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ARTICLE

Control of glyphosate-resistant giant ragweed (*Ambrosia trifida* L.) with premix of iodosulfuron/thiencarbazone applied alone or in tank mixtures in no-till corn (*Zea mays* L.)

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Abstract: The objectives of this study were to evaluate the efficacy of a new premix of iodosulfuron (6%)/thiencarbazone (45%) applied alone or tank-mixed with 2,4-D, dicamba, glyphosate, or metribuzin in the fall and (or) early spring followed by preemergence (PRE) and postemergence (POST) herbicide applications for control of glyphosate-resistant giant ragweed and their effect on corn yield. Field experiments were conducted in no-till corn fields infested with glyphosate-resistant giant ragweed (20–30 plants m^{-2}) near Clay Center and McCool Junction, NE, in 2013 and 2014, respectively. A premix of iodosulfuron/thiencarbazone applied alone or in split applications in the fall and early spring controlled glyphosate-resistant giant ragweed <60% and resulted in a density of 14 giant ragweed plants m^{-2}, which was comparable to the untreated control at 28 d after early spring treatment (DAEST). Metribuzin or 2,4-D applied alone resulted in <75% giant ragweed control at 28 DAEST; however, 2,4-D or dicamba tank-mixed with iodosulfuron/thiencarbazone provided ≥92% control. Treatments including 2,4-D or dicamba led to 85%–98% reduction in giant ragweed biomass at 28 DAEST. A follow-up application of a premix of isoxaflutole/thiencarbazone tank-mixed with atrazine applied PRE was not effective, although a POST application of tembotrione + atrazine resulted in >91% control at 28 d after postemergence treatment. The premix applied alone did not provide effective control of giant ragweed in corn primarily because lack of residual activity.

Key words: corn, weed biology, pest management.

Résumé : L'étude devait servir à évaluer l'efficacité d'un nouveau pré-mélange composé d'iodosulfuron (6 %) et de thiencarbazone (45 %), appliqué seul ou avec du 2,4-D, du dicamba, du glyphosate ou de la métribuzine à l'automne ou au début du printemps, avec application subséquente d'herbicides pré-levée (PRE) et post-levée (POST) pour lutter contre la grande herbe à poux résistante au glyphosate dans le maïs. En 2013 et 2014, les auteurs ont réalisé des expériences sur le terrain, dans des champs de maïs au sol non travaillé, infestés de grande herbe à poux résistante au glyphosate (20 à 30 plants par m^2), près de Clay Center et McCool Junction, au Nebraska (É.-U.). L'application seule du pré-mélange ou son application fractionnée à l'automne et tôt au printemps ramène le peuplement de la grande herbe à poux résistante au glyphosate à moins de 60 %, en réduisant la densité à 14 plants par m^2, ce qui était comparable aux résultats obtenus sur la parcelle témoin non traitée, 28 jours après traitement (JAT) au début du printemps. L'application de métribuzine ou de 2,4-D uniquement réduit la population de l'adventice en dessous de 75 %, 28 JAT au début du printemps; cependant, le mélange de 2,4-D ou de dicamba avec de l'iodosulfuron/thiencarbazone détruit au moins 92 % des plants sur la parcelle témoin. Les traitements incluant du 2,4-D ou du dicamba réduisent la biomasse de la grande herbe à poux de 85 à 98 %, 28 JAT au début de printemps. L'application PRE subséquente d'un pré-mélange d'isoxaflutole/thiencarbazone et d'atrazine n'a eu aucun effet, bien que l'application POST de tembotrione et d'atrazine ait détruit plus de 91 % de la mauvaise herbe dans la parcelle témoin, 28 JAT au début du printemps. L'application du pré-mélange seul n'a pas permis de lutter efficacement contre la grande herbe à poux, principalement faute d'activité résiduelle. [Traduit par la Rédaction]

Mots-clés : maïs, biologie des mauvaises herbes, lutte antiparasitaire.

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Introduction

Corn is the principal food grain crop in the United States, with a planting area of approximately 35.6 million ha in 2015 (USDA 2016). Horowitz et al. (2010) estimated that nearly 23.5% of corn planted in 2005 was under no-till production systems, with a significant increase in no-till planting in recent years due to benefits such as reduced soil erosion, improved water retention, and reduced fuel and labor costs (Swanton et al. 1993; Buhler 1995; Toliver et al. 2012). By 2014, more than 89% of corn planted in the United States were herbicide-tolerant cultivars (USDA 2014). Weed control is one of the challenges no-till corn growers are facing to achieve optimum production. Fickett et al. (2013) reported that broadleaved species such as *Amaranthus* spp., common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), dandelion (*Taraxacum officinale*), and velvetleaf (*Abutilon theophrasti* Medik.) at mean densities of 3, 19, 4, 3, and 3 plants m^{-2}, respectively, caused a mean predicted corn yield loss of 4.5%, with a mean economic loss of CAN$62 ha^{-1}.

Giant ragweed is an annual broadleaved weed that typically emerges from the beginning of March until the end of May in Nebraska (Kaur et al. 2016); however, late-season emergence has been observed in Indiana, Ohio, Tennessee, and Wisconsin (Harrison et al. 2001; Johnson et al. 2006; Regnier et al. 2016). The early emergence of giant ragweed contributes to its early establishment before crops are planted in the spring, making it a competitive weed for light, nutrients, space, and water (Abul-Fatih and Bazzaz 1979). The extent of damage that giant ragweed causes to crops makes it an economically important weed to control: for example, a density of 14 giant ragweed plants 10 m^{-2} was reported to cause a 90% yield loss in corn (Harrison et al. 2001).

Glyphosate has been widely used for postemergence (POST) weed control since the commercialization of glyphosate-resistant corn and soybean. The cost effectiveness, flexibility in application timing, and broad-spectrum weed control made glyphosate a popular choice among growers; however, repeated use of glyphosate for many years has led to the evolution of glyphosate-resistant weeds (Duke and Powles 2008). By 2016, 37 weed species have evolved resistance to glyphosate worldwide, including 16 species in the United States and 5 species in Canada (Heap 2016). Horseweed [*Conyza canadensis* (L.) Cronq.] was the first glyphosate-resistant weed confirmed in 2000 in Delaware (VanGessel 2001), and in 2004, glyphosate-resistant giant ragweed was confirmed in Ohio (Stachler and Loux 2005). As of 2015, glyphosate-resistant giant ragweed biotypes have been confirmed in 15 states in the United States, including Nebraska (Heap 2016), and in Ontario, Canada (Vink et al. 2012).

Acetolactacte synthetase (ALS)-inhibiting herbicides are one of the major classes of herbicides used in grain crop production fields because of their excellent crop safety and broad-spectrum weed control at lower application rates compared with several other herbicide groups (Saari et al. 1994). This group of herbicides has a longer residual activity, resulting in an extended period of weed control (Saari et al. 1992) by inhibiting the biosynthesis of isoleucine, leucine, and valine (Umbargh 1978), causing the plants to eventually die due to a lack of amino acids (Tranel and Wright 2002). A new premix of iodosulfuron-methyl (sufonylurea) (6%)/thiencarbazone-methyl (sulfonylaminocarbonyl-triazolinone) (45%), both ALS-inhibiting herbicides, was registered in 2013 for post-harvest or preplant weed control in the United States (Anonymous 2013). It can be used for foliar and residual weed control when applied to no-till or conservation tillage fields any time after the fall harvest or early spring at least 30 and 60 d prior to planting corn and soybean, respectively. If the soil pH is 7.5 or above, soybean plant back should be delayed to a 9 mo interval (Anonymous 2013). The labeled rate of this herbicide premix is 18 g a.i. ha^{-1} per calendar year in crop stubble for the control of broadleaved weeds up to 11 cm in height and annual grasses <3 cm tall (Anonymous 2013). It can also be tank-mixed with other herbicides with different modes of action (such as 2,4-D, glyphosate, metribuzin, etc.) to expand its weed control spectrum. Several no-till corn producers are now considering fall and (or) early spring application of herbicides for control of winter annual weeds such as horseweed and some early spring weeds such as giant ragweed. Therefore, early spring management of giant ragweed is vital to avoid early-season competition with corn. Davis et al. (2007) reported that glyphosate-resistant horseweed densities were effectively reduced while preventing losses in crop yield when residual herbicides such as chlorimuron, flumetsulam, metribuzin, or sulfentrazone were applied in the spring. Furthermore, Monnig and Bradley (2007) showed that fall and spring applications of chlorimuron/tribenuron + 2,4-D along with applications of chlorimuron/sulfentrazone + 2,4-D reduced the emergence of summer and winter annual weeds compared with a glyphosate + 2,4-D program. Scientific literature is not available about the efficacy of iodosulfuron/thiencarbazone applied alone or tank-mixed with other burndown herbicides for controlling glyphosate-resistant giant ragweed.

The management approach of glyphosate-resistant weeds should be proactive rather than reactive, an approach that includes the use of herbicides with different modes of action along with other methods. For example, a recent study in Nebraska revealed that preplant tillage followed by in-crop herbicide application provided season-long control of glyphosate-resistant giant ragweed in soybean (Ganie et al. 2016, 2017); therefore, an integrated weed management approach including tillage and the use of herbicide tank mixtures should be considered, where diverse methods can reduce the evolution of herbicide-resistant weeds.

The objectives of this study were to compare the efficacy of iodosulfuron/thiencarbazone premix applications for the control of glyphosate-resistant giant ragweed based on fall or spring application, split applications, or in a tank mix with 2,4-D, dicamba, glyphosate, or metribuzin, and to evaluate the effect on crop injury and yields in no-till glyphosate-resistant corn.

Materials and Methods

Field experiments were conducted at a grower's fields near Clay Center in 2012–2013 and at McCool Junction in 2013–2014. The soil at Clay Center was silty clay loam with a pH of 6.5, 17% sand, 58% silt, 25% clay, and 2.5% organic matter. The soil at McCool Junction was silty clay loam with a pH of 6.1, 17% sand, 48% silt, 35% clay, and 4.1% organic matter. The research site at Clay Center was irrigated and at McCool Junction was under rainfed conditions.

At each site, the experiment was arranged in a randomized complete block design with four replications. A total of 15 herbicide treatments including an untreated control were compared (Table 1). Herbicides were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at 276 kPa equipped with a four-nozzle boom and AIXR 110015 flat-fan nozzles (TeeJet, Spraying Systems Co., Wheaton, IL). Herbicide treatments were applied in the fall (15 Oct. 2012 and 13 Nov. 2013) after crop harvest and early spring (4 Apr. 2013 and 8 Apr. 2014) at Clay Center and McCool Junction, respectively. There was a delay in fall herbicide application in 2013 due to the late harvest of corn and unfavorable weather conditions. Glyphosate-resistant corn varieties "Pioneer 1151 HR RR2/LL" and "NK N72Q-3111 RR2/LL" were planted on 15 May 2013 and 9 May 2014 at Clay Center and McCool Junction, respectively. The seeds were planted 3 cm deep at a density of 79 000 seeds ha^{-1}. The plot size was 3 m × 9 m, which included 4 rows of corn spaced 76 cm apart. Herbicides were applied as per the recommended rates in corn (Table 1). No weeds were present at the time of fall herbicide treatments. Giant ragweed was 1–3 cm at the time of early spring herbicide treatment. All treatments except four (including the untreated control) were followed by thiencarbazone/isoxaflutole at 78 g a.i. ha^{-1} + atrazine at 560 g a.i. ha^{-1} applied before emergence (preemergence, PRE) a day after corn planting (17 May 2013 and 9 May 2014) followed by tembotrione at 92 g a.i. ha^{-1} + atrazine at 560 g a.i. ha^{-1} applied after emergence (postemergence, POST; 19 June 2013 and 3 June 2014), and three treatments were applied in the fall and (or) early spring without PRE and POST applications (refer to Table 1 for details of each herbicide program and application timing).

Data collection

During both years, data for visual estimates of giant ragweed control on a scale of 0%–100% (0% being no control and 100% being complete control) were recorded at 14 and 28 d after early spring herbicide application, 14 d after PRE application, and 14 and 28 d after POST herbicide application. Weed densities were assessed from two randomly selected 0.25 m^2 quadrats per plot at 28 d after early spring application and 28 d after POST herbicide application. At 28 d after early spring treatment (DAEST) and 28 d after POST herbicide application, giant ragweed plants that survived herbicide treatments were cut at the stem base close to the soil surface from two randomly selected 0.25 m^2 quadrats per plot, placed in paper bags, dried in an oven for 48 h at 60 °C, and the biomass was determined by taking the average of the two samples. Aboveground biomass was converted into percent biomass reduction compared with the untreated control using the equation

$$(1) \qquad \%\,\text{Biomass reduction} = [(\overline{C} - B)/\overline{C}] \times 100$$

where $\overline{C}$ is the biomass of untreated control and B is the biomass of an individual treated plot. Corn was harvested using a plot combine and yields were adjusted to 10% moisture content.

Statistical analysis

Data were subjected to analysis of variance using PROC MIXED in SAS version 9.3 (SAS Institute Inc., Cary, NC). Data were tested for normality with the use of PROC UNIVARIATE. Data for visual estimates of giant ragweed control, density and, biomass reduction were arcsine square root transformed before analysis; however, back-transformed data are presented based on the mean separation of transformed data. Year, experimental site, and herbicide treatments were considered fixed effects, while replication was considered a random effect in the model. If year × treatment interaction was not significant, data from both years were combined. Where the analysis of variance indicated that treatment effects were significant, means were separated at $p \leq 0.05$ using Tukey–Kramer's pairwise comparison test.

Results and Discussion

Year × treatment interaction was not significant for giant ragweed control estimates, biomass reduction, and density; therefore, with the exception of corn yield, data from both years were combined.

A premix of iodosulfuron/thiencarbazone applied alone at 18 g a.i. ha^{-1} in the fall or early spring resulted in <45% control of glyphosate-resistant giant ragweed (Table 2), while split applications at 9 g a.i. ha^{-1} in the fall and early spring resulted in <60% control at 28 DAEST. Thus, a premix applied alone in the fall or early spring at the labeled rate or in a split application at a reduced rate did not provide acceptable control of giant ragweed. Fall-applied herbicides primarily target winter annual weeds such as horseweed; therefore, giant ragweed control was not expected with fall-applied herbicides;

Table 1. Herbicide treatments, application timings, and rates as well as products used in field experiments for control of glyphosate-resistant giant ragweed in Nebraska in 2013 and 2014 in no-till glyphosate-resistant corn.

Treatment[a]	Product	Rate[a] (g a.e. or a.i. ha^{-1})	Timing[a]	Manufacturer
Iodo/thien fb PRE fb POST	AutumnSuper	18	Fall fb PRE fb POST	Bayer CropScience, Research Triangle Park, NC
Iodo/thien fb PRE fb POST	AutumnSuper	18	Early spring fb PRE fb POST	Bayer CropScience
Iodo/thien fb iodo/thien fb PRE fb POST	AutumnSuper	9 fb 9	Fall fb early spring fb PRE fb POST	Bayer CropScience
Dicamba fb dicamba fb PRE fb POST	Clarity	560 fb 560	Fall fb early spring fb PRE fb POST	BASF, Florham Park, NJ
Iodo/thien + dicamba fb iodo/thien + dicamba fb PRE fb POST	AutumnSuper + Clarity	9 + 560 fb 9 + 560	Fall fb Early spring fb PRE fb POST	Bayer CropScience; BASF
2,4-D fb 2,4-D fb PRE fb POST	2,4-D LV 4	830 fb 830	Fall fb early spring fb PRE fb POST	Winfield United, Shoreview, MN
Iodo/thien + 2,4-D fb iodo/thien + 2,4-D fb PRE fb POST	AutumnSuper + 2,4-D LV 4	9 + 830 fb 9 + 830	Fall fb early spring fb PRE fb POST	Bayer CropScience
Glyphosate fb glyphosate fb PRE fb POST	Roundup PowerMax	840 fb 840	Fall fb PRE fb POST	Monsanto Company, Creve Coeur, MO
Iodo/thien + glyphosate fb Iodo/thien + glyphosate fb PRE fb POST	AutumnSuper + Roundup PowerMax	9 + 840 fb 9 + 840	Fall fb early spring fb PRE fb POST	Bayer CropScience; Monsanto Company
Metribuzin fb metribuzin fb PRE fb POST	Sencor	315 fb 315	Fall fb early spring fb PRE fb POST	Loveland Products, Loveland, CO
Iodo/thien + metribuzin fb iodo/thien + metribuzin fb PRE fb POST	AutumnSuper + Sencor	9 + 315 fb 9 + 315	Fall fb early spring fb PRE fb POST	Bayer CropScience; Loveland Products
Iodo/thien	AutumnSuper	18	Early spring	Bayer CropScience
Iodo/thien + dicamba fb iodo/thien + dicamba	AutumnSuper + Clarity	9 + 560 fb 9 + 560	Fall fb early spring	Bayer CropScience; BASF
Iodo/thien + metribuzin fb iodo/thien + metribuzin	AutumnSuper + Sencor	9 + 315 fb 9 + 315	Fall fb early spring	Bayer CropScience; Loveland Products

Note: a.e., acid equivalent; a.i., active ingredient; AMS, ammonium sulfate (DSM Chemicals North America Inc., Augusta, GA); atra, atrazine; COC, crop oil concentrate (Agridex, Helena Chemicals Co., Collierville, TN); Iodo/thien, iodosulfuron/thiencarbazone-methyl; fb, followed by; PRE, preemergence; POST, postemergence.

[a]PRE herbicide included Corvus (thiencarbazone/isoxaflutole) at 78 g a.i. ha^{-1} + atrazine at 560 g a.i. ha^{-1} applied 1 d after corn planting. POST herbicide included Laudis (tembotrione) at 92 g a.i. ha^{-1} + atrazine at 560 g a.i. ha^{-1}. Adjuvants mixed with herbicide treatments were AMS at 2% *w*/*v* + COC at 1% *v*/*v*.

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Table 2. Control of glyphosate-resistant giant ragweed at 14 and 28 d after early spring treatment and biomass reduction at 28 d after early spring treatment in no-till glyphosate-resistant corn in field experiments conducted in Nebraska in 2013 and 2014.[a]

Treatment[b]	Application timing[b]	Rate (g a.e. or a.i. ha^{-1})	Giant ragweed control[a,b] (%)		Biomass reduction[a,b] (%)
			14 DAEST	28 DAEST	28 DAEST
Untreated control[c]	—	—	0	0	0
Iodo/thien	Fall	18	37bc	25cd	9c
Iodo/thien	Early spring	18	42bc	38bcd	28bc
Iodo/thien fb iodo/thien	Fall fb early spring	9 fb 9	29bcd	58bcd	45b
Dicamba fb dicamba	Fall fb early spring	560 fb 560	84a	98a	90a
Iodo/thien + dicamba fb iodo/thien + dicamba	Fall fb early spring	9 + 560 fb 9 + 560	81a	99a	98a
2,4-D fb 2,4-D	Fall fb early spring	830 fb 830	80a	73bcd	41b
Iodo/thien + 2,4-D fb iodo/thien + 2,4-D	Fall fb early spring	9 + 830 fb 9 + 830	84a	92ab	91a
Glyphosate fb glyphosate	Fall fb early spring	840 fb 840	8d	15d	10c
Iodo/thien + glyphosate fb iodo/thien + glyphosate	Fall fb early spring	9 + 840 fb 9 + 840	31bcd	50bcd	14c
Metribuzin fb metribuzin	Fall fb early spring	315 fb 315	22cd	28cd	21c
Iodo/thien + metribuzin fb iodo/thien + metribuzin	Fall fb early spring	9 + 315 fb 9 + 315	54b	58bcd	47b
Iodo/thien	Early spring	18	20cd	25cd	10c
Iodo/thien + dicamba fb iodo/thien + dicamba	Fall fb early spring	9 + 560 fb 9 + 560	84a	99a	97a
Iodo/thien + metribuzin fb iodo/thien + metribuzin	Fall fb early spring	9 + 315 fb 9 + 315	43bc	45bcd	19c

Note: a.e., acid equivalent; a.i., active ingredient; DAEST, days after early spring treatment; fb, followed by; Iodo/thien, iodosulfuron/thiencarbazone; —, no value. Means within columns followed by different lowercase letters are significantly different according to Tukey–Kramer's pairwise comparison test at $p \leq 0.05$.

[a]Year × treatment interaction was not significant; therefore, data from both years were combined.

[b]Data were arcsine square root transformed before analysis; however, data presented are the means of actual values for comparison based on interpretation from the transformed data.

[c]Control (0%) data from untreated plots were not included in analysis.

however, this premix was useful for control of winter annual weeds such as henbit (*Lamium amplexicaule* L.) and field pennycress (*Thlaspi arvense* L.) (data not shown). Similarly, Wuerffel et al. (2015) reported that fall-applied residual herbicides were not effective for controlling giant ragweed compared with late-spring (before planting) herbicide applications. Hasty et al. (2004) reported that fall application of chlorimuron/sulfentrazone resulted in 63% control of giant ragweed and 74% control when applied in early spring. Herbicides applied in the fall were not effective for giant ragweed control in this study as well as in previous studies (Hasty et al. 2004; Wuerffel et al. 2015). This is likely due to the insufficient length of herbicide residual activity compared with giant ragweed emergence timing from March to May in Nebraska.

Dicamba applied alone or tank-mixed with iodosulfuron/thiencarbazone in the fall and early spring resulted in ≥81% and ≥98% control at 14 and 28 DAEST, respectively (Table 2). Belfry and Sikkema (2015) reported dicamba applied alone or tank-mixed with atrazine applied before corn planting provided >92% control of glyphosate-resistant giant ragweed. Fall and early spring application of 2,4-D was not effective (73% control); however, tank-mixing 2,4-D with iodosulfuron/thiencarbazone provided 84% and 92% giant ragweed control at 14 and 28 DAEST, respectively (Table 2). Barnett et al. (2013) also reported >95% control of glyphosate-resistant giant ragweed by tank-mixing 2,4-D with glufosinate compared with 2,4-D applied alone (<77% control) at 20 d after treatment. Jhala et al. (2014) and Kaur et al. (2014) further reported >90% control of glyphosate-resistant giant ragweed with 2,4-D applied 3 wk before planting soybean. In contrast, Hasty et al. (2004) reported no improvement in control of giant ragweed by tank-mixing residual herbicides with glyphosate and 2,4-D; however, this combination significantly increased control of winter annual weeds such as common chickweed [*Stellaria media* (L.) Vill.], annual bluegrass (*Poa annua* L.), cressleaf groundsel (*Senecio glabellus* Poir.), and shepherd's purse [*Capsella bursa-pastoris* (L.) Medik.]. Metribuzin applied alone in the fall and early spring resulted in 28% control and tank-mixing with iodosulfuron/thiencarbazone provided 58% control at 28 DAEST (Table 2) primarily due to limited residual activity of this combination to provide effective control of giant ragweed that start emerging in March in Nebraska.

Giant ragweed biomass was affected by herbicide treatments due to variability in plant survival in different treatments (Table 2). For example, dicamba applied alone or tank-mixed with iodosulfuron/thiencarbazone resulted in ≥90% reduction in giant ragweed biomass and was comparable to 2,4-D tank-mixed with iodosulfuron/thiencarbazone, although other treatments resulted in <50% biomass reduction. This might be due to giant ragweed's sensitivity to phenoxy herbicides (Jhala et al. 2014), which resulted in excellent control and reduced biomass. Vink et al. (2012) also reported ≥97% reduction in glyphosate-resistant giant ragweed biomass with dicamba applied preplant followed by POST in dicamba-resistant soybean; however, relying only on dicamba may result in the evolution of dicamba-resistant weed. For example, kochia in western Nebraska has been confirmed resistant to dicamba due to repeated application (Crespo et al. 2014).

A PRE application of isoxaflutole/thiencarbazone at 78 g a.i. ha^{-1} tank-mixed with atrazine at 560 g a.i. ha^{-1} was not effective due to giant ragweed being 12–18 cm tall when PRE herbicides were applied in corn. For example, a premix of iodosulfuron/thiencarbazone applied in the fall or early spring at the labeled rate or in split application at a reduced rate resulted in <65% control of giant ragweed regardless of PRE herbicide treatment (Table 3). Belfry and Sikkema (2015) reported 89% control of glyphosate-resistant giant ragweed with isoxaflutole at 105 g a.i. ha^{-1} + atrazine at 1063 g a.i. ha^{-1}; however, this treatment was applied before corn planting, when giant ragweed was <8 cm tall. A follow-up POST application of tembotrione at 92 g a.i. ha^{-1} tank-mixed with atrazine at 560 g a.i. ha^{-1} was effective and provided 81%–99% giant ragweed control at 14 and 28 d after POST (DAPOST) (Table 3). Similarly, Williams et al. (2011) reported 77%–95% control of giant ragweed in sweet corn with a tank mixture of tembotrione and atrazine. A POST application of tembotrione + atrazine was more effective for control of giant ragweed compared with a PRE application of isoxaflutole/thiencarbazone + atrazine. Herbicide treatments without PRE and POST herbicide application limited giant ragweed control to <77% (Table 3). Iodosulfuron/thiencarbazone applied at the labeled rate in the fall or early spring or in split application regardless of the herbicide tank mix but followed by PRE and POST herbicide application resulted in >90% giant ragweed control later in the season in corn. This is due to the emergence of giant ragweed after early-spring herbicide application, indicating the importance of follow-up herbicide application for season-long control of giant ragweed in corn.

Giant ragweed densities differed between herbicide treatments (Table 4). The untreated control had the highest density (25 plants m^{-2}), comparable with glyphosate (16 plants m^{-2}), metribuzin (22 plants m^{-2}), and iodosulfuron/thiencarbazone applied alone (≥20 plants m^{-2}). All other treatments resulted in lower giant ragweed densities (0–6 plants m^{-2}). The results of giant ragweed control and density were reflected in giant ragweed aboveground biomass collected at 28 DAPOST. Similarly, Robinson et al. (2012) reported 96%–99% reduction in glyphosate-resistant giant ragweed biomass with 2,4-D at 28 d after treatment (DAT) under no-crop conditions. Iodosulfuron/thiencarbazone applied alone or tank-mixed with glyphosate applied in the fall or early spring resulted in <60% reduction in giant ragweed biomass due to poor control. There were no injury symptoms in corn in any treatment (data not shown); hence, all herbicide treatments used in this study are safe to use on corn if applied as per the label instructions.

Year × treatment interaction was significant for corn seed yield ($p = 0.0484$); therefore, yield data are presented separately for both years. This might be because the research site in 2013 was irrigated, which resulted in a higher yield compared with 2014. Early-spring application of iodosulfuron/thiencarbazone applied alone or tank-mixed with metribuzin without PRE and POST herbicide applications resulted in the lowest yield and was comparable with the untreated control (<6500 kg ha^{-1}) (Table 4). The treatments without PRE and POST herbicide application resulted in <7200 kg ha^{-1}. In this study, a POST application of tembotrione and atrazine was very effective for controlling giant ragweed, with most treatments resulting in >90% control at 28 DAPOST and at harvest. For example, iodosulfuron/thiencarbazone applied alone in the fall or early spring or in split application and then followed by PRE and POST application of herbicides resulted in >16 000 and >12 000 kg ha^{-1} corn yield in 2013 and 2014, respectively, compared with iodosulfuron/thiencarbazone applied in the early spring without PRE and POST herbicide application (<4700 kg ha^{-1}).

Practical implications

This is the first report evaluating the efficacy of iodosulfuron/thiencarbazone premix applied alone or tank-mixed with commonly used herbicides applied in the fall and (or) early spring followed by PRE application of isoxaflutole/thiencarbazone + atrazine and POST application of tembotrione + atrazine (in most treatments; Table 1) for management of glyphosate-resistant giant ragweed in glyphosate-resistant corn. The results suggested that a premix of iodosulfuron/thiencarbazone applied in the fall or early spring or in split applications were not effective for giant ragweed control. Additionally, fall or early-spring application of dicamba alone or tank-mixed with iodosulfuron/thiencarbazone, or 2,4-D + iodosulfuron/thiencarbazone, provided 92%–99% giant ragweed

Table 3. Control of glyphosate-resistant giant ragweed at 14 d after preemergence, at 14 and 28 d after postemergence, and at harvest in no-till corn in Nebraska in 2013 and 2014.[a]

Treatment[a]	Application timing[a]	Rate[b] (g a.e. or a.i. ha^{-1})	Control[b] (%)			
			14 DAPRE	14 DAPOST	28 DAPOST	At harvest
Untreated control[c]	—	—	0	0	0	0
Iodo/thien fb PRE fb POST	Fall fb PRE fb POST	18	63b	88ab	96a	95a
Iodo/thien fb PRE fb POST	Early spring fb PRE fb POST	18	64b	93a	95a	92a
Iodo/thien fb iodo/thien fb PRE fb POST	Fall fb early spring fb PRE fb POST	9 fb 9	57bc	92a	97a	96a
Dicamba fb dicamba fb PRE fb POST	Fall fb early spring fb PRE fb POST	560 fb 560	92a	96a	98a	97a
Iodo/thien + dicamba fb iodo/thien + dicamba fb PRE fb POST	Fall fb early spring fb PRE fb POST	9 + 560 fb 9 + 560	92a	98a	99a	99a
2,4-D fb 2,4-D fb PRE fb POST	Fall fb early spring fb PRE fb POST	830 fb 830	87a	92a	96a	95a
Iodo/thien + 2,4-D fb iodo/thien + 2,4-D fb PRE fb POST	Fall fb early spring fb PRE fb POST	9 + 830 fb 9 + 830	91a	97a	99a	98a
Glyphosate fb glyphosate fb PRE fb POST	Fall fb early spring fb PRE fb POST	840 fb 840	22d	74b	81b	71b
Iodo/thien + glyphosate fb iodo/thien + glyphosate fb PRE fb POST	Fall fb early spring fb PRE fb POST	9 + 840 fb 9 + 840	63b	86ab	96a	96a
Metribuzin fb metribuzin fb PRE fb POST	Fall fb early spring fb PRE fb POST	315 fb 315	47c	87ab	91a	91a
Iodo/thien + metribuzin fb iodo/thien + metribuzin fb PRE fb POST	Fall fb early spring fb PRE fb POST	9 + 315 fb 9 + 315	82ab	98a	98a	97a
Iodo/thien	Early spring	18	28d	0c	0c	0c
Iodo/thien + dicamba fb iodo/thien + dicamba	Fall fb early spring	9 + 560 fb 9 + 560	81ab	75b	76b	70b
Iodo/thien + metribuzin fb iodo/thien + metribuzin	Fall fb early spring	9 + 315 fb 9 + 315	64b	15c	21c	23c

Note: a.e., acid equivalent; a.i., active ingredient; DAPRE, days after preemergence treatment; DAPOST, days after postemergence treatment; fb, followed by; Iodo/thien, iodosulfuron/thiencarbazone; —, no value. PRE herbicide included Corvus (thiencarbazone/isoxaflutole) at 78 g a.i. ha^{-1} + atrazine at 560 g a.i. ha^{-1} applied 1 d after corn planting. POST herbicide included Laudis (tembotrione) at 92 g a.i. ha^{-1} + atrazine at 560 g a.i. ha^{-1}. Adjuvants mixed with herbicide treatments were AMS at 2% *w*/*v* + COC at 1% *v*/*v*. Means within columns followed by different lowercase letters are significantly different according to Tukey–Kramer's pairwise comparison test at $p \leq 0.05$.

[a]Year × treatment interaction was not significant; therefore, data from both years were combined.

[b]Data were arcsine square root transformed before analysis; however, data presented are the means of actual values for comparison based on interpretation from the transformed data.

[c]Giant ragweed control (0%) data from untreated plots were not included in analysis.

Table 4. Effect of herbicide treatments on glyphosate-resistant giant ragweed density, biomass reduction, and corn yield in field experiments conducted in Nebraska in 2013 and 2014.[a]

			Giant ragweed[b]		Corn yield (kg ha^{-1})	
Treatment	Application timing	Rate (g a.e. or a.i. ha^{-1})	Density (No. m^{-2})	Biomass reduction (%)	2013	2014
Untreated control	—	—	25a	0	3 016d	6 373cd
Iodo/thien fb PRE fb POST	Fall fb PRE fb POST	18	21a	48cd	16 584a	12 668ab
Iodo/thien fb PRE fb POST	Early spring fb PRE fb POST	18	20a	59cd	16 048a	12 170ab
Iodo/thien fb iodo/thien PRE fb POST	Fall fb early spring fb PRE fb POST	9 fb 9	24a	70b	16 735a	12 406ab
Dicamba fb dicamba fb PRE fb POST	Fall fb early spring fb PRE fb POST	560 fb 560	3b	81ab	14 927ab	12 415ab
Iodo/thien + dicamba fb iodo/thien + dicamba fb PRE fb POST	Fall fb early spring fb PRE fb POST	9 + 560 fb 9 + 560	2b	95a	17 692a	12 739ab
2,4-D fb 2,4-D PRE fb POST	Fall fb early spring fb PRE fb POST	830 fb 830	5b	76b	14 275ab	12 543ab
Iodo/thien + 2,4-D fb iodo/thien + 2,4-D fb PRE fb POST	Fall fb early spring	9 + 830 fb 9 + 830	3b	86ab	16 095a	13 766a
Glyphosate fb glyphosate fb PRE fb POST	Fall fb early spring fb PRE fb POST	840 fb 840	26a	19d	8 733bc	11 972ab
Iodo/thien + glyphosate fb iodo/thien + glyphosate fb PRE fb POST	Fall fb early spring fb PRE fb POST	9 + 840 fb 9 + 840	5b	66bc	16 035ab	11 860ab
Metribuzin fb metribuzin fb PRE fb POST	Fall fb early spring fb PRE fb POST	315 fb 315	22a	31d	13 307ab	12 955ab
Iodo/thien + metribuzin fb iodo/thien + metribuzin fb PRE fb POST	Fall fb early spring fb PRE fb POST	9 + 315 fb 9 + 315	5b	74b	15 325a	12 533ab
Iodo/thien	Early spring	18	21a	15d	4 425d	4 696d
Iodo/thien + dicamba fb iodo/thien + dicamba	Fall fb early spring	9 + 560 fb 9 + 560	0b	75b	11 375bc	7 200c
Iodo/thien + metribuzin fb iodo/thien + metribuzin	Fall fb early spring	9 + 315 fb 9 + 315	6b	64bc	5 243cd	5 489cd

Note: a.e., acid equivalent; a.i., active ingredient; fb, followed by; Iodo/thien, iodosulfuron/thiencarbazone-methyl; —, no value. PRE herbicide included Corvus (thiencarbazone/isoxaflutole) at 78 g a.i. ha^{-1} + atrazine at 560 g a.i. ha^{-1} applied 1 d after corn planting. POST herbicide included Laudis (tembotrione) at 92 g a.i. ha^{-1} + atrazine at 560 g a.i. ha^{-1}. Means within columns followed by different lowercase letters are significantly different according to Tukey–Kramer's pairwise comparison test at $p \leq 0.05$.

[a]Year × treatment interactions for giant ragweed density and biomass were not significant; therefore, data from both years were combined; however, interaction was significant for corn yield; therefore, corn yield data from both years were analyzed separately.

[b]Giant ragweed density and biomass data were taken at 28 d after postemergence herbicide application. Data were arcsine square root transformed before analysis; however, data presented are the means of actual values for comparison based on interpretation from the transformed data.

control at 28 DAEST; however, POST application of tembotrione + atrazine was important for providing season-long control. It was observed in this study that a premix of iodosulfuron/thiencarbazone applied in the early spring without PRE and POST herbicides resulted in <30% giant ragweed control throughout the growing season and resulted in <5000 kg ha^{-1} corn yield; therefore, not effective for giant ragweed management. It is concluded that a premix of iodosulfuron/thiencarbazone does not provide acceptable control of giant ragweed but may be used for control of winter annual weed species. ALS-resistant giant ragweed has been reported in the eastern Corn Belt of the United States and in Ontario, Canada; therefore, herbicide programs with multiple effective modes of action are needed to control giant ragweed resistant to glyphosate and ALS inhibitors. Recent studies in Nebraska reported >90% control of giant ragweed with preplant applications of herbicide programs that included 2,4-D as a tank mix partner or preplant tillage (Jhala et al. 2014; Kaur et al. 2014; Ganie et al. 2016, 2017). Therefore, an integrated weed management approach should be adopted for effective management of herbicide-resistant weeds, including giant ragweed.

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