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Timing of Soil-Residual Herbicide Applications for Control of Giant Ragweed (*Ambrosia trifida*)

R. Joseph Wuerffel, Julie M. Young, Joseph L. Matthews, Vince M. Davis, William G. Johnson, and Bryan G. Young*

Fall-applied residual and spring preplant burn-down herbicide applications are typically used to control winter annual weeds and may also provide early-season residual control of summer annual weed species such as giant ragweed. Field experiments were conducted from 2006 to 2008 in southern Illinois to (1) assess the emergence pattern of giant ragweed, (2) evaluate the efficacy of several herbicides commonly used for soil-residual control of giant ragweed, and (3) investigate the optimal application timing of soil-residual herbicides for control of giant ragweed. Six herbicide treatments were applied at four application timings: early fall, late fall, early spring, and late spring. Giant ragweed first emerged in mid- and late-March in 2007 and 2008, respectively. The duration of emergence varied by year, with 95% of emergence complete in late May of 2008, but not until early July in 2007. Giant ragweed emergence occurred more quickly in plots that received a fall application of glyphosate + 2,4-D compared with the nontreated. Fall-applied residual herbicides did not reduce giant ragweed emergence in 2007 when compared with the nontreated, with the exception of chlorimuron + tribenuron applied in late fall. Giant ragweed control from early- and late-spring herbicide applications was variable by year. In 2007, saflufenacil (50 and 100 g ai ha^{-1}) and simazine applied in early spring reduced giant ragweed densities by 95% or greater through mid-May; however, in 2008, early-spring applications failed to reduce giant ragweed emergence in mid-April. The only treatments that reduced giant ragweed densities by > 80% through early July were late-spring applications of chlorimuron + tribenuron or saflufenacil at 100 g ha^{-1}. Thus, the emergence patterns of giant ragweed in southern Illinois dictates that best management with herbicides would include late-spring applications of soil-residual herbicides just before crop planting and most likely requires subsequent control with foliar or soil-residual herbicides after crop emergence.

Nomenclature: 2,4-D; chlorimuron; flumioxazin; glyphosate; saflufenacil; simazine; tribenuron; giant ragweed, *Ambrosia trifida* L.

Key words: Early preplant, emergence patterns, fall-applied, preplant, spring-applied.

Las aplicaciones de herbicidas residuales en el otoño y de herbicidas para eliminación general de vegetación antes de la siembra en la primavera son usadas típicamente para el control de malezas anuales de invierno y que pueden además brindar un control residual de malezas anuales de verano tales como *Ambrosia trifida*, temprano en la temporada. Experimentos de campo fueron realizados entre 2006 y 2008, en el sur de Illinois, para (1) evaluar el patrón de emergencia de *A. trifida*, (2) evaluar la eficacia de varios herbicidas comúnmente usados para el control residual en el suelo de *A. trifida*, e (3) investigar el momento de aplicación óptimo para herbicidas residuales en el suelo para el control de *A. trifida*. Se aplicaron seis tratamientos de herbicidas en cuatro momentos de aplicación: temprano en el otoño, tarde en el otoño, temprano en la primavera, y tarde en la primavera. *A. trifida* emergió primero durante la mitad y el final de Marzo en 2007 y 2008, respectivamente. La duración de la emergencia varió dependiendo del año, con 95% de la emergencia completándose al final de Mayo de 2008, pero no hasta el inicio de Julio en 2007. La emergencia de *A. trifida* ocurrió más rápidamente en parcelas que recibieron una aplicación de glyphosate + 2,4-D durante el otoño al compararse con el testigo sin tratamiento. Los herbicidas residuales aplicados en el otoño no redujeron la emergencia de *A. trifida* en 2007 cuando se compararon con el testigo, con la excepción de chlorimuron + tribenuron aplicados al final del otoño. El control de *A. trifida* con aplicaciones temprano y tarde durante la primavera fue variable dependiendo del año. En 2007, saflufenacil (50 y 100 g ai ha^{-1}) y simazine aplicados temprano en la primavera redujeron las densidades de *A. trifida* en 95% o más hasta la mitad de Mayo. Sin embargo, en 2008, aplicaciones realizadas temprano en la primavera fallaron en reducir la emergencia

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de *A. trifida* en la mitad de Abril. Los únicos tratamientos que redujeron las densidades de *A. trifida* > 80% hasta el inicio de Julio fueron las aplicaciones de chlorimuron + tribenuron o saflufenacil a 100 g ha^{-1} tarde en la primavera. Así, los patrones de emergencia de *A. trifida* en el sur de Illinois dictan que el mejor manejo con herbicidas debería incluir aplicaciones de herbicidas de suelo residuales tarde en la primavera antes de la siembra del cultivo y muy probablemente requiere un control de seguimiento con herbicidas foliares y de suelo residuales después de la emergencia del cultivo.

Giant ragweed is a highly competitive, summer annual weed species in the Asteraceae family, historically an endemic of ruderal habitats in North America, such as floodplains, ditches, or stream banks (Bassett and Crompton 1982). Giant ragweed accumulates biomass rapidly and displays a high degree of phenotypic plasticity in response to competition, contributing to its success as a dominant species (Webster et al. 1994). For example, when competing with six summer annual weed species (common lambsquarters, *Chenopodium album* L.; marijuana, *Cannabis sativa* L.; Pennsylvania smartweed, *Polygonum pensylvanicum* L.; velvetleaf, *Abutilon theophrastii* Medik.; giant foxtail, *Setaria faberi* Herm.; and ivyleaf morningglory, *Ipomea hederacea* Jacq.), giant ragweed accounted for 97% of the biomass by early August, whereas the six competing species accounted for the remaining 3% of the biomass (Abul-Fatih and Bazzaz 1979). Giant ragweed is also an efficient competitor in agricultural fields, with the capacity to drastically reduce corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] yield. Webster et al. (1994) predicted that soybean yield could be reduced by 77% with only one giant ragweed plant m^{-2}. A similar competitive effect has been observed in corn when giant ragweed emerges simultaneously with the crop, with a predicted 13.6% reduction in corn yield with one plant per 10 m^2 (Harrison et al. 2001).

Characterizing the pattern of emergence is important to understand the competitive effect and effective management of a weed species. In ruderal habitats it is advantageous for annual weed species to emerge early to increase their competitive advantage; whereas in agricultural fields (agrestal habitat) that paradigm is reversed and delayed emergence may be favored to escape management tactics (Schutte 2007). Early spring-emerging weeds can be managed with tillage or nonselective herbicides before planting and late-emerging weeds may be suspect to light competition from the closure of the crop canopy. Thus, agrestal weed species with prolonged, discontinuous emergence may gain an advantage (Hartzler et al. 2002; Schutte 2007) by posing a persistent problem for management tactics implemented by growers. Giant ragweed seedlings are among the first emerging summer annuals, with initial emergence often occurring in early March (Abul-Fatih and Bazzaz 1979). Furthermore, giant ragweed emergence patterns in agrestal habitats were similar to those of giant ragweed in ruderal habitats, characterized by one large, initial flush, reaching 95% emergence within approximately 29 d (Stoller and Wax 1973). Contemporary research conducted with giant ragweed biotypes from Ohio and Illinois discovered that these biotypes have seemingly adapted to early-season weed management by extending their period of emergence, reaching 95% emergence after 68 and 80 d, respectively, consequently escaping early-season weed control (Hartzler et al. 2002).

This prolonged emergence pattern is exceptionally problematic for corn and soybean growers for several reasons: (1) preplant tillage may not suffice as a stand-alone control measure, (2) fall-residual and early-spring preplant herbicides may not remain in great enough concentrations to exert herbicidal activity and effect emergence of late-germinating giant ragweed seedlings, and (3) it may force increased reliance on POST herbicide applications, especially if giant ragweed emergence persists after crop emergence. There are several herbicides that effectively control giant ragweed POST; however, giant ragweed biotypes resistant to glyphosate (Weed Science Society of America [WSSA] site of action #9) and acetolactate synthase inhibitors (WSSA site of action #2) have been identified in the Midwest and mid-South, which, if present, severely limit POST options for the control of giant ragweed (Norsworthy et al. 2010; Westhoven et al. 2008; Zelaya and Owen 2004). Saflufenacil is a protoporphyrinogen oxidase (PPO)-inhibiting herbicide (WSSA site of action #14), labeled for use in corn and soybean production, that has soil-residual and foliar activity on many broadleaf weed species, including giant ragweed (Grossmann et al. 2011). Soltani et al.

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(2011) recorded a 73% reduction in giant ragweed density 8 wk after a soil-residual application of saflufenacil, applied at 75 g ai ha^{-1}. Currently there are no giant ragweed biotypes identified with evolved resistance to PPO-inhibiting herbicides; however, a close relative, common ragweed (*Ambrosia artemisiifolia* L.), has developed resistance to this site of action (Rousonelos 2010).

Giant ragweed can be problematic in all tillage systems, including no-tillage crop production (Barnes et al. 2004). Fall-residual and spring preplant burndown herbicide applications are an essential component of no-till cropping systems for the control of winter annual vegetation before planting (Young 2006). Often these applications partially function as early-season residual control of summer annual weed species; preplant spring applications more so than fall-residual applications given the variable residual activity of fall-applied herbicides on summer annual weed species (Davis et al. 2010; Hasty et al. 2004; Monnig and Bradley 2007). Previous research focusing on horseweed (*Conyza canadensis* L. Cronq.) has revealed that fall-applied and preplant burndown herbicide applications, which effectively remove winter annuals, can actually enhance spring emergence of horseweed because of reduced interspecific competition during the primary period of horseweed emergence (Davis et al. 2010). In the same study, horseweed emergence was decreased by 90% through mid-June when an effective herbicide, such as chlorimuron + tribenuron or saflufenacil, was applied in early or late spring (Davis et al. 2010).

Given the latter issues, proper application timing of soil-residual herbicides, combined with an understanding of the local weed emergence patterns, is critical for the management of giant ragweed. Therefore, the following experimental objectives were developed: (1) assess the emergence pattern of giant ragweed in southern Illinois, (2) evaluate the efficacy of several herbicides commonly used for soil-residual control of giant ragweed, and (3) investigate the optimal application timing of soil-residual herbicides for the control of giant ragweed, on the basis of the emergence patterns of biotypes present in southern Illinois.

Materials and Methods

Experiments were conducted from October 2006 to July 2007 and October 2007 to July 2008 in a field with a history of reduced-tillage practices and a substantial giant ragweed infestation. The field was fallow for the duration of the experiment to remove the potential confounding effect of tillage or the timing of tillage on herbicide efficacy or giant ragweed emergence. The field was located at the Southern Illinois University–Belleville Research Center (BRC) in St. Clair County, Illinois (38.51°N, 89.84°W). Treatments were arranged as a randomized complete block in a factorial design with two factors: herbicide (six levels) and application timing (four levels). Every herbicide treatment was applied at each application timing with four replications of each treatment per year. Herbicide treatments included chlorimuron + tribenuron at 35 + 11 g ai ha^{-1}, ester salt of 2,4-D at 560 g ai ha^{-1}, flumioxazin at 72 g ai ha^{-1}, saflufenacil at 50 g ai ha^{-1} and 100 g ai ha^{-1}, and simazine at 1,120 g ai ha^{-1} (Table 1). All treatments included 860 g ai ha^{-1} of glyphosate + ammonium sulfate at 2.8 kg ha^{-1} for control of existing vegetation. Nontreated plots were included for comparison. The four application timings were early fall (October 15 to 30), late fall (November 15 to 30), early spring (March 15 to 30), and late spring (April 15 to 30). Plots were 3 m wide by 9 m long and herbicides were applied to the center 2.3 m with a CO_2 backpack sprayer calibrated to deliver 140 L ha^{-1} at 276 kPa using either XR11002 or XR8002 flat-fan nozzles (TeeJet Technologies, P.O. Box 7900, Wheaton, IL 60187). Clethodim at 136 g ai ha^{-1} (Select Max®, Valent U.S.A. Corporation, Walnut Creek, CA 94596) was applied, as needed, to eliminate competing grass species.

The residual activity of each herbicide was evaluated by counting all emerged giant ragweed plants in three 0.25-m^2 quadrats within each plot starting 2 wk after the early spring application. These quantitative evaluations continued until the first week of July, which coincided with a decline in giant ragweed emergence due to an established vegetative canopy. Heights of three representative giant ragweed plants were recorded within each quadrat at each evaluation.

Statistical Analysis. To quantify giant ragweed emergence in nontreated plots, the greatest mean emergence achieved during the experiment was considered the maximum emergence. Relative emergence was compared with the maximum emergence at each evaluation timing to determine

Table 1. List of herbicides and corresponding rates applied in early and late fall and spring.

Herbicide[a]	Rate	Trade name	Site of action #[b]	Manufacturer
	g ai ha^{-1}			
Chlorimuron + tribenuron	35 + 11	Canopy EX®	2	E. I. du Pont de Nemours and Company,Wilmington, DE 19898.
Saflufenacil	100	Sharpen™	14	BASF Corporation Agricultural Products, Research Triangle Park, NC 27709.
Saflufenacil	50	Sharpen™	14	BASF Corporation Agricultural Products, Research Triangle Park, NC 27709.
Simazine	1,120	Princep 4L®	5	Syngenta Crop Protection, Inc., Greensboro, NC 27409.
Ester salt of 2,4-D	560	2,4-D LV4®	4	Agriliance, LLC, St. Paul, MN 55164.
Flumioxazin	72	Valor®	14	Valent U.S.A. Corporation, Walnut Creek, CA 94596.

[a] All herbicide treatments listed above included 860 g ai ha^{-1} of glyphosate + ammonium sulfate at 2.8 kg ha^{-1} for control of existing winter annual vegetation.

[b] Approved site-of-action number by the Weed Science Society of America.

when emergence surpassed 90%. To visually demonstrate the effects of early-spring interspecific weed competition, the emergence pattern of the southern Illinois giant ragweed biotypes was modeled using a three-parameter logistic model (SigmaPlot 12.3, Systat Software Inc., 1735 Technology Drive, Suite 430, San Jose, CA 95110). The glyphosate + 2,4-D treatment applied in the early fall was included in the model for comparison against the nontreated. This treatment was chosen because early fall-applied 2,4-D would not have direct herbicidal effects on spring giant ragweed emergence while simultaneously providing adequate control of winter annual weed species (Monnig and Bradley 2007). Before this comparison, PROC MIXED (SAS 9.2, SAS Institute Inc., 100 SAS Campus Drive Cary, NC 27513) was used to test for significant interactions among years and treatments.

To test the influence of application timing on giant ragweed density, the density of giant ragweed in treated plots was compared with the density of the nontreated. Analysis was performed with PROC MIXED using Dunnett's multiple comparisons post hoc test (Dunnett 1955) to separate mean giant ragweed density in each treatment vs. the nontreated. The fixed effects (herbicide, application timing, and evaluation timing) and their interactions were compared using a mixed-model, repeated-measures ANOVA and analyzed with PROC MIXED (Littell et al. 1998, 2006). This was used in conjunction with the macro PDMIX800, which slices least-squared means by the fixed effects, assigns a unique LSD to each sliced group, then clusters least-squared means into letter groupings (Saxton 1998). The Box-Cox procedure was implemented before repeated-measures ANOVA to correct for heteroscedasticity in the giant ragweed emergence data; subsequently, the data were log-transformed as suggested by this procedure (Box et al. 1978). The nontreated was excluded from the repeated-measures analysis. Three variance–covariance structures were tested before analysis: compound symmetry, first-order autoregressive AR(1), and uniformity. The AR(1) covariance structure provided the lowest Akaike's information criteria value and was, therefore, selected as the covariance structure for the repeated-measures analysis. All data were back-transformed for data presentation.

Results and Discussion

Emergence Patterns of Giant Ragweed in the Nontreated Check. In 2007, unseasonably warm temperatures in mid- to late March (Figure 1a) triggered considerable giant ragweed emergence before the first scheduled evaluation timing. This was followed by several days of < 0 C minimum temperatures in early April, causing high mortality of giant ragweed seedlings before the second evaluation timing (Figure 1a). Temperatures in the spring of 2008 were typical, with normal temperature fluctuations in the early spring (Figure 1b); therefore, giant ragweed emerged more grad-

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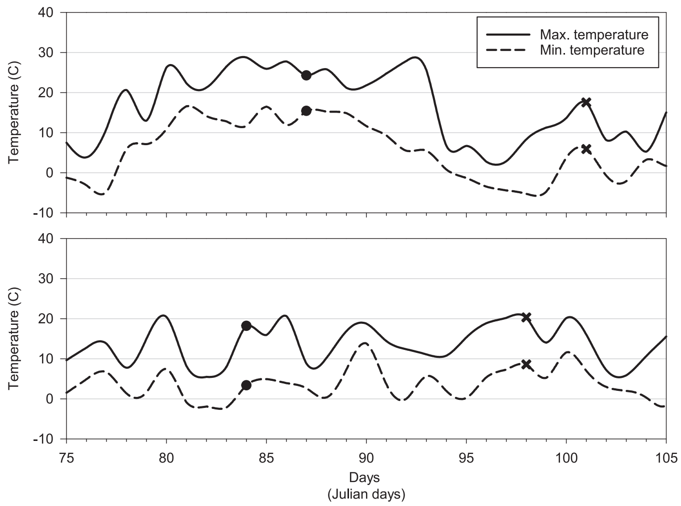

Figure 1. Minimum and maximum temperatures recorded at Southern Illinois University–Belleville Research Center from March 16 to April 15, 2007 and March 15 to April 14, 2008. In 2007, a week of > 20 C maximum temperatures preceded the late March density evaluation timing (•). This was followed by five days of < 0 C minimum temperatures, before the mid-April density evaluation timing (**x**), thereby producing a killing frost. Temperatures flanking the first two evaluation timings varied less in 2008.

ually. This variability in early spring weather resulted in a significant interaction between year and treatment for giant ragweed density and height in the spring of 2007 and 2008; therefore, years are discussed separately.

As previously mentioned, giant ragweed has been traditionally described as a rapid and early-emerging species, often achieving 95% emergence within 1 mo of the early-spring emergence. However, more recent research has identified giant ragweed biotypes from Illinois and Ohio that exhibited a prolonged emergence pattern (Hartzler et al. 2002). At BRC in 2007, giant ragweed emergence started in mid-March and was 95% complete in early July, nearly 100 d later; whereas in 2008, emergence began in late March, reaching 95% emergence in late May, nearly 60 d later (data not shown). This is similar to observations by Hartzler et al. (2002), when giant ragweed took 68 to 80 d to reach 95% emergence. Unlike Hartzler et al. (2002), inter- and intraspecific competition was not controlled by plant removal in nontreated plots, which may explain the greater variability observed in the duration of emergence among years in the present study. The emergence patterns in both years at BRC corresponds to the start of giant ragweed emergence approximately 1 mo before traditional planting dates for corn and soybean, with emergence continuing for 1 to 2 mo after crop planting.

Influence of Winter Annual Weed Competition. A three-parameter logistic model was used to visualize the progression of emergence in plots treated with glyphosate + 2,4-D at early- and late-fall application timings. The density of giant ragweed was heavily influenced by the control of winter annual weed species. In nontreated plots, the winter annual weeds, horseweed, henbit (*Lamium amplexicaule* L.), and small-flowered buttercup (*Ranuculus abortivus* L.), were allowed to compete with giant ragweed in the spring of 2007 and 2008. These winter annuals were effectively controlled by fall-applied herbicide treatments, thereby eliminating early-spring interspecific competition (data not shown). Giant ragweed emergence began in mid-March 2007 in the nontreated, as well as in plots treated with an early-fall application of 2,4-D. Because of the lack of competing winter annual weeds in 2,4-D + glyphosate-treated plots, > 95% emergence was observed before the first evaluation timing in late March (Figure 2). That same year, emergence in the nontreated was considerably slower, reaching 95% emergence in early July, as previously mentioned. In 2008, cooler weather in mid-March delayed giant ragweed emergence in the nontreated and early-fall 2,4-D-treated plots; nevertheless, giant ragweed emergence occurred more quickly in plots that received an early-fall application of 2,4-D + glyphosate, relative to the nontreated (Figure 2). Emergence of giant ragweed in both years was greater at the mid-April evaluation timing for the fall application of 2,4-D + glyphosate compared with the nontreated. Thus, growers would be faced with greater densities of giant ragweed before crop planting because of a fall application of 2,4-D + glyphosate to control winter annual weed species.

Efficacy of Soil-Residual Herbicides on Giant Ragweed. Giant ragweed emergence in nontreated plots extended into early July and late May in 2007 and 2008, respectively. Fall-applied residual herbicides did not reduce giant ragweed emergence at any evaluation timing when compared with the nontreated, with the exception of the early July evaluation of chlorimuron + tribenuron applied in late fall in 2006 (Figure 3). In fact, most fall-applied

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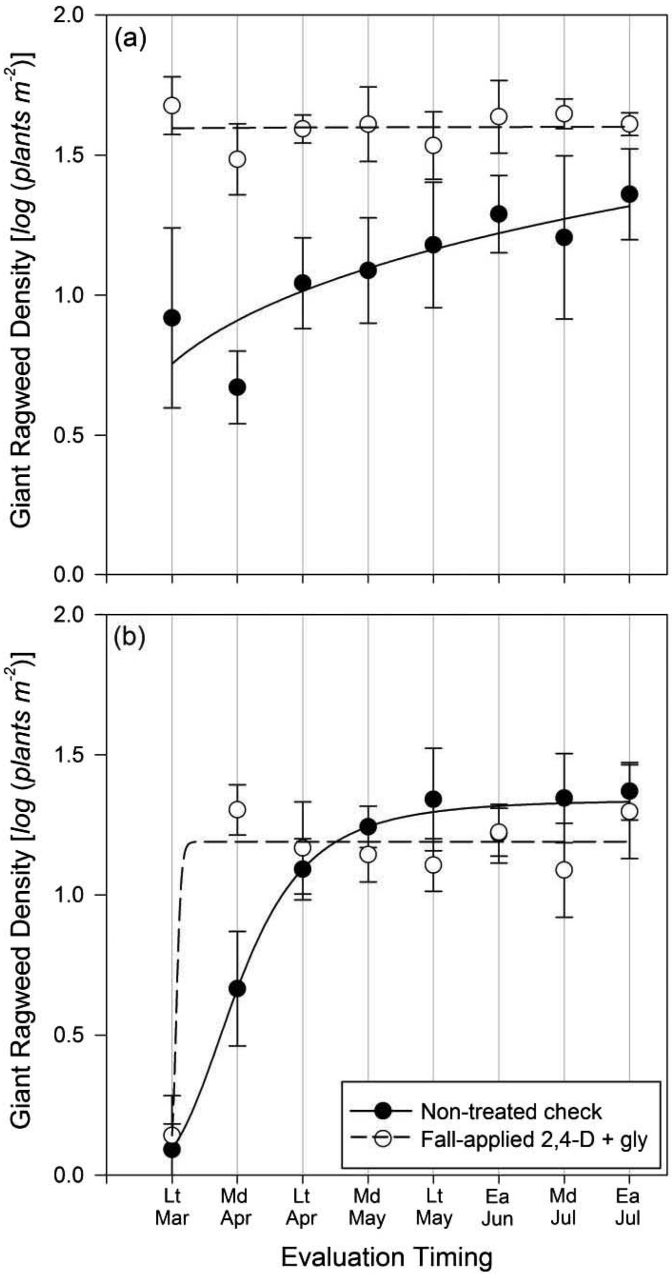

Figure 2. Emergence of giant ragweed in 2007 (a) and 2008 (b), comparing the nontreated and fall-applied 2,4-D, which were void of winter annual weed and interspecific competition. Unusually high temperatures in 2007 resulted in rapid emergence of giant ragweed in the glyphosate + 2,4-D treatment, before the first evaluation time in late March; hence the horizontal dashed-line in (a). Regression from the latter plot was not significant. Error bars represent ±standard error of the mean, $n = 8$.

herbicides resulted in more rapid giant ragweed emergence than the nontreated. For example, fall-applied 2,4-D increased giant ragweed densities through mid-May 2007 compared with the nontreated, which may have been due to the lack of residual control by 2,4-D and the early removal of winter annual weeds (Figure 3).

The reduction in giant ragweed density after early- and late-spring herbicide applications varied by year. In 2007, the residual activity of saflufenacil (50 and 100 g ha^{-1}) and simazine applied in early spring reduced giant ragweed densities by at least 95%, and to a lesser extent (80 to 94%) flumioxazin, but none of these herbicides altered giant ragweed densities by mid-May (Figure 3). Conversely, the premix of chlorimuron + tribenuron in 2007 was consistent among early- and late-spring application timings, providing at least 80% reduction in giant ragweed density into early July. In 2008 early-spring applications of all herbicides failed to reduce giant ragweed emergence in mid-April and only simazine applied in late spring reduced giant ragweed densities at the early July evaluation. In both years, the late-spring applications occurred after 50% emergence was achieved in the nontreated; subsequently, all herbicides provided at least 50% reduction in giant ragweed emergence at the mid-May evaluation, with the exception of 2,4-D in 2007. Chlorimuron + tribenuron and saflufenacil at 100 g ha^{-1} applied in late spring of 2007 were the only treatments that reduced giant ragweed densities through early July by > 80%. Furthermore, the greatest reduction in giant ragweed density in both years occurred with a late-spring application of saflufenacil applied at 100 g ha^{-1}, providing at least 95 and 80% through mid-May and early June, respectively. Soltani et al. (2011) recorded a similar density reduction of 73% 8 wk after planting with soil-residual treatment of saflufenacil at 75 g ha^{-1}. Overall, the combination of chlorimuron + tribenuron or saflufenacil alone at either use rate provided the most consistent giant ragweed control, especially when applied in the spring.

Influence of Application Timing on Soil-Residual Herbicide Efficacy. Previous research by Hasty et al. (2004) found that fall and early-spring applications of chlorimuron + sulfentrazone resulted in 63 and 74% control of giant ragweed, respectively, with no statistical differences. Similar to Hasty et al. (2004), differences in giant ragweed density were not detected between late-fall- and early-spring-applied chlorimuron + tribenuron

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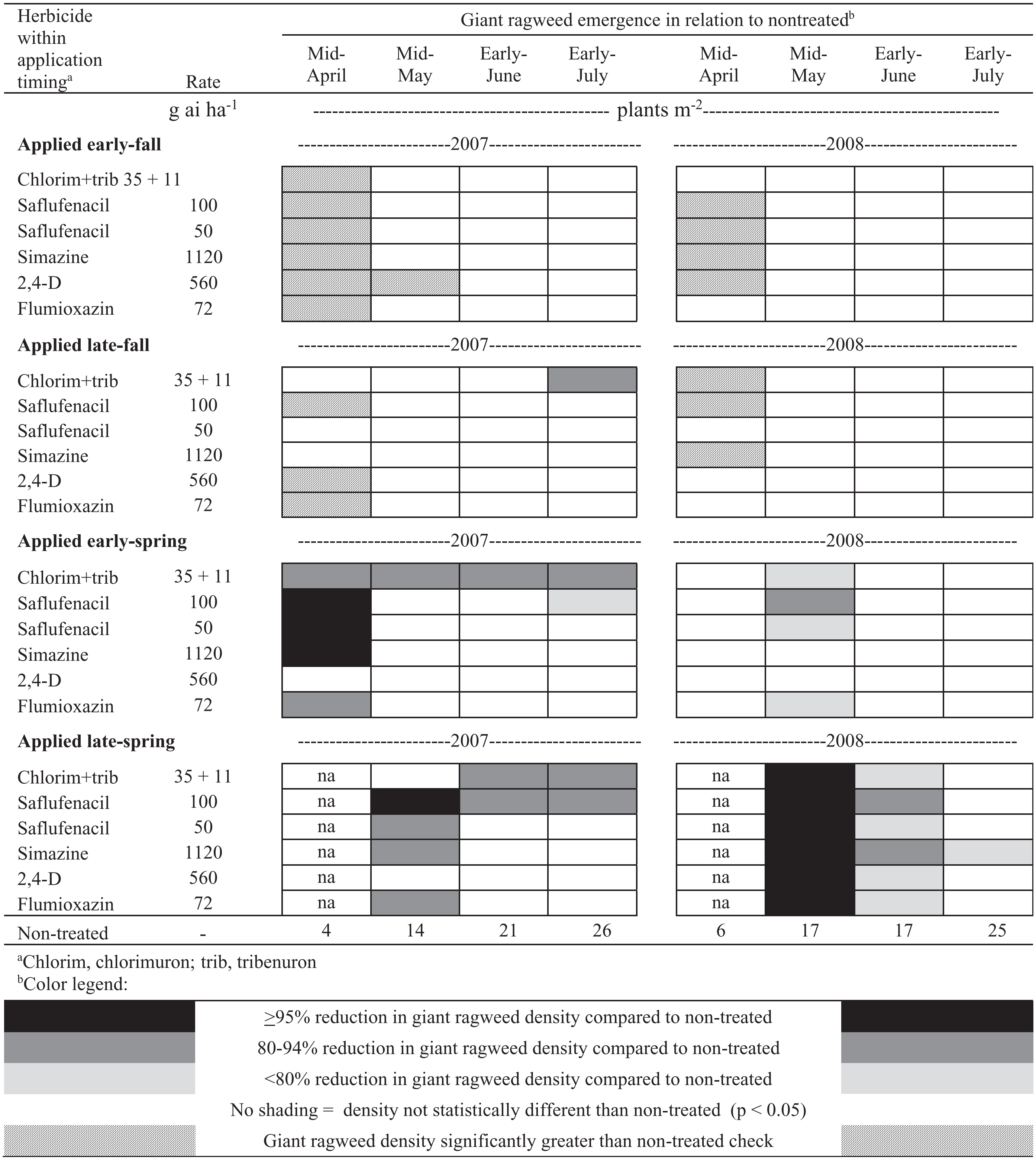

Figure 3. Relative giant ragweed density in treated plots compared with giant ragweed density in the nontreated for 2007 and 2008. Darker shading represents greater density reduction for treatments that were significantly different from the nontreated check using Dunnett's means separation ($\alpha < 0.05$). No data were available (na) for mid-April at the late-spring evaluation timing because late-spring application and the mid-April evaluation occurred on the same day.

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Table 2. Repeated-measures analysis of application timings and their influence on the density of giant ragweed in 2007 and 2008, across four evaluation timings ranging from mid-May to mid- June.

	Giant ragweed evaluation timing[a,b]							
	2007				2008			
Herbicide application timing	Mid-May	Late May	Early June	Mid-June	Mid-May	Late May	Early June	Mid-June
	plants m^{-2}							
Saflufenacil, 100 g ai ha^{-1}								
Early fall	32 a	33 a	33 a	35 a	16 a	8 ab	17 a	15 a
Late fall	12 a	15 ab	19 ab	16 ab	16 a	20 a	21 a	24 a
Early spring	5 ab	6 ab	5 ab	7 ab	1 b	1 bc	6 ab	10 a
Late spring	1 b	3 b	3 b	3 b	0 b	0 c	1 b	8 a
Chlorimuron + tribenuron, 35 + 11 g ai ha^{-1}								
Early fall	16 a	17 a	11 a	8 a	12 a	6 ab	8 a	7 a
Late fall	5 ab	5 a	6 a	4 a	17 a	14 a	14 a	16 a
Early spring	1 b	3 a	2 a	3 a	3 ab	6 ab	9 a	14 a
Late spring	5 ab	8 a	2 a	4 a	0 b	1 b	4 a	5 a

[a] Means are separated within a column (evaluation timing) within each herbicide treatment for comparison across application timing, using the least significant difference. Means followed by a different letter are significantly different ($\alpha = 0.05$).

[b] No significant differences were detected in the early July evaluation timing; therefore, it was excluded from the table; however, it was included in the overall repeated-measures analysis. Counts before mid-May were excluded because early or late spring herbicide applications had not yet occurred.

treatments in both years in the present study (Table 2). This indicates that late-fall applications of chlorimuron + tribenuron have the potential to provide similar levels of residual control when compared with early-spring applications, which is likely due to limited herbicidal breakdown resulting from reduced microbial activity over the winter months. In 2007, chlorimuron + tribenuron applied in early fall resulted in higher giant ragweed densities at the mid-May evaluation than the early-spring application. Even though fall and early-spring applications of chlorimuron + tribenuron resulted in similar levels of giant ragweed control in 2008, neither provided control of giant ragweed adequate for planting soybean in May, thereby necessitating additional control measures.

Giant ragweed density at the mid-May evaluation was reduced after the early-spring application of saflufenacil at 100 g ha^{-1} (1 plant m^{-2}) compared with the late-fall application (16 plants m^{-1}) in 2008, but this difference was not observed in 2007 (Table 2). A distinctly greater amount of precipitation in March 2008 (19.5 cm) compared with March 2007 (0.8 cm) most likely reduced the efficacy of the fall vs. spring herbicide applications in 2008. Monnig and Bradley (2007) also determined that summer annual weed control with fall-applied herbicides is often variable; but overall, applications of chlorimuron + sulfentrazone or + tribenuron made in the early spring, 30 to 60 d before planting, were optimal for reducing winter annual weed density at planting and summer annual weed density after planting. The results from this study are in agreement with Monnig and Bradley (2007): if growers aim to control winter and summer annual weeds, early-spring applications have the potential to provide excellent winter annual control and some level of summer annual control. However, on the basis of the results from this study, control of giant ragweed after applications of chlorimuron + tribenuron or saflufenacil before April can be highly variable and additional control measures near planting will likely be necessary. The importance of residual herbicide application relative to crop planting for management of giant ragweed is demonstrated by saflufenacil at 100 g ai ha^{-1} (Table 2). The density of giant ragweed at the mid-May evaluation was markedly inferior for either of the fall applications compared with the late-spring application (near the time of crop planting).

Influence of Herbicides on Giant Ragweed Height. Most fall-applied herbicides had minimal effects on the height of giant ragweed, with two

Herbicide within application timing[a]	Rate	Giant ragweed heights in relation to nontreated[b] Mid-April	Mid-May	Early June	Early July	Mid-April	Mid-May	Early June	Early July
	g ai ha^{-1}	height (cm)							
Applied early-fall		2007				2008			
Chlorim+trib	35 + 11								
Saflufenacil	100								
Saflufenacil	50								
Simazine	1120								
2,4-D	560								
Flumioxazin	72								
Applied late-fall		2007				2008			
Chlorim+trib	35 + 11								
Saflufenacil	100								
Saflufenacil	50								
Simazine	1120								
2,4-D	560								
Flumioxazin	72								
Applied early-spring		2007				2008			
Chlorim+trib	35 + 11								
Saflufenacil	100								
Saflufenacil	50								
Simazine	1120								
2,4-D	560								
Flumioxazin	72								
Applied late-spring		2007				2008			
Chlorim+trib	35 + 11	na				na			
Saflufenacil	100	na				na			
Saflufenacil	50	na				na			
Simazine	1120	na				na			
2,4-D	560	na				na			
Flumioxazin	72	na				na			
Non-treated	-	3	15	46	95	2	6	14	21

[a]Chlorim, chlorimuron; trib, tribenuron

[b]Color legend:

- ≥95% reduction in giant ragweed height vs. non-treated
- 80-94% reduction in giant ragweed density vs. non-treated
- <80% reduction in giant ragweed density vs. non-treated
- No shading = height not statistically different than non-treated ($p < 0.05$)
- Giant ragweed height significantly greater than non-treated check

Figure 4. Relative giant ragweed heights in treated plots compared with giant ragweed height in the nontreated check in 2007 and 2008. Darker shading represents a greater reduction in height for treatments that were significantly different from the nontreated, using Dunnett's means separation ($\alpha < 0.05$). No data were available (na) for mid-April at the late-spring evaluation timing because late-spring application and the mid-April evaluation occurred on the same day.

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exceptions: (1) giant ragweed plants in the 2,4-D treatment applied in early fall of 2006 (where density was increased because of lack of interspecific competition) were taller than giant ragweed in the nontreated (Figure 4); (2) chlorimuron + tribenuron consistently reduced giant ragweed height in early June by 30 to 45%, with the exception of this premix applied in early fall 2006 and late spring 2008 (Figure 4). Giant ragweed height reductions from early- and late-spring applications paralleled the differences observed in the giant ragweed density reductions; however, no treatment reduced the height of giant ragweed through the early July evaluation. A possible reason for an observed reduction in giant ragweed density, but not in height, is likely from reduced plant competition due to lower densities in treated plots, allowing the giant ragweed to quickly reach the height of the plants in the nontreated, even though emergence was delayed because of the residual herbicide.

In general, residual herbicide application timings for the control of giant ragweed can be ranked as follows: late-spring > early-spring > early or late fall, indicating that fall and early-spring herbicide applications are less desirable if giant ragweed is a predominate weed in a given field. Overall, fall-applied residual herbicides provided poor control of giant ragweed, which often increased initial giant ragweed density and height. The greatest reductions in giant ragweed density and height were achieved after applications of chlorimuron + tribenuron or saflufenacil (100 g ha^{-1}); however, applications were more effective when they occurred near the time of planting (late spring). These data support previous research reports concluding that the efficacy of fall-applied residual herbicides on summer annual weeds is variable, leading to the conclusion that growers should consider the control of winter and summer annual weeds as independent weed management objectives (Hasty et al. 2004; Krausz et al. 2003; Stougaard et al. 1984).

Given that giant ragweed emergence can increase if fall-applied residual herbicides control competing species, growers should consider the impact that winter annual weed management might have on summer annual weed emergence, especially if glyphosate-resistant giant ragweed biotypes are present in no-till cropping systems. The increasing distribution of herbicide-resistant weed biotypes has made weed management a complex task that necessitates informed weed-management decisions. This research further promotes an overall diversified systems approach to weed management that encompasses control tactics for problematic weeds and the interacting effects with weed-management strategies used for additional weed species throughout the growing season.

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