and 2012. Average maximum/minimum temperature for the 5 mo period during which the experiments were conducted (June through October) were 34.4/21.8, 33.0/23.2, 34.6/23.1 28.7/18.3, and 23.6/11.1 C, respectively for June through October, in 2011; and 30.9/19.9, 33.9/22.7, 31.3/21.8, 29.7/19.0, and 24.4/12.7 C, respectively, in 2012. Average monthly day length was 14.2, 14.3, 13.5 12.5, and 11.3 h, respectively, for June through October.

Data Collection and Statistical Aspects. At 1 mo after treatment (MAT), plants were clipped at approximately 5 cm above the soil line and the fresh weight of any remaining nondesiccated foliage determined. Plants were then allowed to regrow for the remainder of the growing season. At 4 MAT (or 3 mo after clipping [MAC]) plants were again clipped and the fresh weight of any regrowth determined. The second evaluation occurred during the second week of October and therefore immediately prior to the first expected frost. Treated-plant weights were expressed as a percentage of the nontreated control; subtracting this value from 100 resulted in a percent-control value. Thus a treatment that had foliage weight equal to the nontreated control at both 1 MAT and 4 MAT had 0% control at both 1 and 4 MAT. Conversely, a treatment that resulted in complete foliage desiccation and prevented any regrowth had 100% control at both 1 and 4 MAT.

Data were first subjected to ANOVA using the PROC MIXED procedure in SAS® (Release 8.3, SAS Institute, Inc., Box 8000, SAS Circle, Cary, NC 27513). Years were treated as a random effect. No treatment-by-year interactions were detected ($P > 0.05$); consequently, data were pooled for further analysis. Specifically, data for each herbicide and herbicide mixture were subjected to nonlinear regression and fitted to the following four-parameter, log-logistic model, which has been previously described (Seefeldt et al. 1995; Wehtje, et al. 2010a,b; and Wehtje and Gilliam 2012), using Prism® software (GraphPad Software, Inc., 2236 Avenida de

https://doi.org/10.1614/WT-D-13-00034.1 Published online by Cambridge University Press

la Playa, La Jolla, CA 92037):

$$\text{Control} = C + (D - C/1 + [x/I_{50}]^b)$$

where C and D are the lower and upper limits of the response, respectively, I_{50} is the rate resulting in 50% control, and b is a unitless value that indicates the slope near the I_{50} value. The selected rates of the two herbicides and the two mixtures were sufficiently low and high so as to result in zero and complete control, respectively (data not shown). Consequently, the lower and upper limits were constrained to 0 and 100, respectively. This allows for more accurate estimations of the I_{50} and the slope (Motulsky and Christopoulos 2004). Individual rate response curves were compared using the goodness of fit procedure as described by Seefeldt et al. (1995). Through this procedure it is possible to determine if two rate response curves are equivalent or not, and if not equivalent, which of the two calculated parameters (i.e., I_{50} and slope) are different.

The rates necessary to provide 95% control (i.e., the LD_{95} value) were calculated for the two herbicides and the two mixtures using the log-logistic model and the parameter estimates as generated by Prism. Prism was also used for graphic data presentation. Cost per acre for the estimated LD_{95} rates for triclopyr, metsulfuron, and the two mixtures were also determined. Herbicide costs were based upon an Internet search for suppliers from which individual 3.8-L containers of triclopyr, or 0.45-kg containers of metsulfuron could be purchased.

Results and Discussion

Poison ivy control at both evaluations, and with both herbicides and the two mixtures, were described by the four-parameter, log-logistic model. Values for r^2 were at least 0.71 for control at 1 MAT, and 0.63 for control at 4 MAT (Table 1; Figure 1). The I_{50} value for metsulfuron alone was 0.0065 kg ha^{-1} at the 1 MAT evaluation, which was significantly

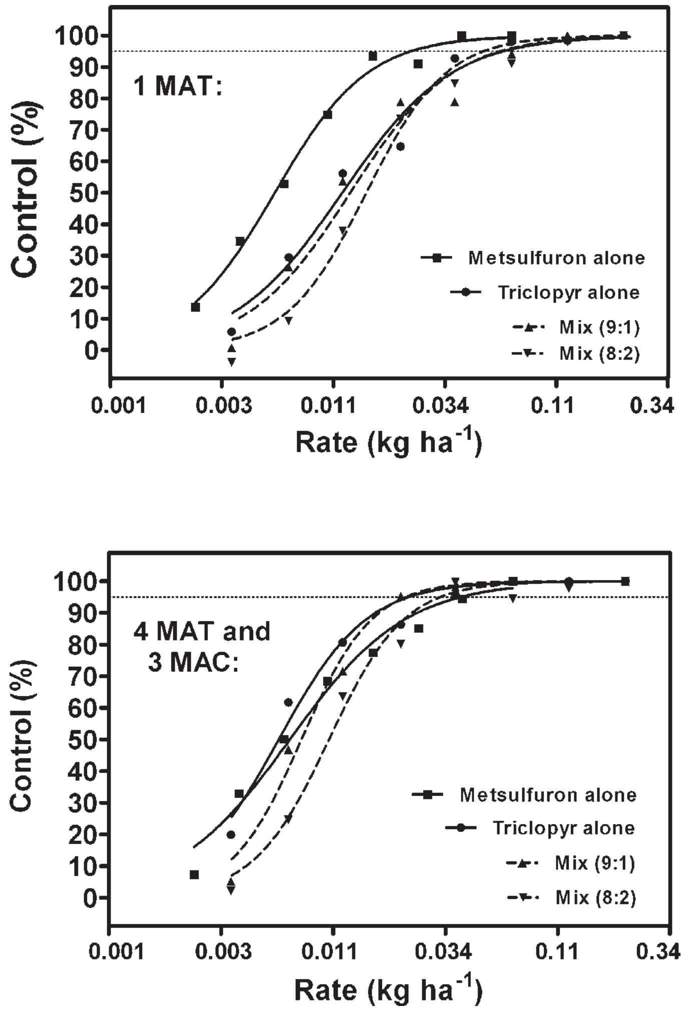

Figure 1. Response of poison ivy to metsulfuron, triclopyr, a 9 : 1, and a 8 : 2 mixture of the two herbicides, respectively. Top control 1 mo after treatment (mAT) and bottom is control at 4 MAT, which is also 3 mo after the clipping (MAC) performed for the first evaluation.

Table 1. Regression parameters from log-logistic analysis, and estimated rates and associated cost for 95% poison ivy control with triclopyr, metsulfuron, and two fixed-ratio mixtures. Data pooled over two repetitions of the experiments conducted in 2011 and 2012.

		Parameter estimates[b]		LD_{95}	
Herbicide or herbicide mixture[a]	Coefficient of determination	LD_{50}	Slope near LD_{50}	Rate	Cost of rate[c]
	r^2	kg ha^{-1}		kg ha^{-1}	\$ ha^{-1}
Control, 1 MAT[d]					
Metsulfuron	0.72	0.0065 a	2.09 a	0.0258	6.09
Triclopyr	0.71	0.0124 b	1.83 a	0.0627	3.26
Tri. + met. (9 : 1)	0.74	0.0123 b	1.99 a	0.0526	3.70
Tri.+ met. (8 : 2)	0.79	0.0158 b	2.51 b	0.0504	4.50
Control, 4 MAT, and 3 mo after clipping					
Metsulfuron	0.63	0.0073 a	1.69 a	0.0403	9.51
Triclopyr	0.83	0.0064 a	2.22 a	0.0235	1.22
Tri + met. (9 : 1)	0.83	0.0081 a	2.76 a	0.0291	2.05
Tri.+ met. (8 : 2)	0.85	0.0108 a	2.58 a	0.0336	2.98

[a] Butoxyethyl ester of triclopyr. Mixtures were prepared by author and based upon acid equivalent weight of triclopyr and active ingredient weight of metsulfuron.

[b] The four-parameter, log-logistic model was used. Maximum and minimum parameters were constrained to 100 and 0, respectively, because the rate extremes for all herbicides and herbicide mixtures resulted in 100 and 0% control. Parameter estimates followed by the same letter are equivalent according to the goodness of fit test as described by Seefeldt et al. (1995).

[c] Cost based upon \$236 kg^{-1} ai for metsulfuron, and \$52 kg^{-1} ae for triclopyr.

[d] Abbreviation: MAT, months after treatment; tri., triclopyr; met, metsulfuron.

https://doi.org/10.1614/WT-D-13-00034.1 Published online by Cambridge University Press

lower than either triclopyr alone or the two mixtures (Table 1). The I_{50} values for triclopyr alone, the 9 : 1mixture, and the 8 : 2 mixture were 0.0124, 0.0123, and 0.0158 kg ha^{-1}, respectively; and these values were statistically equivalent. The lower I_{50} value indicates that metsulfuron is more phytotoxic than triclopyr alone and the two mixtures. The slope value for the 8 : 2 mixture was 2.51, which was significantly higher than the slope values of triclopyr alone (1.83), metsulfuron alone (2.09), and the 9 : 1 mixture (1.99). A higher slope value indicates that the transition between no control and acceptable control occurred over a more limited range of rates with the 8 : 2 mixture than with triclopyr alone, metsulfuron alone, and the 9 : 1 mixture. Rate response curves for the two herbicides and the two mixtures were equivalent at the 4-MAT or the 3-MAC evaluation (Table 1; Figure 1 bottom). Therefore, triclopyr alone, metsulfuron alone, and the two mixtures were equally effective in controlling poison ivy regrowth.

With respect to the cost required for 95% control, triclopyr alone and metsulfuron alone were consistently the least expensive and most expensive treatments, respectively (Table 1). The rate of metsulfuron required for 95% control was almost twofold and eighfold more expensive than the equally effective rate of triclopyr at the 1- and 4-MAT evaluations, respectively. We reported in a previous study that the triethylamine formulation of triclopyr applied alone was more cost effective than 2,4-D (dimethyl amine salt), glyphosate (isopropylamine salt), and glyphosate tank-mixed with either triclopyr or 2,4-D (Wehtje and Gilliam 2012). The cost efficacy of the 9 : 1 and the 8 : 2 mixtures were consistently intermediate to that of the components applied alone. Averaged across the two evaluations, achieving 95% control cost 28 and 65% more with the 9 : 1 and the 8 : 2 mixtures, respectively, relative to triclopyr alone. Since the mixtures were more expensive than triclopyr alone, it can be concluded that the hypothesis that triclopyr plus metsulfuron mixtures may be more cost effective than triclopyr alone is false. Although the mixtures were less cost effective than triclopyr alone, they do offer an indirect benefit of challenging the target weed with two different modes of action. Triclopyr is a synthetic auxin-type herbicide, whereas metsulfuron inhibits the enzyme acetolactate synthase (Senseman 2007). Avoidance of treatments with a single mode of action is considered to be effective in preventing the emergence of herbicide-resistant biotypes (Gressel and Segal 1982).

Literature Cited

Epstein, W. L. and V. S. Byers. 1981. Poison oak and poison ivy dermatitis: prevention and treatment in Forest Service work. Missoula, MT: U.S. Forest Service, Equipment Development Center. 13 p.

Gressel, L. and L. A. Segal. 1982. Interrelating factors controlling the rate of appearance of resistance: the outlook for the future. Pages 325–347 *in* H. M. LeBaron and J. Gressel, eds. Herbicide Resistance in Plants. New York: J. Wiley.

Miller, J. H. and K. V. Miller. 1999. Forest Plants of the Southeast and Their Wildlife Uses. Champaign, IL: Southern Weed Science Society. 452 p.

Mitich, L. W. 1995. Poison-ivy/poison-oak/poison-sumac—the virulent weeds. Weed Technol. 9:653–656.

Motulsky, H. and A. Christopoulos. 2004. Fitting models to biological data using nonlinear regression. New York: Oxford University Press. 351 p.

Seefeldt, S. S., J. E. Jensen, and E. P. Fuerst. 1995. Log-logistic analysis of herbicide dose-response relationships. Weed Technol. 9:218–227.

Senseman, S. A., ed. 2007. Herbicide Handbook. 9th ed. Lawrence, KS: Weed Science Society of America. Pp. 94–95, 359–361.

Streibig, J. C. and J. E. Jensen. 2000. Actions of herbicides in mixtures. Pages 153–180 *in* A. H. Cobb and R. C. Kirkwood, eds. Herbicides and their Mechanisms of Action. Boca Raton, FL: CRC.

Wehtje, G., and C. H. Gilliam. 2012. Cost effectiveness of glyphosate, 2,4-D and triclopyr, alone and in select mixtures for poison ivy control. Weed Technol. 26:469–473.

Wehtje, G., C. H. Gilliam, and S. C. Marble. 2010a. Interaction of prodiamine and flumioxazin for nursery weed control. Weed Technol. 24:504–509.

Wehtje, G., C. H. Gilliam, and S. C. Marble. 2010b. Postemergence weed control with glyphosate plus flumioxazin combinations. Weed Technol. 24:356–360.

Yonce, M. H. and W. A. Skroch. 1989. Control of selected perennial weeds with glyphosate. Weed Sci. 37:360–364.

Received February 22, 2013, and approved June 20, 2013.

https://doi.org/10.1614/WT-D-13-00034.1 Published online by Cambridge University Press