Surfactants Increase Toxicity of Glyphosate and 2,4-D to Brazil Pusley

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Additional index words. surfactants, herbicides, *Richardia brasiliensis*

Abstract. Various combinations of glyphosate and 2,4-D ($\pm$ surfactant) were evaluated for control of Brazil pusley [*Richardia brasiliensis* (Moq.) Gomez]. Typical 2,4-D symptoms on plants were manifested within 2 to 3 days after treatment. Application of glyphosate alone had only marginal effects (14%) on Brazil pusley, but the addition of Induce[®] (nonionic surfactant) significantly increased control to 83% and reduced the fresh weight by 68%. Application of Landmaster[®] II or a tank-mix of glyphosate + 2,4-D ($\pm$ surfactants) resulted in 96% to 100% control. Treatment with 2,4-D alone, or with Induce[®], or L-77[®] (organosilicone surfactant) resulted in 84%, 90%, or 100% control, respectively. Very low fresh weights of Brazil pusley were recorded when 2,4-D + Induce[®] or L-77[®], Landmaster[®] II ($\pm$ surfactants), or the tank-mix ($\pm$ surfactants) were applied. In the regrowth studies, shoot weight was greater following application of glyphosate with or without L-77[®] or Kinetic[®] (a blend of nonionic and organosilicone) than following other treatments. The fresh weight of the shoots in the regrowth study, recorded following the application of 2,4-D or Landmaster[®] II ($\pm$ surfactants), was very low except when Kinetic[®] was added to Landmaster[®] II. No regrowth of shoots occurred following the tank-mix treatment. Similar observations were recorded for roots. Plants treated with 2,4-D did not regrow. The presence of 2,4-D in either formulation accelerated synergistic effect of the glyphosate to the target site. Therefore, 2,4-D could be used either as a component of a formulation or in a tank-mix with glyphosate to control Brazil pusley. Chemical names used: N-(phosphonomethyl glycine) (glyphosate); 2,4-dichlorophenoxyacetic acid (2,4-D).

Brazil pusley, a close relative of Florida pusley (*Richardia scabra* L.), is a perennial with hairy, branched stems that emanate from thick, woody roots. It can reproduce either by seed or asexually (root suckers). This weed is present year-round in Florida and can be found in lawns, roadsides, and disturbed areas. It is native to South America and has been introduced from Texas to Virginia along the coastal plain, as well as in Mexico, South Africa, Indonesia, and Hawaii (Colvin et al., 1996). In a study conducted by Johnson and Mullinix (1997) on weed population dynamics, Florida pusley was determined to be the most prevalent weed species in Georgia, with densities >300 plants/m². Recently, Chandran and Singh (2001) conducted surveys for Brazil and Florida pusley populations in citrus-growing counties of Florida and found that Brazil pusley was dominant.

The use of chemicals for weed control is prevalent in the Florida citrus industry because mechanical control can damage the

shallow root systems of the trees (Tucker et al., 1979). The current approach relies on residual preemergence (PRE) herbicides, usually applied twice a year during February to April and September to November. However, post-emergence (POST) applications are becoming more popular (Singh et al., 1990) to control heavy infestations of weeds in citrus groves. Glyphosate is a broad spectrum, nonselective, systemic POST herbicide. Its activity is affected by environmental factors such as light, temperature, humidity, and soil moisture (Caseley and Coupland, 1985). Glyphosate is used extensively for the control of several annual and perennial grasses (Frenz, 1985) and is important for successful weed control programs in citrus.

Weed control in Florida citrus is difficult to achieve, as light and sandy soils, high radiant energy, and high precipitation require higher than normal herbicide rates for normal weed control. This higher requirement may reflect losses from leaching and volatilization. Crane et al. (1998) reported that tank-mixes of PRE and POST herbicides provided the best control of a wide spectrum of weeds.

The widely used POST broadleaf herbicide, 2,4-D, has been registered in the United States since 1945, and is highly valued for minor crop production, although the majority of its uses are on corn (*Zea mays* L.), turf, and grain crops. The National Agricultural Pesticide Impact Assessment Program (1996) estimated that 2,4-D is used on nearly 12% of the area devoted to orchards, vineyards, and

soft fruits in the United States and Puerto Rico.

Surfactants are used to enhance the performance of foliar-applied chemicals, but their effects on foliar uptake are not well understood. Several workers (Currier and Dybing, 1959; Temple and Hilton, 1963) reported that surfactants may affect spray retention and penetration and may act as humectants (Kirkwood, 1991; Sharma et al., 1989, 1993, 1996; Stevens and Bukovac, 1987) and cosolvents (Wyrill and Burnside, 1977). Stevens et al. (1991) also reported that an organosilicone surfactant may improve absorption of the active ingredient.

Glyphosate alone has only marginal effects on Brazil pusley control in field and greenhouse studies. The present investigation was conducted to determine the effect of various combinations of glyphosate and 2,4-D on this species. The investigation was focused on reducing the dosage while improving efficacy by the addition of surfactant.

Materials and Methods

Plant material. Actively growing Brazil pusley plants (10 to 15 cm tall) were removed with roots attached from citrus groves near the Univ. of Florida's Citrus Research and Education Center, Lake Alfred, and transplanted into 1-qt (0.95-L) plastic pots filled with Candler sand (indocile, hyperthermia, unbolted, Typic Quartzipsamments), a typical soil of the ridge area of central Florida. The sand, collected from a citrus grove near Davenport, Fla., consisted of sand (96.7%), silt (0.8%), clay (2.5%), and organic matter (0.65% to 1.3%), and had a pH of 7.0. Plants were allowed to recover from transplanting shock for 2 weeks in a greenhouse maintained at 25 °C day/16 °C night (± 0.5 °C) and 70% (± 5 %) relative humidity and fertilized with a 20N–20P–20K fertilizer at the end of the second week. Herbicide treatments were applied 3 weeks after transplanting (WAT).

Treatments

Expt. 1. The herbicides used (all rates as active ingredient, a.i.) in this study together with their formulations were: 1) glyphosate as Roundup[®] ULTRA formulation (0.77 kg·ha⁻¹) (Monsanto Chemical Co., St. Louis); 2) 2,4-D as Weedar[®] formulation (0.68 kg·ha⁻¹) [2,4-D dimethylamine salt (456 g·L⁻¹); Rhône-Poulenc Chemical Co., Williamston, N.C.]; 3) Landmaster[®] II (0.96 kg·ha⁻¹), a formulated product containing isopropylamine salts of glyphosate (13.3%), 2,4-D (11.1%), and inert ingredients (75.6%) (Monsanto Chemical Co.); and 4) glyphosate (0.77 kg·ha⁻¹) + 2,4-D (0.68 kg·ha⁻¹) tank-mixed. These herbicides were applied alone and with the adjuvants: 1) Induce[®] (0.25% v/v), a superior nonionic, low foam surfactant (Helena Chemical Co., Memphis, Tenn.); 2) Silwet L-77[®] (0.1% v/v) an organosilicone (Loveland Industries, Greeley, Colo.); and 3) Kinetic[®] (0.25%), a blend of polyalkyleneoxide modified polydimethylsiloxane and nonionic surfactants 99% (Helena Chemical Co.).

Received for publication 7 Feb. 2000. Accepted for publication 17 Oct. 2000. Florida Agricultural Experiment Station Journal Series No. R-07314. We thank Gary Test and Kathryn Thornhill for extending their valuable help and cooperation in conducting various studies. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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The test plants (one per pot and four per treatment) were sprayed with treatment solutions, using a Chamber Track Sprayer (Allen Machine Works, Midland, Mich.) fitted with flat fan nozzles (Teejet 8002 Flat fan spray nozzles; Spraying Systems Co., Wheaton, Ill.), which delivered 230 L·ha⁻¹ at 138 kPa, using distilled water as a carrier volume. The treated plants were transferred to the greenhouse. All plants were regularly watered overhead to maintain optimum moisture.

Observations of herbicide effects were recorded weekly for 5 weeks. Visual control ratings were made on a scale of 0% to 100%, with 0 indicating an actively growing plant and 100 indicating complete damage of the shoot portion (Frans et al., 1986). At 5 WAT, plants were harvested at soil level and the fresh weights recorded. The roots (still in pots with soil) were watered and allowed to re-sprout for an additional 6 weeks after harvest. The re-sprouted plants were then harvested at the soil level and weighed. Subsequently, the soil was separated from the roots, which were later classified as alive or dead, and the fresh weight of live tissues with active buds was recorded and the dead roots discarded.

Expt. 2. In Expt. 1, Landmaster®II or tank-mix treatments killed all plants without incorporating adjuvants. Therefore, determination of the effects of surfactants on either herbicide (Landmaster®II or the tank-mix) treatment was not possible. The purpose of the second study was to investigate whether the addition of surfactant would result in treatment differences when reduced rates of the herbicides were used. The rates were 0.48 kg·ha⁻¹ of Landmaster®II, 0.51 kg·ha⁻¹ of 2,4-D, or a tank-mix of 0.34 kg·ha⁻¹ of 2,4-D + 0.56 kg·ha⁻¹ of glyphosate. The rates of glyphosate alone and of surfactants were the same as in Expt. 1, because glyphosate alone had only marginal effects in the experiment. The observations were recorded as in Expt. 1.

Expt. 3. The second study indicated that even lower rates of 2,4-D significantly controlled Brazil pusley, and that 2,4-D may have been the most efficacious component of two formulations. Therefore, this study was designed to examine the effects of 2,4-D at several rates (0.17, 0.34, 0.51 kg·ha⁻¹) alone

and tank-mixed with glyphosate. The tank-mix formulations were prepared as glyphosate (0.38 or 0.56 kg·ha⁻¹) + 2,4-D (0.10 or 0.17 kg·ha⁻¹). Visual ratings of 4 WAT are presented.

Statistics. Each experiment was performed twice and was arranged as a randomized complete-block design with four single plant replications in each treatments. The data for the two replications were combined after performing a test of homogeneity of variance, and were transformed to arc-sine values and subjected to analysis of variance (ANOVA), but are presented in the original form for clarity. The means were separated using Fisher's protected least significant difference test (LSD at $P = 0.05$).

Results and Discussion

Expt. 1. Symptoms were observed within 2 to 3 d on plants treated with 2,4-D, regardless of formulation, and ranged from 10% to 15%; twisting and curling of the leaves, petioles and stems, were typical of injury by herbicides belonging to the phenoxyacetic acid family. Injury was more pronounced with 2,4-D than with other chemicals (Table 1, Expt. 1). Glyphosate alone had only marginal effects (14%); however, addition of surfactant, significantly increased response from 23% to 83% (Table 1, Expt. 1). A similar effect of adjuvants on herbicide action was reported for velvetleaf (*Abutilon theophrasti* Medic.) by Downer et al. (1998). Landmaster®II and tank-mix formulations were very effective (96% to 100%) whether applied alone or with surfactant. While application of 2,4-D alone gave 84% control, addition of Induce® to 2,4-D increased the percentage of control to 90% ($P \leq 0.05$) and the addition of L-77® to 2,4-D gave 100% control.

Reducing the concentration of 2,4-D by 25%, Landmaster®II by 50%, and in tank-mix (glyphosate by 25% + 2,4-D by 50%) did not significantly affect this outcome (Table 1, Expt. 2). The effect of Landmaster®II on Brazil pusley control did not differ from that of glyphosate + 2,4-D.

Fresh weight, recorded 5 WAT, was not affected by treatment with glyphosate alone

(Table 1, Expt. 1), but was reduced significantly when Induce® was added. Similarly, Young and Hart (1998) reported that the addition of surfactant to the herbicide isoxaflutole [5-cyclo-propyl-4-(2-methylsulphonyl-4-trifluoromethylbenzoyl)isoxazole] improved control of giant foxtail (*Setaria faberi* Herrm.). In the present study, fresh weight was also significantly reduced by 2,4-D, Landmaster®II, or a combination of glyphosate and 2,4-D. Addition of Induce® or L-77® to 2,4-D reduced fresh weight than other 2,4-D treatments (Table 1, Expt. 1). Similar results were obtained in the second study, where reduced rates of 2,4-D, Landmaster®II or tank-mix of glyphosate + 2,4-D were used (Table 1, Expt. 2). There were no significant differences in response to the various herbicide treatments (i.e., 2,4-D, Landmaster®II, tank-mix) with or without added surfactant.

In the first study (Table 2, Expt. 1), the weight of regrown shoots was higher when plants were treated with glyphosate alone or glyphosate with L-77® than when other treatments were applied. This effect was consistent with values for percentage of control for these treatments (Table 1, Expt. 1). The fresh weight of regrown shoots following application of 2,4-D or Landmaster®II, with or without surfactant, was very low; no regrowth occurred in plants treated with Landmaster®II + Kinetic® (Table 2, Expt. 1). The tank-mix formulation prevented shoot growth for 5 weeks. Similarly, in the second study, regrowth of shoots occurred only in the glyphosate treatment, although their weight was very low (Table 2, Expt. 2). Similar observations were recorded when the weight of the viable rootstock was measured after the second harvest of shoots (Table 2, Expts. 1 and 2). Apparently the herbicide had reached the root system, killing both the foliage and roots.

Conclusions

Glyphosate alone was ineffective in controlling Brazil pusley but addition of surfactant improved its efficacy. Treatment with 2,4-D was also effective. When Landmaster®II and the tank-mix of glyphosate

Table 1. Effects of herbicides, with and without surfactant, on control of Brazil pusley.^z

Herbicide	Rate (kg·ha ⁻¹)	Surfactant							
		None	Induce® (0.25%)	L-77® (0.1%)	Kinetic® (0.25%)	None	Induce® (0.25%)	L-77® (0.1%)	Kinetic® (0.25%)
Expt. 1		Weed control (%)				Weed fresh wt (g)			
Glyphosate	0.77	14	83	23	74	10.7	5.1	9.6	6
2,4-D	0.68	84	90	100	83	5.7	1.7	0	5.1
Landmaster®II	0.96	96	100	99	100	1.1	0	1.7	0
Glyphosate + 2,4-D	0.77 + 0.68	100	100	100	0	0	0	0	0
Control		0	0	0	0	15.8	15.8	15.8	15.8
LSD _{0.05}		7.6				4.7			
Expt. 2									
Glyphosate	0.77	0	42	10	46	6.7	3.5	3	3.7
2,4-D	0.51	100	96	98	100	0	0	1.1	0
Landmaster®II	0.48	100	96	99	100	1.9	1.1	0.8	0.8
Glyphosate + 2,4-D	0.56 + 0.34	100	100	100	96	0	0	0	0
Control		0	0	0	0	7.6	7.6	7.6	7.6
LSD _{0.05}		7.1				3			

^zValues are means for four replications in each experiment.

Table 2. Effects of herbicides, with and without surfactant, on fresh weight of resprouted shoots and viable rootstocks off Brazil pusley.^z

Herbicide	Rate (kg·ha ⁻¹)	Surfactant							
		None	Induce® (0.25%)	L-77® (0.1%)	Kinetic® (0.25%)	None	Induce® (0.25%)	L-77® (0.1%)	Kinetic® (0.25%)
Expt. 1		Regrowth shoot wt(%)				Rootstock wt (g)			
Glyphosate	0.77	4.3	1.1	4.1	2.6	2.8	3.0	4.1	0.7
2,4-D	0.68	1.4	1.0	1.2	1.7	0.6	0.0	0.0	0.0
Landmaster®II	0.96	0.8	1.5	1.9	0.0	0.4	0.0	0.0	0.0
Glyphosate + 2,4-D	0.77 + 0.68	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Control		3.0	3.0	3.0	3.0	2.3	2.3	2.3	2.3
LSD _{0.05}		2.6				2.2			
Expt. 2									
Glyphosate	0.77	0.8	0.7	0.6	0.6	0.7	0.8	0.5	1.0
2,4-D	0.51	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Landmaster®II	0.48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Glyphosate + 2,4-D	0.56 + 0.34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Control		1.3	1.3	1.3	1.3	1.9	1.9	1.9	1.9
LSD _{0.05}		0.8				0.7			

^zValues are means for four replications in each experiment.

Table 3. Effect of rate of 2,4-D, with and without glyphosate, on control of Brazil pusley 3 and 4 weeks after treatment (Expt. 3).

Treatment	Rate (kg·ha ⁻¹)	Control (%) ^z	
		3rd week	4th week
2,4-D	0.17	98	99
	0.34	98	99
	0.51	100	100
	0.68	100	100
Glyphosate + 2,4-D	0.56 + 0.17	90	99
	0.56 + 0.10	90	99
	0.38 + 0.17	91	99
	0.38 + 0.10	86	93
Control		0	0
LSD _{0.05}		11	4

^zVisual ratings 5 WAT.

+ 2,4-D formulations were compared in all the observations, the tank-mix formulation was most effective, killing 100% of the plants, and preventing regrowth; presumably the active ingredient reached the root systems because all were dead. Subsequent experiments confirmed that 2,4-D was responsible for the effect of mixtures. Both 2,4-D alone and the tank-mix of glyphosate + 2,4-D gave 85% to 100% control of plants (Table 3), and even the lowest dose of 2,4-D was effective. No shoots regrew following 2,4-D treatment. Therefore, 2,4-D was the most effective ingredient in both Landmaster®II and the tank-mix of glyphosate + 2,4-D, and accelerated movement of glyphosate to the target site, hence effectively controlling the plants. Similarly, Isaac et al. (1998) found that 2,4-D increased the activity of halosulfuron [methyl 5-[[4,6-dimethoxy-2-pyrimidinyl]amino]carbonyl) aminosulfonyl]-3-chloro-1-methyl-1-*H*-pyrazole-4-carboxylate] on common lambsquarters (*Chenopodium album* L.). Kunkel and Baron (1998) observed that most of the existing 2,4-D tolerances for apples (*Malus domestica* L.) and pears (*Pyrus communis* L.) have been reduced from 5.0 to 0.05 mg·L⁻¹, a 100-fold decrease. Therefore, the results of this study indicate that 2,4-D may be combined with glyphosate in either a formulated product or a tank-mix to control Brazil pusley.

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