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DOI: 10.1017/wet.2024.110

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

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Abstract

Early soybean planting and cover crop adoption in the US 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 soil management, soybean planting time, and 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). Postemergence (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 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.

Nomenclature: giant ragweed, *Ambrosia trifida* L.; cereal rye, *Secale cereale* L.; soybean, *Glycine max* (L.) Merr.

Keywords: Cereal rye, cover crop, integrated weed management, planting green, planting time, tillage.

Introduction

Giant ragweed is a summer annual weed species native to North America and ranked among the most difficult weeds to manage in the US Midwest (Chudzik et al. 2024a; 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 (ALS) inhibitors, or both (Glettner and Stoltenberg 2015; Marion et al. 2017; Wilson et al. 2020). More recently, a protoporphyrinogen oxidase (PPO) inhibitors (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 US Corn Belt (Kaur et al. 2016; Werle et al. 2014), populations in the eastern part of the US 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., 2021a).

Herbicides represent the main tactic for weed control by growers, being applied on more than 95% of corn and soybean acreage in the US (USDA-NASS 2021, 2020). Difficult-to-control species, such as 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 at corn planting, particularly corn herbicide mixes containing mesotrione and atrazine (Silva et al. 2023; Striegel et al. 2021b, Westrich et al. 2024). Silva et al. (2023) compared multiple corn residual herbicide mixes and found that the combination of different sites of action were key to improving giant ragweed control, a finding also by DeWerff and Werle (2024) with soybean herbicides. However, control levels of giant ragweed were lower when compared to the small-seeded waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] (DeWerff and Werle, 2024). Combining multiple active ingredients and incorporating nonchemical strategies is key for 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, creates an integrated approach to weed management, enhancing the likelihood of successful weed control, 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 years) of seeds present on 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, cereal rye adoption 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. 2022a, 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. 2022a; Nunes et al. 2024). There is a trade-off when planning to terminate the cover crop early (i.e., >7 d before planting) as 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 indicates 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. 2022b). 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. 2022b; Nunes et al. 2023b).

Integrating both early planted soybeans 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 US Midwest (Nichols et al. 2020). While previous research has explored different aspects of giant ragweed control, the specific integration amongst 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 soil management, soybean planting time, and 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 (hereafter referred to as “Janesville”, WI; 42.7255, -89.0221) and at the University of Nebraska-Lincoln Havelock Research Farm near Lincoln, NE (“Lincoln”, NE; 40.8552, -96.6161). 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 m long by 3 m wide, 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 depth of 2.5 cm. Soybean cultivars, cereal rye 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 replications (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) plus ammonium sulfate (AMS) at 1,400 g ha⁻¹. Preemergence herbicide treatments consisted of the absence (No PRE) or application (Yes PRE) of a commercial premix (Sonic[®], Corteva Agriscience LLC, Indianapolis, IN) of sulfentrazone (280 g ai ha⁻¹) plus 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 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 LLC, Indianapolis, IN) plus AMS were applied POST. In Wisconsin, POST application took place when ~50% of giant ragweed plants within each treatment reached a height of 10 cm. In Nebraska, where an early and shorter emergence window

of giant ragweed was expected (Kaur et al. 2016) and observed (de Sousa Ferreira field observations), the application timing was synchronized with planting dates and deployed when 50% of giant ragweed plants within the same soybean planting time treatments reached 10 cm in height. In treatments where 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 plus glufosinate (657 g ha⁻¹, Liberty herbicide; Bayer CropScience, Research Triangle, NC) plus ammonium sulfate 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 CO₂-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 and TeeJet® AIXR11002 were used, respectively (TeeJet®, 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 m² (30.5 x 30.5 cm) quadrats per plot were clipped at the soil level and dried until constant weight at 60 C to determine aboveground cereal rye biomass. At POST application, two 0.25 m⁻² quadrats (50 x 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-year 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-year 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 Co., Nevada, IA) equipped with a Seed Spector LRX (Almaco Co.) grain gauge in Wisconsin and a Zurn 150 plot combine (ZURN USA Inc., Brooklyn Park, MN) equipped with a HarvestMaster H2 GrainGage (Juniper Systems) 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 (ANOVA) 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 LSD (Least Significant Difference) 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.

Results and Discussion

Weather

The accumulated precipitation was below the 30-year average over the growing season (April–October) for both sites and years (Table 4). The 2023 growing season was marked by drought conditions across the Midwest, with the first 3 months of the season (April – 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 ($< 0.5 \text{ Mg ha}^{-1}$) 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. 2022a).

When the cereal rye can be drilled earlier in the fall, shortly after corn silage harvest for instance (September–October), substantial amounts of biomass ($> 3 \text{ Mg ha}^{-1}$) can be achieved

even with termination occurring from April to early May, as 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. 2023a). However, in this study, the biomass levels obtained did not reach the 4.8 Mg ha⁻¹ threshold suggested by Chudzik et al. (2024b), 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 the cover crop goals.

Giant ragweed density

In Wisconsin 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 by planting time interaction ($p < 0.001$). No difference in density was observed for early-planted soybean, across soil management practices, while for late-planted soybeans, planting green resulted in at least 50% lower density than other soil management practices (Supplementary Table S1).

In Wisconsin 2023, the soil management by 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. 2021a), delaying planting and spring tillage can be beneficial to reduce 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. (2021a) and observed in this study by G. Chudzik, compared to Nebraska as previously reported by Kaur et al. (2016) and observed in this study by V. de Sousa Ferreira.

In Nebraska 2022, the soil management by planting time and the soil management by PRE herbicide interactions were significant ($p = 0.002$ and 0.041 , respectively). In Nebraska 2023, the soil management by PRE herbicide interaction was significant ($p = 0.034$). For both years, no-till was consistently amongst 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, where 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. 2018a).

Additionally, after tillage, giant ragweed emergence is typically reduced compared to no-till, providing additional time for POST weed control operations (Goplen et al. 2018b). For both years, giant ragweed densities in no-till were at least 60% less for PRE than 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 no-till. For PRE herbicide integrated with cereal rye cover crop, giant ragweed densities were at least 69% less than no PRE. Therefore, integrating cereal rye with a PRE herbicide can offer a multi-tactic approach to managing giant ragweed populations in Nebraska. Conversely, growers may adopt deep tillage (e.g., moldboard plow) as a one-time 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 less than 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 in 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. (2024b) but also suggests that, besides 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, Wisconsin) has been previously reported with low levels of giant ragweed control by PRE herbicides due to the high giant ragweed seedling densities and reduced efficacy to some herbicide sites of action (Silva et al. 2023; Striegel et al. 2021b). The population at this site/location was not effectively controlled when cloransulam was applied POST (Werle et al. 2023), suggesting resistance to 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 are highly recommended to reduce selection pressure for additional resistance (Norsworthy et al. 2012).

Soybean Grain Yield

In Wisconsin, a soil management x planting time interaction for soybean yield was significant in 2022 ($p=0.017$) and 2023 (<0.001). The PRE treatment effect was also significant in 2023 ($p<0.001$). In 2022, yield was greater for no-till than other soil management treatments for early planted soybean (Table 8). Soybeans under no-till and cereal rye treatments yielded less in late-planted than early-planted soybean, while soybeans under tillage maintained yields between planting times. In 2023, where the main effect of PRE was significant, soybean yield in the no PRE treatments was $3,930 \text{ kg ha}^{-1}$, lower than the $4,160 \text{ kg ha}^{-1}$ observed in the PRE treatments. Early terminated cereal rye and tillage did not differ in yield, regardless of planting time. However, early-plant soybean yields did not differ among soil management treatments, whereas late-planted soybean yields were greater in 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 those planted early. Lower yield for late-planted soybeans 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 ($p=0.001$). Soybeans under cereal rye early terminated and planting green yielded on average 200 kg ha^{-1} higher than 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 water supply during soybean filling stages. The negative effect of 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 2023, the PRE main effect ($p < 0.001$) and the planting time \times soil management interaction ($p = 0.034$) were significant. The no PRE soybean treatments yielded $1,930 \text{ kg ha}^{-1}$ compared to $2,820 \text{ kg ha}^{-1}$ in the PRE treatments. Early-planted soybean in the planting green treatments yielded less than in other treatments, while late-planted soybeans yielded less in both cereal rye and no-till treatments than tillage. Additionally, planting green was the only treatment with reduced yield in early-planted soybeans (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 $4.5 \text{ plants m}^{-2}$ lower than 16.1 , 13.4 , and $12.6 \text{ plants m}^{-2}$ 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. 2023b; Nunes et al. 2024).

In contrast to observations in Wisconsin 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), where the yield loss due to delayed planting observed in Wisconsin was higher, with losses of more than $25 \text{ kg ha}^{-1} \text{ d}^{-1}$, compared to eastern Nebraska, where daily losses were not different from $0 \text{ kg ha}^{-1} \text{ d}^{-1}$. 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 $43 \text{ kg ha}^{-1} \text{ d}^{-1}$.

Practical Implications

A proactive, integrated approach is necessary to control giant ragweed effectively. In this study, all treatments received herbicide applied burndown or pre-plant 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 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 soybeans are 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 management. 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 inform grower management decisions, as results and recommendations obtained from Wisconsin differed from Nebraska's in this study.

Acknowledgments

We thank the members of the University of Wisconsin-Madison Cropping Systems Weed Science and the University of Nebraska-Lincoln Extension Weed Science programs for their technical support during this project. We appreciate the support from the Rock County Farm (Janesville, WI) staff.

Funding

This research was partially funded by the Wisconsin Soybean Marketing Board.

Competing interests

The authors declare none.

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

Site	Year	pH	OM (%)	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 in Janesville, WI and Lincoln, NE sites in 2022 and 2023.

Year	Janesville, WI				Lincoln, NE			
	Soybean		Cereal rye		Soybean		Cereal rye	
	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 (CC) field operations at Janesville, WI, and Lincoln, NE sites in 2022 and 2023.

Field operation	Janesville, WI		Lincoln, NE	
	2021-22	2022-23	2021-22	2022-23
Cereal rye planting	11/5/21	10/28/22	11/16/21	11/2/22
Early soybean planting + PRE application	5/16/22	5/18/23	5/12/22	5/15/23
Early soybean: CC early termination	5/4/22	5/9/23	4/26/22	4/27/23
Early soybean: CC late termination	5/17/22	5/18/23	5/11/22	5/15/23
Late soybean planting + PRE application	6/1/22	5/31/23	5/31/22	5/23/23
Late soybean: CC early termination	5/17/22	5/18/23	5/19/22	5/15/23
Late soybean: CC late termination	6/1/22	5/31/23	5/31/22	5/22/23
Soybean harvest	10/18/22	10/10/23	9/30/22	9/28/23

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

Month	Janesville, WI						Lincoln, NE					
	Average temperature			Precipitation			Average temperature			Precipitation		
	2022	2023	30-yr	2022	2023	30-yr	2022	2023	30-yr	2022	2023	30-yr
	-----C-----			-----mm-----			-----C-----			-----mm-----		
April	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
June	20.3	20.5	20.1	59	45	139	23.5	23.2	22.3	115	69	124
July	22	22	22.2	96	81	105	25.1	23.4	24.8	66	187	101
August	20.8	21.2	21	86	63	113	24.7	24.1	23.6	19	101	93
September	16.9	18.4	16.9	114	92	99	20.8	20.9	19.3	33	26	85
October	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

Table 5. Cereal rye cover crop (CC) dry biomass at termination time as affected by soybean planting time and CC termination treatments at Janesville, WI, and Lincoln, NE sites in 2022 and 2023.

Soybean planting time	CC termination ^a	Janesville, WI		Lincoln, NE					
		2022	2023	2022	2023				
		-----Mg ha ⁻¹ -----							
Early	Early terminated	0.17	c ^b	0.39	c	0.1	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	2.4	a	3.64	a	1.52	a	1.82	a

^a Cereal rye cover crop treatments included cereal rye cover crop early terminated 14 d before soybean planting (Early terminated), and cereal rye cover crop terminated at soybean planting (Planting green).

^b Mean values followed by the same lower-case letter within a column are not different at $\alpha=0.05$.

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.

Planting time	2022				2023							
	PRE herbicide				Soil management ^a							
	No		Yes		No-till		Cereal rye early terminated		Cereal rye planting green		Tillage	
	----- plants m ⁻² -----											
Early	118	aA ^b	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 lower-case letter within a column are not different at $\alpha=0.05$. Mean values followed by the same upper-case letter within planting time and year are not different at $\alpha=0.05$.

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.

Soil management ^a	2022				2023							
	Planting time		Herbicide		Herbicide							
	Early	Late	No pre	Pre	No pre	Pre						
	----- plants m ⁻² -----											
No-till	77.9	aA ^b	68.5	aA	162.3	aA	19	aB	56.4	aA	22.8	aB
Cereal rye early terminated	5.6	cA	8.1	bA	27.2	bA	0	bB	18.6	bA	6.3	bA
Cereal rye planting green	28.9	bA	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

^aSoil 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).

^bMean values followed by the same lower-case letter within a column are not different at $\alpha=0.05$. Mean values followed by the same upper-case letter within planting time and year are not different at $\alpha=0.05$.

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

Soil management ^b	Janesville, WI								Lincoln, NE					
	Planting time								2022 ^a			2023		
	2022				2023				Planting Time					
	Early		Late		Early		Late		Early		Late		Late	
----- kg ha ⁻¹ -----														
No-till	5,450	aA ^c	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

^aMeans were not separated when main effects or interactions for a specific factor were not significant, e.g., for Wisconsin, in 2022 the use of PRE herbicide did not have significant main effect or interactions, therefore, means were not separated by use of PRE herbicide.

^bSoil management practices include conventional tillage ('tillage'), no-till ('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').

^cMean values followed by the same lower-case letter within a column are not different at $\alpha=0.05$. Mean values followed by the same upper-case letter within planting times within year are not different at $\alpha=0.05$.