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Corresponding author:
Rodrigo Werle; Email: rwerle@wisc.edu

Postemergence giant ragweed management as affected by soil and cover crop management, soybean planting time, and preemergence herbicide application

Guilherme Chudzik[1], Jose J. Nunes[2], Nicholas J. Arneson[3], Ryan P. DeWerff[4], Victor de Sousa Ferreira[5], Christopher Proctor[6], David E. Stoltenberg[7], Shawn Conley[8] and Rodrigo Werle[9]

[1]Graduate Student, Department of Plant and Agroecosystem Sciences, University of Wisconsin–Madison, Madison, WI, USA; [2]Graduate Student, Department of Plant and Agroecosystem Sciences, University of Wisconsin–Madison, Madison, WI, USA; [3]Outreach Program Manager, Department of Plant and Agroecosystem Sciences, University of Wisconsin–Madison, Madison, WI, USA; [4]Research Specialist, Department of Plant and Agroecosystem Sciences, University of Wisconsin–Madison, Madison, WI, USA; [5]Graduate Student, Department of Agronomy and Horticulture, University of Nebraska, Lincoln, NE, USA; [6]Associate Professor, Department of Agronomy and Horticulture, University of Nebraska, Lincoln, NE, USA; [7]Professor, Department of Plant and Agroecosystem Sciences, University of Wisconsin–Madison, Madison, WI, USA; [8]Professor, Department of Plant and Agroecosystem Sciences, University of Wisconsin–Madison, Madison, WI, USA and [9]Associate Professor, Department of Plant and Agroecosystem Sciences, University of Wisconsin–Madison, Madison, WI, USA

Abstract

Early soybean planting and cover crop adoption in the U.S. Midwest prompt investigation into the impact of these practices on weed community dynamics and best management practices. While previous research has explored different aspects of giant ragweed control, the specific integration among soil management practices, including cover crop adoption, soybean planting timing, and herbicide use, has not been thoroughly investigated. This study assessed the effects of soil management, soybean planting time, and preemergence (PRE) herbicide application on giant ragweed control and soybean yield in Wisconsin and Nebraska in 2022 and 2023. The study included a factorial arrangement of four soil management treatments (conventional tillage, no-till, and fall-planted cereal rye early terminated and terminated at planting [planting green]), two soybean planting times, and two PRE herbicide treatments (PRE and no PRE). POST herbicides were applied when ~50% of giant ragweed plants within each treatment reached ~10 cm in height. In Nebraska, cereal rye and tillage treatments without a PRE had at least 67% lower giant ragweed density than no-till at POST. In no-till, densities were at least 60% lower with PRE compared to no PRE. In Wisconsin, cereal rye did not reduce giant ragweed density at POST compared to no-till, likely due to relatively low biomass accumulation. In contrast, delayed soybean planting reduced giant ragweed density for most treatments but lowered soybean yield in no-till and planting-green treatments. The PRE herbicides had either no effect or positive effects on reducing giant ragweed density and increasing soybean yield. Overall, this study suggests that soil management and soybean planting timing are crucial for effective giant ragweed management in Wisconsin, where biotypes with a long emergence window during the spring and summer are present, while in Nebraska, soil management and soybean planting timing are less critical due to giant ragweed biotypes with an early and short emergence window in the spring.

Introduction

Giant ragweed is a summer annual weed species native to North America and ranked among the most difficult weeds to manage in the U.S. Midwest (Chudzik et al. 2024; Regnier et al. 2016). The competitive nature of giant ragweed is evident in its major impact on soybean yield when the species is not properly managed (Abul-Fatih et al. 1979; Webster et al. 1994). Several giant ragweed populations in the United States, including in Wisconsin, have evolved resistance to glyphosate, acetolactate synthase inhibitors, or both (Glettner and Stoltenberg 2015; Marion et al. 2017; Wilson et al. 2020). More recently, a protoporphyrinogen oxidase inhibitor–(i.e., fomesafen- and lactofen-) resistant giant ragweed population was identified in Wisconsin (Faleco et al. 2024). While herbicide resistance hinders control measures, the timing of weed emergence is another critical factor influencing management practices (Werle et al. 2014). Although there are reports on giant ragweed emerging only early in the season in the western part of the U.S. Corn Belt (Kaur et al. 2016; Werle et al. 2014), populations in the eastern part of the U.S. Corn Belt have been documented to show an extended period of emergence from April into July, often requiring multiple POST herbicide applications for effective control (DeWerff and Werle 2024; Schutte et al. 2012; Striegel et al. 2021b).

Herbicides represent the main tactic for weed control by growers, being applied on more than 95% of corn (*Zea mays* L.) and soybean acreage in the United States (USDA-NASS 2020, 2021). Difficult-to-control species like giant ragweed require strategic herbicide management. According to Wuerffel et al. (2015), the emergence pattern of giant ragweed dictates the best herbicide programs, where residual herbicides should be applied at planting time, followed by foliar or residual herbicides after crop emergence, for effective giant ragweed control. Residual herbicide mixes used for giant ragweed control at soybean planting are generally less effective compared to those used at corn planting, particularly corn herbicide mixes containing mesotrione and atrazine (Silva et al. 2023; Striegel et al. 2021a; Westrich et al. 2024). Silva et al. (2023) compared multiple corn residual herbicide mixes and found that the combination of different sites of action was key to improving giant ragweed control, a finding also reported by DeWerff and Werle (2024) with soybean herbicides. However, control levels of giant ragweed were lower when compared to small-seeded waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] (DeWerff and Werle 2024). Combining multiple active ingredients and incorporating nonchemical strategies is key to enhancing giant ragweed control (Faleco et al. 2024; Ganie et al. 2016; Johnson et al. 2007).

Even though giant ragweed in Wisconsin can still be controlled by a wide range of POST herbicides (Werle et al. 2023), herbicides are not the only tools available to effectively control weeds (Ganie et al. 2016; Owen et al. 2015). Agricultural practices, such as cover crop adoption, timing of operations, and soil management, can greatly affect conditions in which weed seeds germinate and grow (Chahal et al. 2021; Nunes et al. 2024; Teasdale and Mohler 1993). Consequently, utilizing a diverse range of control strategies, including preventive, biological, chemical, cultural, and/or mechanical strategies, creates an integrated approach to weed management, enhancing the likelihood of successful weed control and delaying further herbicide resistance evolution (Harker and O'Donovan 2013; Norsworthy et al. 2012).

Tillage is a common mechanical practice used for seedbed preparation and weed control before crop establishment but is generally considered detrimental to soil health (Blanco-Canqui and Lal 2009). Despite its potential negative effects, tillage can benefit weed management by reducing the reliance on commonly used burndown herbicides (Dang et al. 2018). Ganie et al. (2016) found that preplant tillage effectively controlled early-season giant ragweed in Nebraska, providing an alternative control method and alleviating selection pressure imposed by commonly used burndown herbicides. In contrast, conservation practices, such as no-till, can serve as a more sustainable alternative to traditional tillage systems, particularly from a soil health standpoint (Blanco-Canqui and Lal 2009; Triplett and Dick 2008). One benefit of no-till systems compared to tillage is the higher giant ragweed seed predation by insects, birds, and rodents (Davis et al. 2013; Harrison et al. 2003) and the rapid decay (~2 yr) of seeds present on the soil surface (Davis et al. 2016; Harrison et al. 2007). In these systems, where soil disturbance is absent, growers typically rely on herbicides for preplant burndown treatments to manage emerging giant ragweed seedlings (Zimmer et al. 2018). Whether employing tillage or burndown herbicides, the essential aim remains the same: starting the crop season with a clean field by effectively controlling weeds, ensuring lower weed densities, and minimizing early competition with the crop, ultimately preventing yield losses and delaying resistance to commonly used POST herbicides (Davis et al. 2010; Ganie et al. 2016; Harrison et al. 2001; Norsworthy et al. 2012).

In addition to no-till systems, adoption of cereal rye as a cover crop can enhance soil health and sustainability (Blanco-Canqui and Lal 2009). Using cereal rye as a fall-seeded cover crop can serve as an additional tool for early-season weed suppression and increase the sustainability of weed management by reducing selection pressure for herbicide resistance (Grint et al. 2022b; Werle et al. 2017). A key point for cover crop management is termination time in the spring; late-terminated cereal rye can produce more biomass than early-terminated rye, increasing weed suppression (Grint et al. 2022b; Nunes et al. 2024). There is a trade-off when planning to terminate the cover crop early (i.e., >7 d before planting): it restricts the growth window for the cereal rye cover crop, leading to reduced biomass accumulation and, consequently, lower weed suppression potential. However, previous research has indicated that early soybean planting dates in Wisconsin are associated with increased yields (Mourtzinis et al. 2017), supporting the need to optimize soybean planting times. Delaying cereal rye termination until or after crop planting enables growers to benefit from the increased biomass production to suppress weeds without delaying crop planting time, thus optimizing yield potential (Grint et al. 2022a). This practice is commonly referred to as planting green, aiming to maximize the benefits that cover crops can provide (Reed et al. 2019). For instance, corn can be sensitive to high levels of cover crop biomass, potentially leading to yield losses, while properly managed cereal rye cover crop biomass usually has little to no direct impact on soybean yield (DeSimini et al. 2020; Grint et al. 2022a; Nunes et al. 2023a).

Integrating both early-planted soybean and cover crops can be challenging because of the short growth window that the cover crop will have when planting the crop earlier in the U.S. Midwest (Nichols et al. 2020). While previous research has explored different aspects of giant ragweed control, the specific integration among soil management, including cover crop adoption, soybean planting timing, and herbicide use has not been thoroughly investigated. This study aimed to fill this knowledge gap by assessing the effects of soil management, soybean planting time, and preemergence (PRE) herbicide application on giant ragweed control and soybean yield in southern Wisconsin and eastern Nebraska in 2022 and 2023.

Materials and Methods

Field Procedures

Experiments were conducted at the Rock County Farm near Janesville, WI (42.726°N, 89.022°W), and at the University of Nebraska–Lincoln Havelock Research Farm near Lincoln, NE (40.856°N, 96.616°W). The soil characteristics for each site are presented in Table 1. The experiments were established in fields naturally infested with giant ragweed; in Wisconsin, corn was grown the year prior (corn-soybean rotation field), while in Nebraska, the field was fallow the year prior (fallow-soybean sequence). Plot dimensions were 9.1 × 3 m, consisting of four rows of soybean (row spacing of 76 cm). Cereal rye was no-till drilled in the fall before each experimental season with a row spacing of 19 cm and at a depth of 2.5 cm. Soybean cultivars, cereal rye

Table 1. Soil information for field experiments conducted at the Rock County Farm near Janesville, WI, and the Havelock Research Farm near Lincoln, NE, in 2022 and 2023.

Site	Year	pH	Organic matter	Soil texture
			%	
Janesville, WI	2022	6.5	3.3	silt loam (21% sand, 60% silt, 19% clay)
	2023	6.4	3.6	silt loam (21% sand, 62% silt, 17% clay)
Lincoln, NE	2022	5.9	3.7	clay loam (20% sand, 49% silt, 31% clay)
	2023	5.9	3.7	clay loam (20% sand, 49% silt, 31% clay)

Table 2. Soybean cultivar, cereal rye varieties, and seeding rates for field experiments conducted at the Janesville, WI, and Lincoln, NE, sites in 2022 and 2023.

	Janesville, WI				Lincoln, NE			
	Soybean		Cereal rye		Soybean		Cereal rye	
Year	Cultivar	Seeding rate	Variety	Seeding rate	Cultivar	Seeding rate	Variety	Seeding rate
		seeds ha^{-1}		kg ha^{-1}		seeds ha^{-1}		kg ha^{-1}
2022	NK20-E3	345,947	Aroostook	67.3	NK29-Z4E3	321,236	Elbon	112.2
2023	NK22-C4E3	345,947	Aroostook	67.3	NK29-Z4E3	321,236	Elbon	112.2

Table 3. Timing of soybean and cereal rye cover crop field operations at the Janesville, WI, and Lincoln, NE, sites in 2022 and 2023.[a]

Field operation	Janesville, WI		Lincoln, NE	
	2021–2022	2022–2023	2021–2022	2022–2023
Cereal rye planting	5 Nov 2021	28 Oct 2022	16 Nov 2021	2 Nov 2022
Early soybean planting + PRE application	16 May 2022	18 May 2023	12 May 2022	15 May 2023
Early soybean: CC early termination	4 May 2022	9 May 2023	26 Apr 2022	27 Apr 2023
Early soybean: CC late termination	17 May 2022	18 May 2023	11 May 2022	15 May 2023
Late soybean planting + PRE application	1 Jun 2022	31 May 2023	31 May 2022	23 May 2023
Late soybean: CC early termination	17 May 2022	18 May 2023	19 May 2022	15 May 2023
Late soybean: CC late termination	1 Jun 2022	31 May 2023	31 May 2022	22 May 2023
Soybean harvest	18 Oct 2022	10 Oct 2023	30 Sep 2022	28 Sep 2023

[a]Abbreviation: CC, cover crop.

varieties, and seeding rates are shown in Table 2. Timing of field operations is shown in Table 3.

Experiments were established in a three-way factorial arrangement in a randomized complete-block design with four replicates (a total of 16 treatments). Factor A consisted of four soil management treatments: conventional tillage (Wisconsin, chisel plow in the fall and field cultivator in the spring within a day of planting; Nebraska, field cultivator in the spring within a day of planting), no-till, and two no-till fall-planted cereal rye treatments (early terminated [chemical termination 10 to 14 d before soybean planting] and late terminated [chemical termination within 3 d after soybean planting, referred to as planting green]). Factor B consisted of soybean planting time (early [mid-May] and late [late May]). Early and late in this context refer to the designated planting times within the study and not necessarily to the earliest and latest planting times according to regional farming practices. Factor C consisted of PRE herbicide application (yes and no PRE).

Herbicide Applications

Cereal rye was terminated with glyphosate (1,260 g ae ha^{-1}, Roundup PowerMAX®, Bayer Crop Science, St. Louis, MO, USA) plus ammonium sulfate (AMS) at 1,400 g ha^{-1}. PRE herbicide treatments consisted of the absence (no PRE) or application (yes PRE) of a commercial premix (Sonic®, Corteva Agriscience, Indianapolis, IN, USA) of sulfentrazone (280 g ai ha^{-1}) + cloransulam (36 g ai ha^{-1}). This commercial premix provided superior performance of residual giant ragweed control when compared to other herbicides in research previously conducted at the Janesville, WI, site (DeWerff and Werle 2024). Glyphosate was also applied to all no-till treatments (including cereal rye treatments) within a respective soybean planting time to control emerged weeds, aiming to create the same weed-free conditions for all treatments at crop planting. To simulate common practices employed by soybean growers, glyphosate, 2,4-D (1,064 g ae ha^{-1}, Enlist One®, Corteva Agriscience), and AMS were applied POST. At Janesville, POST application took place when ~50% of giant ragweed plants within each treatment reached a height of 10 cm. At Lincoln, where an early and shorter emergence window of giant ragweed was expected (Kaur et al. 2016) and observed (VdSF field observations; July 2022 and 2023), the application timing was synchronized with planting dates and deployed when 50% of giant ragweed plants with the same soybean planting time treatments reached 10 cm in height. In treatments in which giant ragweed was absent, the POST application was made to control other weeds to prevent interference with study results. To simulate what a grower would do to have clean end-of-season fields following the POST application, glyphosate + glufosinate (657 g ha^{-1}, Liberty®, Bayer Crop Science, Research Triangle Park, NC, USA) + AMS were applied late post (LPOST) if new cohorts of giant ragweed and/or other weeds were present at the soybean R1 growth stage. Herbicides were applied using a CO_2-pressurized backpack sprayer with six nozzles spaced 50.8 cm apart at a boom height 50 cm from the soil surface. For PRE and POST applications, TeeJet® TTI11002

Table 4. Monthly precipitation and average temperature during the growing season at the Janesville, WI, and Lincoln, NE, sites in 2022 and 2023.

	Janesville, WI						Lincoln, NE					
	Average temperature			Precipitation			Average temperature			Precipitation		
Month	2022	2023	30-yr	2022	2023	30-yr	2022	2023	30-yr	2022	2023	30-yr
	C			mm			C			mm		
Apr	5.9	9.5	8.1	120	55	97	9.6	11.3	10.5	47	35	77
May	16	16	14.6	31	64	111	17.4	18.9	16.5	128	10	136
Jun	20.3	20.5	20.1	59	45	139	23.5	23.2	22.3	115	69	124
Jul	22	22	22.2	96	81	105	25.1	23.4	24.8	66	187	101
Aug	20.8	21.2	21	86	63	113	24.7	24.1	23.6	19	101	93
Sep	16.9	18.4	16.9	114	92	99	20.8	20.9	19.3	33	26	85
Oct	9.5	10.8	10	29	118	78	12.5	12.4	12.2	18	43	66
Total	15.9	17.3	16.1	535	519	742	19.1	19.2	18.5	426	472	682

and TeeJet® AIXR11002 nozzles were used, respectively (TeeJet® Technologies, Springfield, IL, USA). The sprayers were calibrated to deliver 140 L ha^{-1}.

Data Collection

The study had four cereal rye termination times, consisting of early termination and planting green for two soybean planting times (Table 3). At each cereal rye cover crop termination time, biomass from three random 0.1-m^{-2} (30.5 × 30.5 cm) quadrats per plot were clipped at the soil level and dried until a constant weight at 60 C to determine aboveground cereal rye biomass. At POST application, two 0.25-m^{-2} quadrats (50 × 50 cm) were randomly placed in the center row of treated plots to determine giant ragweed plant density and the height of five randomly selected plants immediately before application.

The 30-yr average (1991 to 2020), 2022, and 2023 temperature and rainfall data were obtained using Daymet weather data for 1-km grids (Thornton et al. 2022). Monthly temperature and precipitation for 2022, 2023, and 30-yr normal were summarized using R statistical software (version 4.3.1; R Core Team 2023).

At crop maturity, the center two rows of each plot were harvested using an ALMACO plot combine (ALMACO, Nevada, IA, USA) equipped with a Seed Spector LRX (ALMACO) grain gauge in Wisconsin and with a Zurn 150 plot combine (ZURN USA, Brooklyn Park, MN, USA) equipped with a HarvestMaster H2 GrainGage (Juniper Systems, Logan, UT, USA) in Nebraska. Soybean yield data were adjusted to 13% moisture.

Data Analyses

Statistical analyses were performed using R statistical software (version 4.3.1; R Core Team 2023). Before analyses, model assumptions were visually assessed for normal distribution and homogeneity of variance. A square-root transformation met model assumptions for cover crop biomass and giant ragweed density at the POST timing; back-transformed means are presented. For soybean yield data, no transformation was needed. Analysis of variance was conducted for each response variable to assess differences among treatments. Fixed effects included soil management, planting time, and PRE treatment, while replications were treated as a random effect. Means were separated using Fisher's protected least significant difference (LSD) test with the EMMEANS package ($P \leq 0.05$) (Lenth 2023). Interactions between treatments and years were significant for all response variables ($P < 0.05$; data not shown); thus data for each response variable were analyzed and are presented and discussed separately for each site-year.

Table 5. Cereal rye cover crop dry biomass at termination time as affected by soybean planting time and cover crop termination treatments at the Janesville, WI, and Lincoln, NE, sites in 2022 and 2023.[a,b,c]

		Janesville, WI		Lincoln, NE	
Soybean planting time	CC termination	2022	2023	2022	2023
		Mg ha^{-1}			
Early	Early terminated	0.17 c	0.39 c	0.10 c	0.21 c
	Planting green	1.05 b	1.25 b	0.46 b	0.88 b
Late	Early terminated	1.12 b	1.22 b	1.29 a	0.68 b
	Planting green	2.40 a	3.64 a	1.52 a	1.82 a

[a]Abbreviation: CC, cover crop.
[b]Cereal rye CC treatments included cereal rye CC terminated 14 d before soybean planting (early terminated) and cereal rye CC terminated at soybean planting (planting green).
[c]Means followed by the same letter within a column are not different according to Fisher's LSD ($\alpha = 0.05$).

Results and Discussion

Weather

The accumulated precipitation was below the 30-yr average over the growing season (April to October) for both sites and years (Table 4). The 2023 growing season was marked by drought conditions across the Midwest, with the first 3 mo of the season (April to June) being particularly dry at both sites.

Cereal Rye Cover Crop Biomass

For all site-years, cover crop biomass was affected by termination timing and soybean planting time main effects ($P < 0.05$). The early termination of cereal rye for early-planted soybean consistently resulted in lower levels of biomass (<0.5 Mg ha^{-1}) for all site-years, while delaying cereal rye termination time until late May led to higher biomass levels across years, with 2.4 to 3.6 Mg ha^{-1} in Wisconsin and 1.5 to 1.8 Mg ha^{-1} in Nebraska (Table 5). The levels of biomass obtained in this study are consistent with findings from other studies where cereal rye was late established (October/November) during the fallow period in corn-soybean rotation in Wisconsin (Grint et al. 2022b).

When the cereal rye can be drilled earlier in the fall, shortly after corn silage harvest (September to October), for example, substantial amounts of biomass (>3 Mg ha^{-1}) can be achieved even with termination occurring from April to early May, as

Table 6. Giant ragweed density as affected by PRE herbicide, soybean planting time, and soil management treatments at the Janesville, WI, site in 2022 and 2023.[a,b]

Planting time	PRE herbicide (2022)		Soil management (2023)			
	No	Yes	No-till	Cereal rye early terminated	Cereal rye planting green	Tillage
	plants m^{-2}					
Early	118 aA	67 aB	6 aC	7 aBC	12 aB	23 aA
Late	61 bA	45 bB	6 aA	5 aA	6 bA	3 bA

[a]Soil management practices include conventional tillage (chisel plow in the fall and field cultivator in the spring), no-till, cereal rye cover crop terminated 14 d before soybean planting (cereal rye early terminated), and cereal rye cover crop terminated at soybean planting (cereal rye planting green).
[b]Mean values followed by the same lowercase letter within a column are not different according to Fisher's LSD (α = 0.05). Mean values followed by the same uppercase letter within planting time and year are not different according to Fisher's LSD (α = 0.05).

Table 7. Giant ragweed density as affected by PRE herbicide, soybean planting time, and soil management treatments at the Lincoln, NE, site in 2022 and 2023.[a,b]

Soil management	Planting time (2022)		Herbicide (2022)		Herbicide (2023)	
	Early	Late	No PRE	PRE	No PRE	PRE
	plants m^{-2}					
No-till	77.9 aA	68.5 aA	162.3 aA	19.0 aB	56.4 aA	22.8 aB
Cereal rye early terminated	5.6 cA	8.1 bA	27.2 bA	0.0 bB	18.6 bA	6.3 bA
Cereal rye planting green	28.9 bA	0.0 cB	10.4 bcA	4.6 abA	7.3 bA	17.1 abA
Tillage	0.2 cB	13.6 bA	5.7 cA	3.1 abA	0.1 cA	0.1 cA

[a]Soil management practices include conventional tillage (field cultivator in the spring), no-till, cereal rye cover crop terminated 14 d before soybean planting (cereal rye early terminated), and cereal rye cover crop terminated at soybean planting (cereal rye planting green).
[b]Mean values followed by the same lowercase letter within a column are not different according to Fisher's LSD (α = 0.05). Mean values followed by the same uppercase letter within planting time and year are not different according to Fisher's LSD (α = 0.05).

observed in studies conducted in Nebraska (Werle et al. 2017) and Wisconsin (West et al. 2020). Moreover, in the combination of early fall planting times with delayed spring termination time, the cereal rye achieved more than 10 Mg ha^{-1} in Wisconsin (Nunes et al. 2023b). However, in this study, the biomass levels obtained did not reach the 4.8 Mg ha^{-1} threshold suggested by Chudzik et al. (2025), considered the necessary amount of biomass to obtain 50% reduction in giant ragweed density in Wisconsin. Growers should consider the best cover crop management strategies based on cover crop goals.

Giant Ragweed Density

In Wisconsin in 2022, giant ragweed density was not affected by tillage and cover crop treatments at the POST herbicide timing ($P = 0.139$), whereas density was affected by soybean planting time and PRE herbicide ($P < 0.001$). Giant ragweed density was less for late than early soybean planting and less for PRE herbicide than no PRE herbicide (Table 6). Moreover, in 2022, a LPOST application was required to control giant ragweed plants that emerged after the first application timing. Giant ragweed density at LPOST exhibited a Soil Management × Planting Time interaction ($P < 0.001$). No difference in density was observed for early-planted soybean across soil management practices, while for late-planted soybean, planting green resulted in at least 50% lower density than other soil management practices (Supplementary Table S1).

In Wisconsin in 2023, the Soil Management × Planting Time interaction was significant ($P < 0.001$). Giant ragweed density was less for late than early soybean planting time in the planting-green and tillage treatments but was not affected by planting time in the early-terminated and no-till treatments (Table 6). Tillage was the soil management with the highest giant ragweed density when soybean was planted early, while values were not different among soil management treatments for soybean planted late. Previous research has documented tillage's effectiveness for giant ragweed control in areas with biotypes with an early emergence window (Ganie et al. 2016; Goplen et al. 2018a, 2018b). This study shows that for biotypes with a longer emergence window (Striegel et al. 2021b), delaying planting and spring tillage can be beneficial to reducing giant ragweed density in-season. In both years, giant ragweed plants were observed at the end of the season in Wisconsin. In contrast, no plants emerged after the POST application in Nebraska, confirming a longer emergence window in Wisconsin, as previously reported by Striegel et al. (2021b) and observed in this study by GC, compared to Nebraska, as previously reported by Kaur et al. (2016) and observed in this study by VdSF.

In Nebraska in 2022, the Soil Management × Planting Time and the Soil Management × PRE Herbicide interactions were significant ($P = 0.002$ and 0.041, respectively). In Nebraska in 2023, the Soil Management × PRE Herbicide interaction was significant ($P = 0.034$). For both years, no-till was consistently among the treatments with the highest giant ragweed densities at the time of POST application, especially for no PRE (Table 7). Both tillage and no-till received an intervention (mechanical or chemical) at planting, but no-till showed higher giant ragweed density at POST, except for PRE treatments in 2022, for which densities were the same. This result is consistent with previous reports that found effective control of early-emerged giant ragweed by spring tillage (Ganie et al. 2016; Goplen et al. 2018b).

Additionally, after tillage, giant ragweed emergence is typically reduced compared to no-till, providing additional time for POST weed control operations (Goplen et al. 2018a). For both years, giant ragweed densities in no-till were at least 60% less for PRE than they were for no PRE (Table 7). For no PRE, giant ragweed densities in early-terminated and planting-green cereal rye treatments were at least 65% less than they were for no-till. For PRE herbicide

Table 8. Soybean grain yield as affected by planting time and soil management treatment levels at the Janesville, WI, and Lincoln, NE, sites in 2022 and 2023.[a,b]

	Janesville, WI				Lincoln, NE		
	2022 planting time		2023 planting time			2023 planting time	
Soil management	Early	Late	Early	Late	2022[c]	Early	Late
	kg ha^{-1}						
No-till	5,450 aA	4,740 aB	4,320 aA	3,450 bB	1,670 b	2,800 aA	2,200 bA
Cereal rye early terminated	5,100 bA	4,770 aB	4,390 aA	4,160 aA	1,980 a	2,800 aA	2,460 bA
Cereal rye planting green	5,130 bA	4,330 bB	4,170 aA	3,260 bB	1,910 a	440 bB	1,570 bA
Tillage	5,060 bA	4,890 aA	4,180 aA	4,440 aA	1,710 b	3,090 aA	3,640 aA

[a]Soil management practices include conventional tillage, no-till, cereal rye cover crop early terminated 14 d before crop planting (cereal rye early terminated), and cereal rye cover crop terminated at planting (cereal rye planting green).
[b]Mean values followed by the same lowercase letter within a column are not different at $\alpha = 0.05$. Mean values followed by the same uppercase letter within planting times within a year are not different at $\alpha = 0.05$.
[c]Means were not separated when main effects or interactions for a specific factor were not significant; for example, for Wisconsin in 2022, the use of PRE herbicide did not have a significant main effect or interactions, therefore means were not separated by use of PRE herbicide.

integrated with cereal rye cover crop, giant ragweed densities were at least 69% less than they were for no PRE. Therefore integrating cereal rye with a PRE herbicide can offer a multitactic approach to managing giant ragweed populations in Nebraska. Conversely, growers may adopt deep tillage (e.g., moldboard plow) as a onetime intervention strategy to bury giant ragweed seeds, thus reducing weed emergence (DeVore et al. 2013; Leon and Owen 2006).

Cereal rye did not reduce giant ragweed density in Wisconsin compared to no-till. In Nebraska, cereal rye accumulated <1.8 Mg ha^{-1} yet had lower giant ragweed density compared to no-till in no PRE treatments, suggesting that the biomass levels achieved at the Nebraska site (Table 5) were sufficient to provide giant ragweed suppression. The giant ragweed suppression observed with cereal rye in Nebraska not only contradicts the findings of Chudzik et al. (2025) but also suggests that, besides having differing emergence patterns, the Nebraska giant ragweed biotype may respond differently than Wisconsin biotypes to cereal rye biomass. This observed difference may be attributed to variations in local environmental conditions, differences between the biotypes, or potentially higher seed predation or mortality in Nebraska where cover crops are present, warranting further research. De Bruin et al. (2005) also investigated cereal rye for control of a range of weeds, including giant ragweed, under different soybean planting times and found that weed suppression by cereal rye was variable, depending on weed density, soil, and environmental factors.

The Wisconsin site (Rock County Farm, Janesville) has been previously reported with low levels of giant ragweed control by PRE herbicides due to high giant ragweed seedling densities and reduced efficacy to some herbicide sites of action (Silva et al. 2023; Striegel et al. 2021a). The population at this site/location was not effectively controlled when cloransulam was applied POST (Werle et al. 2023), suggesting resistance to Weed Science Society of America Group 2 herbicides, and was better controlled when cloransulam was applied PRE in a mixture with other herbicides, such as sulfentrazone and flumioxazin (DeWerff and Werle 2024), compared to cloransulam alone. Therefore mixing and rotating herbicide mixtures from multiple sites of action combined with additional management strategies is highly recommended to reduce selection pressure for additional resistance (Norsworthy et al. 2012).

Soybean Grain Yield

In Wisconsin, a Soil Management × Planting Time interaction for soybean yield was significant in 2022 ($P = 0.017$) and 2023 ($P < 0.001$). The PRE treatment effect was also significant in 2023 ($P < 0.001$). In 2022, yield was greater for no-till than it was for other soil management treatments for early-planted soybean (Table 8). Soybean under no-till and cereal rye treatments yielded less in late-planted than in early-planted soybean, while soybean under tillage maintained yields between planting times. In 2023, when the main effect of PRE was significant, soybean yield in the no PRE treatments was 3,930 kg ha^{-1}, lower than the 4,160 kg ha^{-1} observed with the PRE treatments. Early-terminated cereal rye and tillage did not differ in yield, regardless of planting time. However, early-planted soybean yields did not differ among soil management treatments, whereas late-planted soybean yields were greater for early-terminated cereal rye and tillage treatments compared to other soil management treatments. Soybean yield was 20% less for no-till and planting-green treatments planted late than it was for those planted early. The lower yield for late-planted soybean confirms findings from other studies in the same region, where delayed planting reduced yield potential (Gaspar and Conley 2015; Mourtzinis et al. 2017).

In Nebraska, the soil management effect on soybean yield was significant in 2022 ($P = 0.001$). Soybean under cereal rye early terminated and planting green yielded on average 200 kg ha^{-1} more than did no-till and tillage in 2022 (Table 8), for which precipitation was near average (Table 4). However, from July until harvest time, low precipitation occurred, limiting the water supply during soybean filling stages. The negative effect of a water deficit during seed formation on soybean seed yield has been reported previously, with drought stress during early formation and pod-filling stages leading to the greatest reduction in seed yield (Sionit and Kramer 1977). Therefore we hypothesized that the treatments with cereal rye biomass in this study retained moisture during these stages, resulting in higher soybean yields than no-till and tillage treatments.

In Nebraska in 2023, the PRE main effect ($P < 0.001$) and the Planting Time × Soil Management interaction ($P = 0.034$) were significant. The no PRE soybean treatments yielded 1,930 kg ha^{-1}, compared to 2,820 kg ha^{-1} in the PRE treatments. Early-planted soybean in the planting-green treatments yielded less than in other treatments, while late-planted soybean yielded less in both cereal rye and no-till treatments than in tillage. Additionally, planting green was the only treatment with reduced yield in early-planted soybean (Table 8). Early in the season, dry conditions posed a challenge for cereal rye treatments, particularly for planting green with poorly established soybean stands. The main effect of soybean density stand was significant ($P < 0.001$), with planting green averaging 4.5 plants m^{-1} lower than 16.1, 13.4, and 12.6 plants m^{-1}

for tillage, cereal rye early-terminated, and no-till treatments, respectively. The soybean densities among tillage, early-terminated cereal rye, and no-till treatments did not differ. The association between lower soybean stand densities and lower yield in the planting-green system has been previously reported (Liebl et al. 1992; Nunes et al. 2023a; Nunes et al. 2024).

In contrast to observations in Wisconsin in 2022, a later planting date did not affect soybean yield in either year of the study in Nebraska. This finding aligns with those of Edreira et al. (2017), who found that the yield loss due to delayed planting observed in Wisconsin was higher, with losses of >25 kg ha^{-1} d^{-1}, compared to eastern Nebraska, where daily losses were not different from 0 kg ha^{-1} d^{-1}. However, findings from this study contradict those of Bastidas et al. (2008), who found that delayed planting after May 1 in Nebraska resulted in linear yield declines between 17 and 43 kg ha^{-1} d^{-1}.

Practical Implications

A proactive, integrated approach is necessary to control giant ragweed effectively. In this study, all treatments received herbicide applied burndown or PRE tillage to control emerged giant ragweed plants that would otherwise have had a competitive advantage over the soybean crop. The results show that in Nebraska, soybean planting dates are flexible, without major impacts on giant ragweed control and soybean yield, with tillage or cover crop adoption generally leading to the lowest POST giant ragweed densities. In Wisconsin, delayed soybean planting generally reduced giant ragweed density by allowing more giant ragweed plants to emerge and be controlled by an effective management strategy (i.e., tillage or herbicide burndown) before crop establishment. However, this strategy came with a trade-off in Wisconsin, particularly for no-till and cover crop treatments, for which delayed planting resulted in lower soybean yields, especially in the 2023 drought year. This suggests that later planting under these soil management strategies is more likely to lead to lower yield potential than is earlier planting. Across all site-years, soil residual PRE herbicide effectively reduced giant ragweed density and/or protected soybean yield.

Additionally, the planting-green system offers another strategy as part of an integrated weed management program. However, in the case of dry spring conditions, results from this study support that cereal rye should be terminated before planting to protect soybean yield potential, particularly when soybean is planted later. Delaying planting time can create an opportunity to control more weeds before crop establishment but can also result in lower yield potential. For regions with giant ragweed biotypes with an extended emergence window, this study highlights the importance of managing weed control and planting timing for effective giant ragweed control. This research highlights that general weed management recommendations are not always a one-size-fits-all solution. Regional and local research findings are essential to informing grower management decisions, as results and recommendations obtained from Wisconsin differed from Nebraska's in this study.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/wet.2024.110

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