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Summer Annual Weed Control with 2,4-D and Glyphosate

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The introduction of 2,4-D-resistant crops stacked with glyphosate resistance will enable the use of 2,4-D and glyphosate for weed control in corn, cotton, and soybean. Because there is little reported on the effectiveness of 2,4-D plus glyphosate on summer annual weed control, the objective was to evaluate 2,4-D and glyphosate tank mixtures on summer annual weed control. Six rates of 2,4-D (0, 280, 420, 560, 840, and 1,120 g ae ha^{-1}) and three rates of glyphosate (0, 840, and 1,120 g ae ha^{-1}) were applied to common lambsquarters, common waterhemp, giant ragweed, giant foxtail, and velvetleaf. Glyphosate at 840 g ha^{-1} controlled all weeds 94 to 100%. Giant ragweed was controlled 99 to 100% by 2,4-D alone when rates were 280 g ha^{-1} or higher. Common lambsquarters, common waterhemp, and velvetleaf control increased as 2,4-D rates increased, with 1,120 g ha^{-1} providing 90 to 94% control.

Nomenclature: Glyphosate; 2,4-D; common lambsquarters, *Chenopodium album* L. CHEAL; common waterhemp, *Amaranthus rudis* Sauer AMATA; giant ragweed, *Ambrosia trifida* L. AMBTR; giant foxtail, *Setaria faberi* Herrm SETFA; velvetleaf, *Abutilon theophrasti* Medik. ABUTH; corn, *Zea mays* L.; cotton, *Gossypium hirsutum* L.; soybean, *Glycine Max* (L.) Merr.

Key words: Aryloxyalkanoate dioxygenase-12, aryloxyalkanoate dioxygenase-1, glyphosate resistant.

La introducción de cultivos con resistencia a 2,4-D en combinación con resistencia a glyphosate hará posible el uso de 2,4-D y glyphosate para el control de malezas en maíz, algodón y soya. Debido a que hay pocos reportes sobre la efectividad de 2,4-D más glyphosate en el control de malezas anuales de verano, el objetivo fue evaluar mezclas en tanque de 2,4-D y glyphosate en el control de estas malezas. Seis dosis de 2,4-D (0, 280, 420, 560, 840 y 1120 g ae ha^{-1}) y tres dosis de glyphosate (0, 840 y 1120 g ae ha^{-1}) fueron aplicadas a *Chenopodium album*, *Amaranthus rudis*, *Ambrosia trifida*, *Setaria faberi* y *Abutilon theophrasti*. Glyphosate a 840 g ha^{-1} controló todas las malezas de 94 a 100%. *A. trifida* fue controlada 99 a 100% con 2,4-D solamente cuando las dosis fueron 280 g ha^{-1} o mayores. El control de *C. album*, *A. rudis* y *A. theophrasti* aumentó al incrementarse las dosis de 2,4-D, con 1120 g ha^{-1} brindando 90 a 94% de control.

The introduction of 2,4-D- and glyphosate -resistant corn, cotton, and soybean will enable the use of 2,4-D and glyphosate in crop to control summer annual weeds (Wright et al. 2010). Fall and spring herbicide applications commonly use 2,4-D and glyphosate as tank-mix partners to control spring or winter annual weeds and perennial weeds (Loux et al. 2010). Because of the activity on broadleaf weeds, low cost, and low probability of resistance (Beckie 2006), 2,4-D is an attractive option for summer annual weed control. Glyphosate, the most commonly used herbicide in the United States, is a broad-spectrum systemic herbicide that is effective on many weed species. Although information exists in the literature on how these tank partners control a variety of weeds, less is known about the control of common summer annual weeds in midwestern U.S. corn and soybean production systems.

The use of glyphosate has increased 10-fold in the United States from 1995 to 2006 (USDA-NASS 2012) and concomitantly the evolution of weeds resistant to glyphosate has increased (Johnson et al. 2009) from no documented cases in 1995 to 21 glyphosate-resistant weeds in 2012 (Heap 2012). Additionally, 116 weed species are documented to be acetolactate synthase (ALS) resistant and 69 weed species are resistant to photosystem II inhibitors (Heap 2012). Furthermore, 11 biotypes of giant ragweed have been reported to be cross-resistant to ALS inhibitors and glyphosate, whereas common waterhemp has been reported to have 522 biotypes with cross-resistance to three herbicide modes of actions (in some combination of ALS inhibitors, photosystem II inhibitors, protoporphyrinogen oxidase inhibitors, 4-hydroxphenylpyruvate dioxygenase inhibitors, and glyphosate) (Heap 2012). Because weeds are evolving resistance to glyphosate and other mechanisms of action, a more diverse weed-control approach is needed to sustain the use of glyphosate. This may include using herbicides with different mechanisms of action, such as auxin herbicides. New trait technologies incorporating 2,4-D and glyphosate resistance in soybean will enable growers to apply POST tank mixes of 2,4-D plus glyphosate to control summer annual weeds; however, little is reported on the effectiveness of mixtures of 2,4-D and glyphosate on common waterhemp, giant ragweed, velvetleaf, and giant foxtail. The objective of this research was to evaluate the effectiveness of mixtures of 2,4-D and glyphosate on the control of common lambsquarters, common waterhemp, giant ragweed, giant foxtail, and velvetleaf.

Materials and Methods

A total of five field experiments was conducted in 2009 and 2010 at the Throckmorton-Purdue Agricultural Center near Lafayette, IN (40°18′00.32″N, 86°54′20.17″W). Soil type was a Toronto-Millbrook complex (Fine-silty, mixed, mesic,

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Table 1. Visible estimate of giant ragweed control 0 (no injury) to 100% (complete plant death) at 28 d after treatment. Data were arcsine square root transformed for analysis and back transformed for clarity. Studies were conducted near Lafayette, IN in 2009 and 2010.

2,4-D	Glyphosate	Giant ragweed 10 to 25 cm		Giant ragweed 26 to 46 cm	
g ae ha^{-1}		%			
0	0	0	C[a]	0	B
280	0	100	A	99	A
420	0	100	A	99	A
560	0	100	A	100	A
840	0	100	A	99	A
1,120	0	100	A	100	A
0	840	98	B	94	A
280	840	100	A	97	A
420	840	100	A	98	A
560	840	100	A	100	A
840	840	100	A	100	A
1,120	840	100	A	100	A
0	1,120	99	B	100	A
280	1,120	100	A	100	A
420	1,120	100	A	100	A
560	1,120	100	A	100	A
840	1,120	100	A	100	A
1,120	1,120	100	A	100	A

[a] Within rows means followed by the same letter are not significantly different ($P \leq 0.05$) according to Tukey pair-wise comparison.

Table 2. Giant ragweed dry weight in grams per plant. Data were log transformed and back tranformed for clarity. Studies were conducted near Lafayette, IN in 2009 and 2010.

2,4-D	Glyphosate	Giant ragweed 10 to 25 cm		Giant ragweed 26 to 46 cm	
g ae ha^{-1}		g plant^{-1}			
0	0	28	A[a]	96	A
280	0	0	D	3.7	BC
420	0	0	D	3.7	BC
560	0	0.1	D	1.6	CD
840	0	0.1	CD	2.8	CD
1,120	0	0	D	1.1	CD
0	840	0.3	C	4.7	B
280	840	0	D	0.7	CD
420	840	0	D	0.5	CD
560	840	0	D	0.6	D
840	840	0	D	0	D
1,120	840	0	D	0	D
0	1,120	0.2	BC	1.0	CD
280	1,120	0	D	0	D
420	1,120	0	D	0	D
560	1,120	0	D	0	D
840	1,120	0	D	0	D
1,120	1,120	0	D	0	D

[a] Within rows means followed by the same letter are not significantly different ($P \leq 0.05$) according to Tukey pair-wise comparison.

superactive Udollic Epiaqualf). A natural population of common lambsquarters, common waterhemp, giant ragweed, giant foxtail, and velvetleaf was utilized in a fallow field. Each weed species was evaluated in two experimental runs and all weed species were susceptible to glyphosate.

The experimental design was a randomized complete block with a factorial treatment arrangement. The first factor was 2,4-D (dimethylamine salt) (Weedar 64, Nufarm Inc., Burr Ridge, IL 60527) at rates of 0, 280, 420, 560, 840, and 1,120 g ha^{-1} and the second factor was glyphosate (dimethylamine salt) (Durango DMA, Dow AgroSciences, Indianapolis, IN 46268) at rates of 0, 840, and 1,120 g ha^{-1}. Herbicides were applied with ammonium sulfate at 20 g L^{-1}. Treatments were replicated four times in plots that measured 3.1 by 6.2 m. Before herbicide application, five weeds of each species were selected and flagged within each plot for evaluation. Giant ragweed plants were flagged at two heights, 10 to 25 cm and 26 to 46 cm, common waterhemp and velvetleaf were 20 to 30 cm, and common lambsquarters were 10 to 20 cm. Giant foxtail was assessed by measuring a quadrat of 929 cm^2. All treatments were applied in 140 L ha^{-1} carrier volume with a CO_2-pressurized backpack sprayer at 138 kPa with a 2.3-m-wide boom and XR11002 flat fan nozzles (TeeJet Spraying Systems Company, Wheaton, IL 60189).

Visible estimates of weed control from 0 (no injury) to 100% (complete plant death) were determined at 28 d after treatment for each of the five marked plants. At 28 d after treatment, plants were harvested, dried in a forced air dryer for 7 d at 40 C, and dry weight was recorded. Percent weed control was arcsine square root transformed (Ahrens et al. 1990). Plant dry weight was log transformed as determined by the results of the Box-Cox procedure (Box et al. 1978). Nontransformed data are presented for clarity. ANOVA was conducted using the SAS MIXED procedure (SAS Institute, Inc., Cary, NC 27513) with experiment set as a random variable. Means were separated using Tukey's pair-wise comparison ($P \leq 0.05$).

Results and Discussion

Both glyphosate and 2,4-D provided effective control of 10- to 25-cm and 26- to 46-cm giant ragweed. Glyphosate alone at 840 and 1,120 g ha^{-1} controlled giant ragweed 94 to 100%, whereas 2,4-D controlled giant ragweed 99 to 100% (Table 1). When 2,4-D was applied with glyphosate, control was 100% in all treatments. The dry weight of 10- to 25-cm giant ragweed was reduced 99% when glyphosate treatments were applied alone, but with the addition of 2,4-D to glyphosate plant dry weight was reduced 100% (Table 2). Dry weight of 26- to 46-cm giant ragweed was reduced by 95 to 99% with glyphosate. When 2,4-D was applied alone, dry weight was reduced by 96 to 99%. Combinations of glyphosate plus 2,4-D reduced dry weight of giant ragweed by 99% or more. Although 10- to 25-cm giant ragweed had reduced control when glyphosate was applied alone, 2,4-D alone can be an effective option to control giant ragweed, especially giant ragweed that is glyphosate or ALS resistant (Heap 2012).

Glyphosate applied at 840 g ha^{-1} controlled velvetleaf (Table 3) and reduced dry weight 99 to 100% (Table 4). Glyphosate at both rates provided effective control of velvetleaf, whereas 2,4-D at a rate of 840 g ha^{-1} or more was required for adequate control.

Common waterhemp control was 97 to 100% when glyphosate treatments were applied alone or with 2,4-D (Table 3). Reduced control was observed when 2,4-D treatments $<$ 1,120 g ha^{-1} were applied without glyphosate.

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Table 3. Visible estimate of velvetleaf, common waterhemp, and common lambsquarters control 0 (no injury) to 100% (complete plant death) at 28 d after treatment. Data were arcsine square root transformed for analysis and back transformed for clarity. Studies were conducted near Lafayette, IN in 2009 and 2010.

2,4-D	Glyphosate	Velvetleaf		Common waterhemp		Common lambsquarters	
g ae ha^{-1}		%					
0	0	0	E[a]	0	D	0	E
280	0	36	D	42	C	69	D
420	0	67	C	62	B	78	C
560	0	83	B	62	B	79	BC
840	0	89	AB	68	B	87	ABC
1,120	0	94	AB	94	A	90	AB
0	840	99	A	100	A	100	A
280	840	97	A	99	A	100	A
420	840	99	A	100	A	100	A
560	840	100	A	97	A	100	A
840	840	100	A	100	A	100	A
1,120	840	100	A	100	A	100	A
0	1,120	100	A	99	A	100	A
280	1,120	100	A	100	A	100	A
420	1,120	100	A	98	A	100	A
560	1,120	100	A	100	A	100	A
840	1,120	100	A	100	A	100	A
1,120	1,120	100	A	100	A	100	A

[a] Within rows means followed by the same letter are not significantly different ($P \leq 0.05$) according to Tukey pair-wise comparison.

Table 4. Velvetleaf, common waterhemp, and common lambsquarters dry weight in grams per plant. Data were log transformed and back tranformed for clarity. Studies were conducted near Lafayette, IN in 2009 and 2010.

2,4-D	Glyphosate	Velvetleaf		Common waterhemp		Common lambsquarters	
g ae ha^{-1}		g plant^{-1}					
0	0	4.4	A[a]	1.5	A	1.0	A
280	0	2.5	B	0.7	AB	0.8	AB
420	0	1.8	BC	0.6	BC	0.8	AB
560	0	1.1	C	0.7	BC	0.6	BC
840	0	0.5	D	0.6	C	0.7	BC
1,120	0	0.5	D	0.2	D	0.5	C
0	840	0	E	0	D	0	D
280	840	0.1	E	0.1	D	0	D
420	840	0	E	0	D	0	D
560	840	0	E	0	D	0	D
840	840	0	E	0	D	0	D
1,120	840	0	E	0	D	0	D
0	1,120	0	E	0.1	D	0	D
280	1,120	0	E	0.1	D	0	D
420	1,120	0	E	0.1	D	0	D
560	1,120	0	E	0.1	D	0	D
840	1,120	0	E	0	D	0	D
1,120	1,120	0	E	0	D	0	D

[a] Within rows means followed by the same letter are not significantly different ($P \leq 0.05$) according to Tukey pair-wise comparison.

All treatments including glyphosate reduced common waterhemp dry weight by 93 to 100% (Table 4). When treatments of 2,4-D alone were applied, dry weight was reduced by 53 to 87%. Common waterhemp has been documented to have resistance to six modes of action (Heap 2012), including resistance to glyphosate and 2,4-D. Tank mixtures may help delay resistance, but an integrated weed management approach may be the most beneficial means to control this weed as it has been shown to easily evolve resistance to herbicides (Heap 2012).

All treatments including glyphosate controlled common lambsquarters and dry weight was reduced by 100% (Tables 3 and 4). 2,4-D treatments applied without glyphosate had 87 to 90% control at 840 and 1,120 g ha^{-1}, respectively. Dry weight was reduced by 50% when 1,120 g ha^{-1} 2,4-D was applied. Although the common lambsquarters population in our study was susceptible to glyphosate, some populations have been reported to have tolerance to glyphosate (Westhoven et al. 2008). In glyphosate-tolerant common lambsquarters, 2,4-D tank mixtures could be beneficial.

Giant foxtail control was 100% and dry weight was reduced 100% when glyphosate treatments were applied at 840 or 1,120 g ha^{-1} (data not shown). 2,4-D treatments had no effect on giant foxtail. In other research, reduced grass control has been observed with glyphosate plus 2,4-D (Flint and Barrett 1989; O'Sullivan and O'Donovan 1980).

The addition of 2,4-D to glyphosate on glyphosate-sensitive weeds did little to improve control, but 2,4-D applied alone was effective at controlling giant ragweed, common lambsquarters, common waterhemp, and velvetleaf. Glyphosate rates $\geq$ 840 g ha^{-1} controlled all weeds by 94 to 100%. Giant ragweed was controlled 99 to 100% by 2,4-D alone when rates were $\geq$ 280 g ha^{-1}. The addition of 2,4-D to glyphosate improved giant ragweed control 2 to 6%. Common lambsquarters, common waterhemp, and velvetleaf control increased as 2,4-D rates increased, with 1,120 g ha^{-1} providing 90 to 94% control, whereas glyphosate alone had excellent control of these weeds.

Glyphosate at 840 and 1,120 g ha^{-1} provided control of glyphosate-susceptible weeds evaluated in this study. In the cases where glyphosate did not control weeds 100%, 2,4-D aided some in controlling these weeds. In this study the dimethylamine salts of glyphosate and 2,4-D were evaluated on glyphosate-susceptible weeds. Future research should include evaluations of the efficacy of the newly developed choline salt of 2,4-D mixed with glyphosate (Scherder et al. 2010).

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