This is a "preproof" accepted article for Weed Science. This version may be subject to change in the production process, *and does not include access to supplementary material*.
DOI: 10.1017/wsc.2024.71

Short title: Emergence of GR *B. scoparia*

Effect of Fall- and Spring-Planted Cover Crops and Residual Herbicide on Emergence Dynamics of Glyphosate-Resistant Kochia (*Bassia scoparia*)

Sachin Dhanda[1], and Vipan Kumar[2]

[1]Graduate Research Assistant, Kansas State University, Agricultural Research Center, Hays, KS, USA

[2]Associate Professor, Cornell University, School of Integrative Plant Science, Soil and Crop Sciences Section, Ithaca, NY, USA

Author for correspondence: Vipan Kumar, Associate Professor, Cornell University, School of Integrative Plant Science, Soil and Crop Sciences Section, 1115 Bradfield Hall, Ithaca, NY 14853
Email: vk364@cornell.edu

Abstract

Two separate field experiments were conducted during the 2021-22 and 2022-23 growing seasons at Kansas State University Agricultural Research Center near Hays, KS to understand the emergence dynamics of glyphosate-resistant (GR) kochia [*Bassia scoparia* (L.) A. J. Scott] as influenced by fall- and spring-planted cover crops (CC) and residual herbicide. Study sites were under winter wheat (*Triticum aestivum* L.)-sorghum [*Sorghum bicolor* (L.) Moench]-fallow rotation with a natural seedbank of GR *B. scoparia*. In experiment 1, fall-planted CC mixture (triticale/winter peas/radish/rapeseed) was planted after wheat harvest and terminated at triticale [x*Triticosecale* Wittm. Ex A. Camus [*Secale* x *Triticum*] heading stage (next spring before sorghum planting). In experiment 2, spring-planted CC mixture (oats/barley/spring peas) was planted in sorghum stubbles and terminated at oats (*Avena sativa* L.) heading stage. Four treatments were established in each experiment: (1) nontreated control (no CC and no herbicide), (2) chemical fallow (no CC but glyphosate + acetochlor/atrazine or flumioxazin/pyroxasulfone + dicamba were used to control weeds), (3) CC terminated with glyphosate, and (4) CC terminated with glyphosate plus residual herbicide (acetochlor/atrazine for fall-planted CC and flumioxazin/pyroxasulfone for spring-planted CC). Results indicated that fall-planted CC delayed GR *B. scoparia* emergence by 3 to 5 weeks whereas spring-planted CC delayed emergence by 0 to 2 weeks compared to nontreated. Fall-planted CC terminated with glyphosate plus acetochlor/atrazine reduced the cumulative emergence of GR *B. scoparia* by 90 to 95% compared to nontreated across both yrs. Similarly, spring-planted CC terminated with glyphosate plus flumioxazin/pyroxasulfone reduced the cumulative emergence of GR *B. scoparia* by 83 to 90% compared to nontreated. These results suggest that fall- or spring-planted CC in combination with residual herbicide at termination can be utilized for GR *B. scoparia* suppression. Results from this study will help in developing prediction models for GR *B. scoparia* emergence under different CC strategies.

Keywords: Central Great Plains; cover crops; cumulative emergence; emergence periodicity; weed seedbank

Introduction

Kochia [*Bassia scoparia* (L.) A. J. Scott] is an invasive summer annual broadleaf weed belonging to the 'Chenopodiaceae' family (Kumar et al. 2019). *Bassia scoparia* is tolerant to various abiotic stresses, including drought, heat, cold and salinity (Christoffoleti et al. 1997; Friesen et al. 2009). *Bassia scoparia* is a C_4 summer annual plant that can thrive well under hot temperatures. It can germinate early in the spring and seedlings can survive spring freezing night temperatures (Dille et al. 2017; Friesen et al. 2009; Kumar et al. 2018). *Bassia scoparia* exhibits wide genetic diversity due to a high degree of outcrossing and pollen-mediated gene flow (Beckie et al. 2016; Mengistu and Messersmith 2002). *Bassia scoparia* is a prolific seed producer and single plant can produce up to 100,000 seeds that can be dispersed over long distances via wind-mediated tumbling mechanism (Christoffoleti et al. 1997; Friesen et al. 2009; Kumar et al. 2019).

Bassia scoparia has been reported to reduce the grain yield of many field crops, including corn (*Zea mays* L.), grain sorghum [*Sorghum bicolor* (L.) Moench ssp. *bicolor*], soybean [*Glycine max* (L.) Merr.], sugarbeet (*Beta vulgaris* L.), sunflower (*Helianthus annuus* L.), alfalfa (*Medicago sativa* L.), canola (*Brassica napus* L.), spring wheat (*Triticum aestivum* L.) and spring oats (*Avena sativa* L.) (Geddes and Sharpe 2022; Kumar and Jha 2015; Lewis and Gulden 2014; Wicks et al. 1994, 1997). The magnitude of crop yield loss depends on the *B. scoparia* density and time of emergence (Geddes and Sharpe 2022; Wicks et al. 1994, 1997). For instance, *B. scoparia* reduced grain sorghum yield by 95% at a density of 184 plants m^{-2} (Wicks et al. 1994), 23 to 77% in soybean at 20 to 135 plants m^{-2} (Geddes and Sharpe 2022; Wicks et al. 1997), 60% in sugarbeet at 268 plants m^{-2} (Kumar and Jha 2015), and 62 to 95% in sunflower at 34 to 905 plants m^{-2} (Lewis and Gulden 2014).

Bassia scoparia has high tendency to evolve herbicide resistance (Heap 2024). Currently, *B. scoparia* populations have evolved resistance to five different herbicide sites of action (SOA), including inhibitors of acetolactate synthase (ALS) (Group 2), synthetic auxins (Group 4), photosystem (PS) II (Group 5), 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) (Group 9), and protoporphyrinogen oxidase (PPO) (Group 14) (Heap 2024). Among all reported resistance cases, multiple resistance to glyphosate and ALS inhibitors has been reported widespread among *B. scoparia* populations across the U.S. Great Plains (Beckie et al. 2013; Heap 2024; Kumar et al. 2015; Sharpe et al. 2023). Effective and alternative strategies are urgently needed to mitigate the further evolution and spread of herbicide-resistant *B. scoparia* (Kumar et al. 2019).

Bassia scoparia exhibits an extended period of emergence during the growing season (Dille et al. 2017). In addition, differential emergence patterns have been reported among different *B. scoparia* populations from the U.S. Great Plains (Dille et al. 2017; Kumar et al. 2018). For instance, Dille et al. (2017) reported that 168 cumulative growing degree days (GDD) were needed for 10% emergence of *B. scoparia* populations from Kansas, while only 90 GDD were needed for Wyoming and Nebraska populations in a fallow study. Similarly, Kumar et al. (2018) reported that 151 to 346 cumulative GDD were needed for 10% emergence of *B. scoparia* populations from Kansas, 241 to 266 GDD for Oklahoma population, and 185 to 291 GDD for Montana population in a common garden study conducted in Montana. These studies also found that the emergence of most *B. scoparia* populations from the U.S. Great Plains occurred between April 9 and May 31, which could overlap with the planting window of cash crops based on the region (Dille et al. 2017; Kumar et al. 2018)

Winter wheat-grain sorghum-fallow (W-S-F) is a dominant crop rotation in the semiarid central Great Plains (CGP) region, including Kansas (Holman et al. 2022). This 3-year crop rotation includes a fallow period of about 10 months between winter wheat harvest and sorghum planting as well as 10 months of fallow period between sorghum harvest and the next winter wheat planting (Kumar et al. 2020). Replacing these fallow periods with cover crops (CC) may provide effective weed suppression in no-till (NT) cropping systems of the CGP region (Kumar et al. 2020). For instance, Petrosino et al. (2015) reported 78 to 94% reduction in *B. scoparia* density with fall-planted CC (triticale/triticale-hairy vetch mixture) compared to chemical fallow in winter wheat-fallow rotation. Obour et al. (2022) reported that spring-planted CC (oats/triticale/spring peas) during the fallow phase of W-S-F rotation reduced total weed biomass (dominated by *B. scoparia* with 36% mean relative abundance) by 86 to 99% compared to weedy fallow. Nonetheless, there appears to be limited information exists on the impact of fall or spring-planted CC in combination with residual herbicides at termination on the emergence of GR *B. scopari*a in the NT dryland W-S-F rotation. Therefore, the main objective of this study was to determine the effect of fall- and spring-planted CC terminated with glyphosate alone or glyphosate with residual herbicide on emergence dynamics and periodicity of GR *B. scoparia* in NT dryland W-S-F crop rotation.

https://doi.org/10.1017/wsc.2024.71 Published online by Cambridge University Press

Materials and Methods

Experiment 1. Effect of fall-planted CC on GR *B. scoparia* emergence

A field study was conducted at Kansas State University Agricultural Research Center near Hays (KSU-ARCH), KS (38.85196°N, 99.34279°W; semiarid central Great Plains region) from fall 2021 through fall 2023. Detailed information about this study has previously been described in Dhanda et al. (2024). The field site was under a NT dryland W-S-F rotation with a history of natural seedbank of GR *B. scoparia* and Palmer amaranth (*Amaranthus palmeri* S. Watson). All three phases of the crop rotation (W-S-F) were present in each experimental yr. Each yr, a CC mixture of winter triticale [x*Triticosecale* Wittm. Ex A. Camus [*Secale* x *Triticum*] (60%)/winter peas (*Pisum sativum* L.) (30%)/rapeseed (*Brassica napus* L.) (5%)/radish (*Raphanus sativus* L.) (5%) was drilled at a seeding rate of 67 kg ha^{-1} in wheat stubble during fall (September/October) and terminated in the following spring at the triticale heading stage (Table 1). The design was randomized complete block with four replications. Treatments were (1) nontreated control, (2) chemical fallow, (3) CC terminated with glyphosate (Roundup PowerMax, Bayer Crop Science, St. Louis, MO) at 1260 g ae ha^{-1}, and (4) CC terminated with glyphosate at 1260 g ae ha^{-1} plus a premix of acetochlor/atrazine (Degree Xtra, Bayer Crop Science, St. Louis, MO) at 1665/826 g ai ha^{-1} were established. In nontreated control, no CC was planted and no herbicides were applied to control weeds whereas in chemical fallow, no CC was planted but the plot area was treated with glyphosate at 1260 g ae ha^{-1} plus a premix of acetochlor/atrazine at 1665/826 g ai ha^{-1} plus dicamba (Clarity, BASF Corporation, Research Triangle Park, NC) at 560 g ae ha^{-1} at the same time as CC termination in the spring. The individual plot size was 45-m long and 6.5-m wide each yr. A grain sorghum hybrid 'DKS 38-16' was planted at a seeding rate of 114,855 seeds ha^{-1} in rows spaced 76-cm apart within 3 to 4 weeks of CC termination each yr. Table 1 provides the details of CC planting and termination dates as well as the dates for planting and harvesting grain sorghum for each experimental yr.

Experiment 2. Effect of spring-planted CC on GR *B. scoparia* emergence

A field study was conducted at KSU-ARCH, KS during the 2022 and 2023 growing seasons. Similar to field experiment 1, the field site was under a NT dryland W-S-F rotation with a history of natural seedbank of GR *B. scoparia* and *A. palmeri*. The soil type at the experimental site was Roxbury silt loam with a pH of 6.9 and organic matter of 1.6%. Each yr, all three phases of the crop rotation (W-S-F) were present. A CC mixture of oats (*Avena sativa* L.) (40%)/barley

(*Hordeum vulgare* L.) (40%)/spring peas (*Pisum sativum* L.) (20%) was drilled at a seeding rate of 67 kg ha^{-1} in sorghum stubble in March and terminated it at the oats heading stage (Table 1). The study was under a randomized complete block design with four replications. Treatments were (1) nontreated control, (2) chemical fallow, (3) CC terminated with glyphosate (Roundup PowerMax, Bayer Crop Science, St. Louis, MO) at 1260 g ae ha^{-1}, and (4) CC terminated with glyphosate at 1260 g ae ha^{-1} plus a premix of flumioxazin/pyroxasulfone (Fierce EZ, Valent USA, Walnut Creek, CA) at 106/134 g ai ha^{-1} were established each yr. In nontreated control, no CC was planted and no herbicides were applied to control weeds whereas in chemical fallow, no CC was planted but the plot area was treated with glyphosate at 1260 g ae ha^{-1} plus a premix of flumioxazin/pyroxasulfone at 106/134 g ai ha^{-1} plus dicamba (Clarity, BASF Corporation, Research Triangle Park, NC) at 560 g ae ha^{-1} at the same time as CC termination. The individual plot size was 45-m long and 6.5-m wide each yr. Winter wheat variety 'Joe' was planted at a seeding rate of 67 kg ha^{-1} in rows spaced 19.1 cm apart. Details for CC planting and termination dates and dates for planting and harvesting winter wheat and grain sorghum for each experimental yr are provided in Table 1.

Data Collection

Both fall-and spring-planted CC biomass was recorded by manually harvesting aboveground shoots from two 1-m^2 quadrats from each plot just before CC termination and oven-dried at 72 C for 4 days to obtain dry biomass. For both experiments, each yr, two permanent 1-m^2 quadrats were established in each plot during mid-February for GR *B. scoparia* emergence counts. Newly emerged GR *B. scoparia* seedlings from each permanent quadrat were counted when cotyledons were fully expanded and removed manually every week starting from their first appearance (Hartzler et al. 1999). *Amaranthus palmeri* and puncturevine (*Tribulus terrestris* L.) were also present each yr and were removed manually along with GR *B. scoparia* every week. The end date for counting the emergence of GR *B. scoparia* was chosen each yr when no new emergence was observed over 21 days in both experiments. The average number of GR *B. scoparia* seedlings from the two permanent quadrats in each plot at each sample timing was used for data analysis. Data on daily minimum and maximum air temperature and precipitation during each growing season were obtained from the Kansas State University mesonet weather station (https://mesonet.k-state.edu) located approximately 400 m away from the study site (38.8495°N, 99.3446°W) (Figure 1).

Weekly emergence data from both experiments were used to calculate the cumulative and daily emergence of GR *B. scoparia*. Cumulative emergence of GR *B. scoparia* under each treatment was determined by adding average emergence counts from both quadrats on a sample date and the previously sampled date. The daily emergence of GR *B. scoparia* under each treatment was calculated by dividing the average emergence counts from both quadrats on a sample date with the number of days between a sample date and the previously sampled date. The peak emergence period for GR *B. scoparia* was determined using a quality control method (Jha and Norsworthy 2009; Montgomery et al. 2001). The peak emergence was considered when the daily emergence was greater than the total emergence in a season divided by the number of days between the first and the last day of emergence plus the standard deviation of daily emergence of all replications in a treatment.

Statistical Analyses

Data for cumulative emergence from both experiments at each sample timing were subjected to ANOVA separately using PROC MIXED procedure and were tested for homogeneity of variance and normality of the residuals using the PROC UNIVARIATE procedure in SAS 9.3 (SAS Institute, Inc., SAS Campus Drive, Cary, NC). Cumulative emergence counts at each sample timing were log-transformed to improve the normality of the residuals and homogeneity of variance; however, back-transformed data were presented with mean separation based on the transformed data. For each experiment, treatment, yr, sample timing (CC termination and last emergence timing), and their interactions were considered as fixed effects and replication and all interactions involving replication were considered as random effects. The yr-by-treatment interaction for each experiment was significant ($P < 0.05$), therefore, data for each experiment were analyzed separately for each yr. The interaction between treatment and sampling timing for both experiments was significant ($P < 0.05$), therefore, data were sorted by sampling timings using PROC SORT. Treatment means were separated using Fisher's protected LSD test ($P < 0.05$) for each emergence sampling timing.

Results and Discussion

The total amount of precipitation received during the fall-planted CC growing season (September to May) in 2021-2022 and 2022-2023 were 99 and 130 mm, respectively. The average fall-planted CC biomass at the time of termination was 1130 kg ha^{-1} in 2022 and 1470 kg ha^{-1} in 2023. Similarly, the total amount of precipitation received during the spring-planted CC growing

https://doi.org/10.1017/wsc.2024.71 Published online by Cambridge University Press

season (March to June) was 164 mm in 2022 and 184 mm in 2023 (Figure 1). Average spring-planted CC biomass at the time of termination was 1290 kg ha^{-1} in 2022 and 4060 kg ha^{-1} in 2023. Relatively higher CC biomass in 2023 compared to 2022 might be due to the higher rainfall and better growth of CC in 2023.

Experiment 1. Effect of fall-planted cover crops on GR *B. scoparia* emergence

In 2022, the GR *B. scoparia* in nontreated control emerged between March 29 and June 20 with two emergence peaks from April 19 to May 2 (Figure 2). These peak emergence periods coincided with precipitation events (Figures 1 and 2). There were 3 rainfall events (each event >5 mm) from April 19 to May 2 with a total rainfall of 32 mm during this period (Figure 1). The emergence of GR *B. scoparia* at the end of March indicates its early emergence in spring as previously reported in several studies (Dille et al. 2017; Friesen et al. 2009; Kumar et al. 2018). Herbicide application was made on May 11 in chemical fallow treatment, therefore, the emergence of GR *B. scoparia* in chemical fallow was similar to nontreated before May 11 (Figure 3). After herbicide application in chemical fallow, the cumulative emergence of GR *B. scoparia* was reduced by 65% compared to nontreated (Figure 3). Both CC treatments delayed GR *B. scoparia* emergence by 3 weeks compared to nontreated and chemical fallow with the first emergence observed on April 19. These results indicate the suppressive effect of live CC on GR *B. scoparia* emergence. Previous studies have also noted a delayed emergence of weeds with live CC or dry biomass as residue (Moore et al. 1994; Norsworthy et al. 2007; Teasdale and Pillai 2005). Actively growing CC (green) could reduce weed emergence by changing the quality of light mainly red-to-far red (R:FR) ratio that reaches the weed seeds on soil surface and ultimately changes their physiological development (Silva and Bagavathiannan 2023). Also, *B. scoparia* seedlings might have died rapidly just after germination due to light restriction and root competition from CC plants. The peak emergence of GR *B. scoparia* in CC terminated with glyphosate only occurred from May 17 to June 13, which coincided with precipitation events. There were 3 rainfall events (each of >10 mm) from May 17 to June 13 with a total rainfall of 82 mm during this period (Figure 1). No peak emergence of GR *B. scoparia* was observed under CC terminated with glyphosate plus acetochlor/atrazine. This indicates the synergistic effect of CC and residual herbicide to suppress *B. scoparia* emergence. The cumulative emergence of GR *B. scoparia* under CC terminated with glyphosate plus acetochlor/atrazine was reduced by 90% and 84% compared to nontreated and CC terminated with glyphosate alone, respectively. Petrosino et

https://doi.org/10.1017/wsc.2024.71 Published online by Cambridge University Press

al. (2015) also reported 78 to 94% reduction in *B. scoparia* density with fall-planted CC (triticale/triticale-hairy vetch mixture) compared to chemical fallow in winter wheat-fallow rotation. Results indicated >95% emergence of GR *B. scoparia* occurred before grain sorghum planting (June 2) in all treatments, indicating the importance of early-season control of *B. scoparia*.

In 2023, the emergence of GR *B. scoparia* seedlings was first observed on April 12 in nontreated and chemical fallow and emergence continued up to July 25 in nontreated and July 11 in chemical fallow (Figure 2). The relatively late emergence of GR *B. scoparia* in 2023 (April 12) compared to 2022 (March 29) could be because of lower precipitation from March 15 to April 15 in 2023 (12 mm) compared to 2022 (28 mm). The peak emergence under both nontreated and chemical fallow occurred from May 10 to May 23, coinciding with rainfall events with a total of 44 mm (13% of total rainfall from March to August) (Figures 1 and 2). Herbicide application in chemical fallow was made on May 22; therefore, the emergence of GR *B. scoparia* in chemical fallow and nontreated control was similar before May 22 (Figure 3). After herbicide application in chemical fallow, the cumulative emergence was reduced by 95% compared to nontreated. Both CC treatments delayed the GR *B. scoparia* emergence by 5 weeks compared to nontreated and chemical fallow with the first emergence observed on May 17. Delayed emergence of GR *B. scoparia* coincides with that of *A. palmeri* emergence in the southcentral Great Plains (Liu et al. 2022). This timing provides an opportunity to control both *B. scoparia* and *A. palmeri* simultaneously, saving on herbicide applications that would otherwise be necessary in early spring (March or April) to control *B. scoparia* separately. Additionally, the weak and less vigor seedlings by CC suppression can be easily killed with herbicides to start clean for the subsequent cash crop (Brainard et al. 2005; Steckel et al. 2003). It was interesting to note that no peak emergence was observed in both CC treatments, indicating the effective suppression of GR *B. scoparia* through fall-planted CC. The cumulative emergence of GR *B. scoparia* under CC terminated with glyphosate plus acetochlor/atrazine was reduced by 95% compared to nontreated and chemical fallow and by 82% compared to CC terminated with glyphosate only. Several previous research studies have also reported the importance of residual herbicides in combination with CC termination for a season-long weed control (Dhanda et al. 2024; Whalen et al. 2020).

Experiment 2. Effect of spring-planted cover crops on GR *B. scoparia* emergence

https://doi.org/10.1017/wsc.2024.71 Published online by Cambridge University Press

In 2022, GR *B. scoparia* emerged from March 15 to June 20 in nontreated and March 15 to June 13 in chemical fallow with their peak emergence from April 12 to May 2 (Figure 4). The peak emergence periods coincided with 3 rainfall events (each of >5 mm) with a total of 32 mm during this period of April 12 to May 2 (Figure 1). Emergence of GR *B. scoparia* from nontreated and chemical fallow was similar before herbicide application in chemical fallow (June 23). GR *B. scoparia* under both CC treatments emerged at the same time (March 15) as nontreated and chemical fallow (Figures 4 and 5). This could be because of the early emergence of *B. scoparia* compared to CC planting (March 16). Peak emergence occurred under both CC treatments from April 12 to May 2 and was similar to nontreated and chemical fallow but the peaks were smaller (3 to 6 seedlings m^{-2}) under both CC treatments than nontreated and chemical fallow (38 to 48 seedlings m^{-2}) (Figure 4). There was no emergence of GR *B. scoparia* after CC terminated with glyphosate plus flumioxazin/pyroxasulfone, however; seedlings emerged (0.1 seedlings m^{-2}) from July 5 to July 17 in CC terminated with glyphosate only. These results further corroborate the importance of adding residual herbicide with CC for season-long weed control. These results are consistent with Perkins et al. (2021), who reported 75 to 94% lower density of *A. palmeri* with a CC mixture of cereal rye and hairy vetch and residual herbicides (flumioxazin/pyroxasulfone, flumioxazin, pyroxasulfone, or acetochlor) compared to CC without residual herbicide. The cumulative emergence of GR *B. scoparia* under both CC treatments was reduced by 90% compared to nontreated. These results are consistent with Petrosino et al. (2015), who also reported a 94% reduction in *B. scoparia* density in western Kansas with spring-planted CC (triticale or a triticale-hairy vetch mixture).

In 2023, GR *B. scoparia* emerged from March 22 to July 18 in both nontreated and chemical fallow with their peak emergence from April 12 to April 18 and May 10 to May 16 (Figure 4). In both CC treatments, the emergence of GR *B. scoparia* was delayed by 2 weeks and occurred from April 5 to July 25. The CC was planted relatively early in 2023 (March 3) compared to 2022 (March 16), this might have resulted in emergence delay in 2023 compared to no delay in 2022 (Figures 3 and 5). There was no peak emergence in both CC treatments, indicating an effective GR *B. scoparia* suppression. Both CC treatments reduced GR *B. scoparia* emergence by 77 to 83% compared to nontreated or chemical fallow. Interestingly, more than 95% of GR *B. scoparia* emerged in nontreated, chemical fallow, CC terminated with flumioxazin/pyroxasulfone before CC termination and 70% emerged before termination in CC terminated with glyphosate only (Figure 5). These results indicate the role of live (green) CC for spring-planted window, whereas for fall-planted CC, both live CC and residue can play a role for GR *B. scoparia* suppression. Significantly lower cumulative emergence of GR *B. scoparia* in CC terminated with glyphosate only compared to chemical fallow suggests reduced herbicide selection pressure (Figure 5), which could ultimately delay or mitigate the evolution of further herbicide resistance. Obour et al. (2022) also reported that spring-planted CC (oats/triticale/spring peas) in W-S-F rotation reduced total weed density by 82% compared to weedy fallow.

In summary, these results indicate that integration of either fall- or spring-planted CC can reduce GR *B. scoparia* emergence in the W-S-F rotation in the semiarid environment. Furthermore, fewer and late emerging GR *B. scoparia* with reduced vigor would produce lower biomass with lower seed production potential, which can further help in reducing the weed seedbank (Brainard et al. 2011; Sias et al. 2021). However, it is important to note that growing CC under a moisture-limited environment sometimes could also negatively impact the yield of the successive cash crops (Holman et al. 2018; Nielsen et al. 2016). Conversely, beyond weed suppression, CC can enhance soil health, control erosion, and improve nutrient cycling, thereby increasing the overall sustainability of cropping systems (Ghimire et al. 2018; Yousefi et al. 2024). These results will be helpful in developing prediction models for GR *B. scoparia* emergence under CC plus residual herbicide strategy which can play an important role in scheduling GR *B. scoparia* control measures (Reinhardt Piskackova et al. 2021). Future studies should evaluate the economics of growing CC in the NT dryland W-S-F rotation. Additionally, research should assess integrating other weed control tactics (such as harvest weed seed control, strategic tillage, spray drones etc.) in combination with fall or spring-planted CC and residual herbicides on the seedbank dynamics of GR *B. scoparia* in the region.

Acknowledgments. We thank Mr. Taylor Lambert and Mr. Matthew Vredenburg for their assistance in conducting the field study.

Funding. The funding from the NC:SARE Graduate Student Grant (GNC22-346) supported this work.

Competing Interests. The authors declare no competing interests.

https://doi.org/10.1017/wsc.2024.71 Published online by Cambridge University Press

References

Beckie H, Blackshaw R, Hall L, Johnson E (2016) Pollen- and seed-mediated gene flow in kochia (*Kochia scoparia*). Weed Sci 64:624–633

Beckie HJ, Blackshaw RE, Low R, Hall LM, Sauder CA, Martin S, Brandt EN, Shirriff SW (2013) Glyphosate- and acetolactate synthase inhibitor-resistant kochia (*Kochia scoparia*) in western Canada. Weed Sci 61:310–318

Brainard DC, Bellinder RR, DiTommaso A (2005) Effects of canopy shade on the morphology, phenology, and seed characteristics of Powell amaranth (*Amaranthus powellii*). Weed Sci 53:175–186

Brainard DC, Bellinder RR, Kumar V (2011) Grass-legume mixtures and soil fertility affect cover crop performance and weed seed production. Weed Technol 25:473–479

Christoffoleti PJ, Westra PB, Moore F (1997) Growth analysis of sulfonylurea-resistant and -susceptible kochia (*Kochia scoparia*). Weed Sci 45:691–695

Dhanda S, Kumar V, Dille JA, Obour A, Yeager EA, Holman J (2024) Influence of cover crop residue and residual herbicide on emergence dynamics of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) in grain sorghum. Weed Sci https://doi.org/10.1017/wsc.2024.22

Dille JA, Stahlman PW, Du J, Geier PW, Riffel JD, Currie RS, Wilson RG, Sbatella GM, Westra P, Kniss AR, Moechnig MJ (2017) Kochia (*Kochia scoparia*) emergence profiles and seed persistence across the central Great Plains. Weed Sci 65:614–625

Friesen LF, Beckie HJ, Warwick SI, Van Acker RC (2009) The biology of Canadian weeds. 138. *Kochia scoparia* (L.) Schrad. Can J Plant Sci 89:141–167

Geddes CM, Sharpe SM (2022) Crop yield losses due to kochia (*Bassia scoparia*) interference. Crop Protec 157:105981

Ghimire R, Ghimire B, Mesbah AO, Idowu OJ, O'Neill MK, Angadi SV, Shukla MK (2018) Current status, opportunities, and challenges of cover cropping for sustainable dryland farming in the Southern Great Plains. J Crop Improv 34:1–20

Hartzler RG, Buhler DG, Stoltenberg DE (1999) Emergence characteristics of four annual weed species. Weed Sci 47:578–584

Heap I (2024) The International Herbicide-resistant weed database. http://www.weedscience.org. Accessed: July 4, 2024

https://doi.org/10.1017/wsc.2024.71 Published online by Cambridge University Press

Holman J, Arnet K, Dille A, Kisekka I, Maxwell S, Obour A, Roberts T, Roozeboom K, Schlegel A (2018) Can cover (or forage) crops replace fallow in the semiarid Central Great Plains? Crop Sci 58:1–13

Holman JD, Obour AK, Assefa Y (2022) Productivity and profitability with fallow replacement forage, grain, and cover crops in W-S-F rotation. Crop Sci 62:913–927

Jha P, Norsworthy JK (2009) Soybean canopy and tillage effects on emergence of Palmer amaranth (*Amaranthus palmeri*) from a natural seedbank. Weed Sci 57:644–651

Kumar V, Jha P (2015) Influence of glyphosate timing on *Kochia scoparia* demographics in glyphosate-resistant sugar beet. Crop Protect 7:39–45

Kumar V, Jha P, Dille JA, Stahlman PW (2018) Emergence dynamics of kochia (*Kochia scoparia*) populations from the U.S. Great Plains: a multi-site-year study. Weed Sci 66: 25–35

Kumar V, Jha P, Giacomini D, Westra E, Westra P (2015) Molecular basis of evolved resistance to glyphosate and acetolactate synthase-inhibitor herbicides in kochia (*Kochia scoparia*) accessions from Montana. Weed Sci 63:758–769

Kumar V, Jha P, Jugulam M, Yadav R, Stahlman PW (2019) Herbicide-resistant kochia (*Bassia scoparia*) in North America: a review. Weed Sci 67:4–15

Kumar V, Obour A, Jha P, Liu R, Manuchehri MR, Dille JA, Holman J, Stahlman PW (2020) Integrating cover crops for weed management in the semiarid US Great Plains: opportunities and challenges. Weed Sci 68:311–323

Lewis DW, Gulden RH (2014) Effect of kochia (*Kochia scoparia*) interference on sunflower (*Helianthus anuus*) yield. Weed Sci 62:158–165

Liu R, Kumar V, Jha P, Stahlman PW (2022) Emergence pattern and periodicity of Palmer amaranth (*Amaranthus palmeri*) populations from southcentral Great Plains. Weed Technol 36:110–117

Mengistu LW, Messersmith CG (2002) Genetic diversity of kochia. Weed Sci 50:498–503

Montgomery DC, Runger GC, Hubele NF (2001) Engineering Statistics. 2nd edn. New York: Wiley. Pp 448–480

Moore MJ, Gillespie TJ, Swanton CJ (1994) Effect of cover crop mulches on weed emergence, weed biomass, and soybean (*Glycine max*) development. Weed Technol 8:512–518

Nielsen DC, Lyon DJ, Higgins RK, Hergert GW, Holman JD, Vigil MF (2016) Cover crop effect on subsequent wheat yield in the central Great Plains. Agron J 108:243–256

Norsworthy, J. K., M. S. Malik, P. Jha, and M. B. Riley. 2007. Suppression of *Digitaria sanguinalis* and *Amaranthus palmeri* using autumn-sown glucosinolate-producing cover crops in organically grown bell pepper. Weed Res 47:425–432

Obour AK, Dille J, Holman J, Simon LM, Sancewich B, Kumar V (2022). Spring-planted cover crop effects on weed suppression, crop yield, and net returns in no-tillage dryland crop production. Crop Sci 62:1981–1996

Perkins CM, Gage KL, Norsworthy JK, Young BG, Bradley KW, Bish MD, Hager A, Steckel LE (2021) Efficacy of residual herbicides influenced by cover-crop residue for control of *Amaranthus palmeri* and *A. tuberculatus* in soybean. Weed Technol 35:77–81

Petrosino JS, Dille JA, Holman JD, Roozeboom KL (2015) Kochia suppression with cover crops in southwestern Kansas. Crop Forage Turf Man 1:1–8

Reinhardt Piskackova TA, Reberg-Horton SC, Richardson RJ, Jennings KM, Franca L, Young BG, Leon RG (2021) Windows of action for controlling palmer amaranth (*Amaranthus palmeri*) using emergence and phenology models. Weed Res 61:188–198

Sharpe SM, Leeson JY, Geddes CM, Willenborg CJ, Beckie HJ (2023) Survey of glyphosate-and dicamba-resistant kochia (*Bassia scoparia*) in Saskatchewan. Can J Plant Sci 22: 472–480

Sias C, Wolters BR, Reiter MS, Flessner ML (2021) Cover crops as a weed seed bank management tool: A soil down review. Ital J Agron 16:1852

Silva G, Bagavathiannan M (2023) Mechanisms of weed suppression by cereal rye cover crop: A review. Agron J 115:1571-1585

Steckel LE, Sprague CL, Hager AG, Simmons FW, Bollero GA (2003) Effects of shading on common waterhemp (*Amaranthus rudis*) growth and development. Weed Sci 51:898–903

Teasdale JR, Pillai P (2005) Contribution of ammonium to stimulation of smooth pigweed (*Amaranthus hybridus* L.) germination by extracts of hairy vetch (*Vicia villosa* Roth) residue. Weed Bio Manag 519–25

Westra EP, Nissen SJ, Getts TJ, Westra P, Gaines TA (2019) Survey reveals frequency of multiple resistance to glyphosate and dicamba in kochia (*Bassia scoparia*). Weed Technol 33:664–672

https://doi.org/10.1017/wsc.2024.71 Published online by Cambridge University Press

Whalen DM, Shergill LS, Kinne LP, Bish MD, Bradley KW (2020) Integration of residual herbicides with cover crop termination in soybean. Weed Technol 34:11–18

Wicks GA, Martin AR, Haack AE, Mahnken GW (1994) Control of triazine-resistant kochia (*Kochia scoparia*) in sorghum (*Sorghum bicolor*). Weed Technol 8:748–753

Wicks GA, Martin AR, Hanson GW (1997) Controlling kochia (*Kochia scoparia*) in soybean (*Glycine max*) with postemergence herbicides. Weed Technol 11:567–572

Yousefi M, Dray A, Ghazoul J (2024) Assessing the effectiveness of cover crops on ecosystem services: a review of the benefits, challenges, and trade-offs. Int J Agri Sustain 22:2335106

Table 1. Planting and termination dates for cover crops and planting and harvesting dates for grain sorghum and winter wheat during 2021-22 and 2022-23 seasons at Kansas State University Agricultural Research Center near Hays, KS.

Crop	Operation	2021-22	2022-23
Fall-planted cover crop	Planting	October 7, 2021	September 30, 2022
	Termination	May 11, 2022	May 22, 2023
Grain sorghum	Planting	June 2, 2022	June 15, 2023
	Harvesting	October 26, 2022	October 19, 2023
Spring-planted cover crop	Planting	March 16, 2022	March 3, 2023
	Termination	June 23, 2022	June 13, 2023
Winter wheat	Planting	September 30, 2022	October 2, 2023
	Harvesting	July 6, 2023	July 10, 2024

https://doi.org/10.1017/wsc.2024.71 Published online by Cambridge University Press

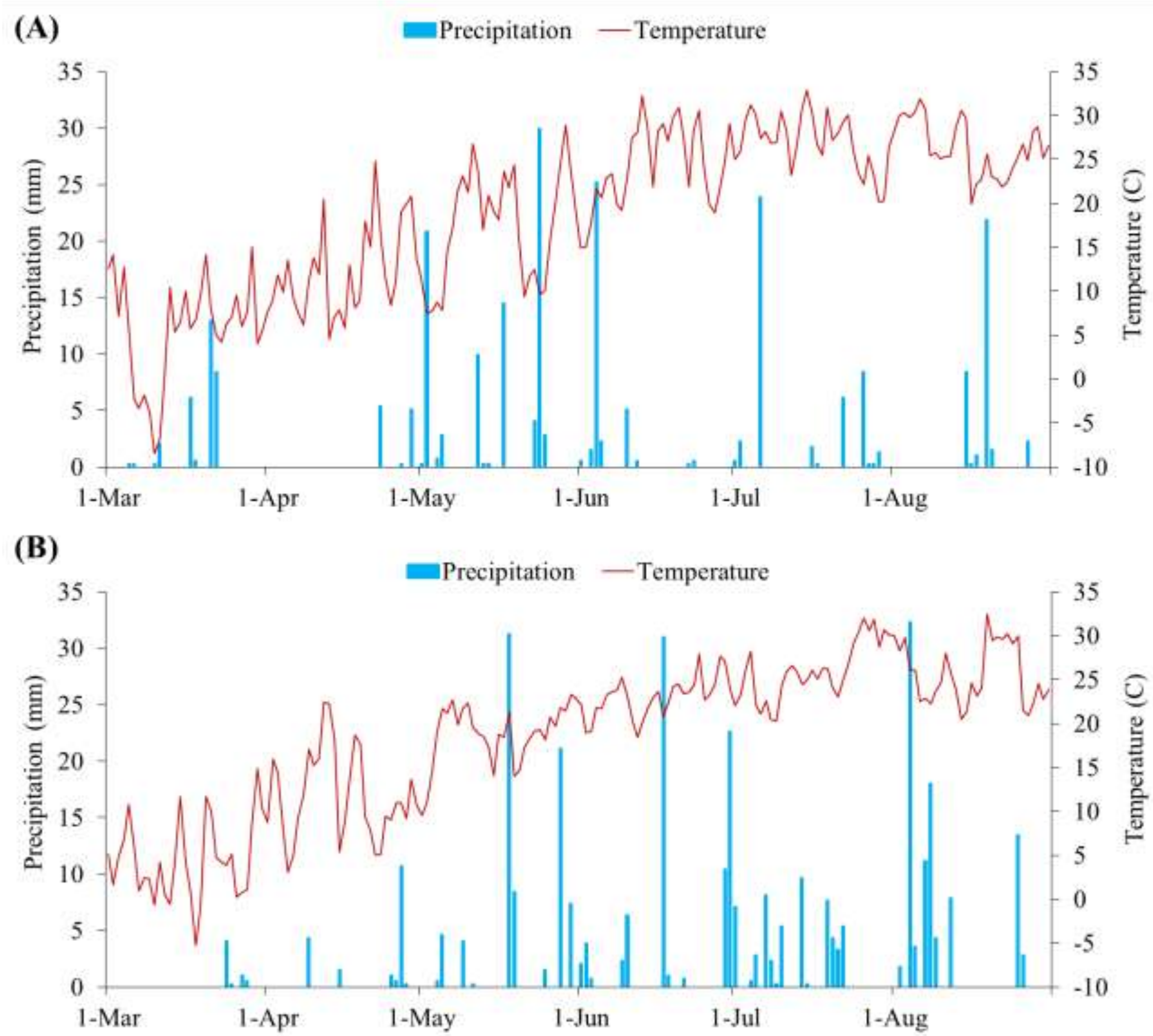

Figure 1. Daily average air temperature (C) and precipitation (mm) during the growing seasons of 2022 (A) and 2023 (B).

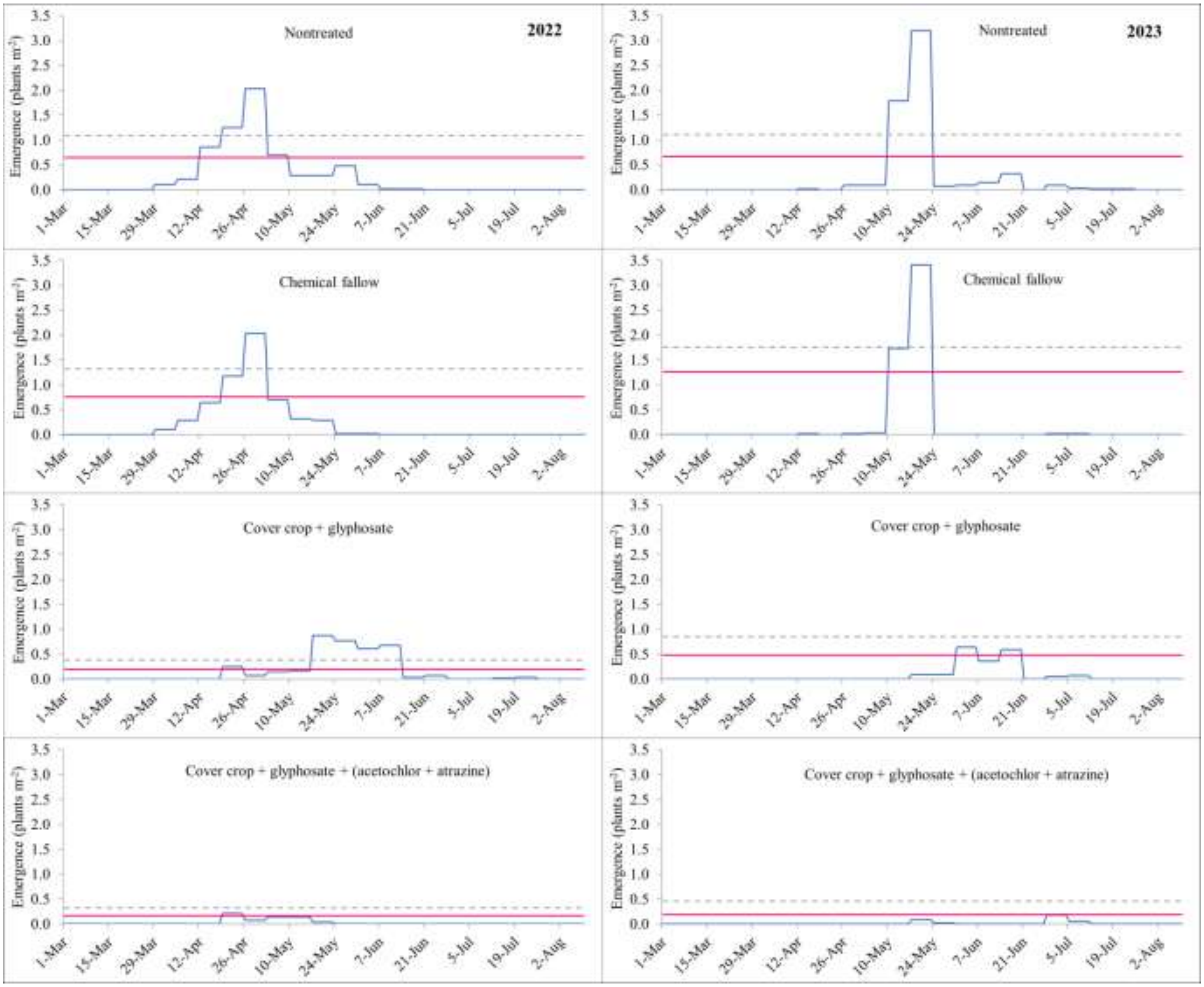

Figure 2. Daily emergence of glyphosate-resistant *Bassia scoparia* under different fall-planted cover crop treatments in 2022 and 2023. The horizontal solid line for each treatment represents the daily mean emergence and the dashed line represents the mean plus the standard deviation for each treatment.

https://doi.org/10.1017/wsc.2024.71 Published online by Cambridge University Press

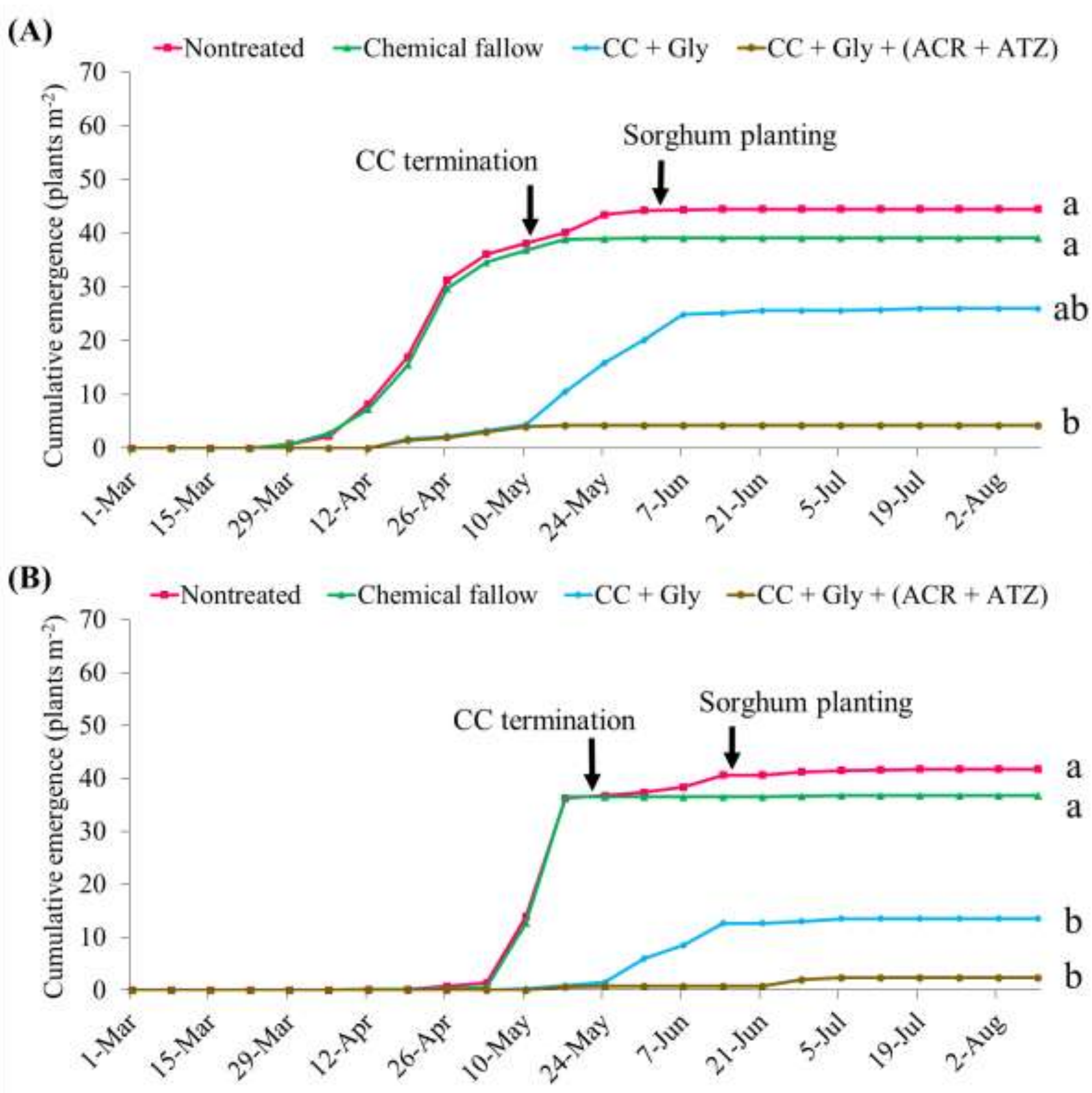

Figure 3. Cumulative emergence of glyphosate-resistant *Bassia scoparia* under different fall-planted cover crop (CC) treatments in 2022 (A) and 2023 (B). Arrows indicate the dates for fall-planted CC termination and planting of grain sorghum. Means for the cumulative emergence at the end of the line followed by the same letters are not significantly different based on Fisher's Protected LSD test. CC + Gly indicates CC terminated with glyphosate only and CC + Gly + (ACR + ATZ) indicates CC terminated with glyphosate plus a premix of acetochlor and atrazine.

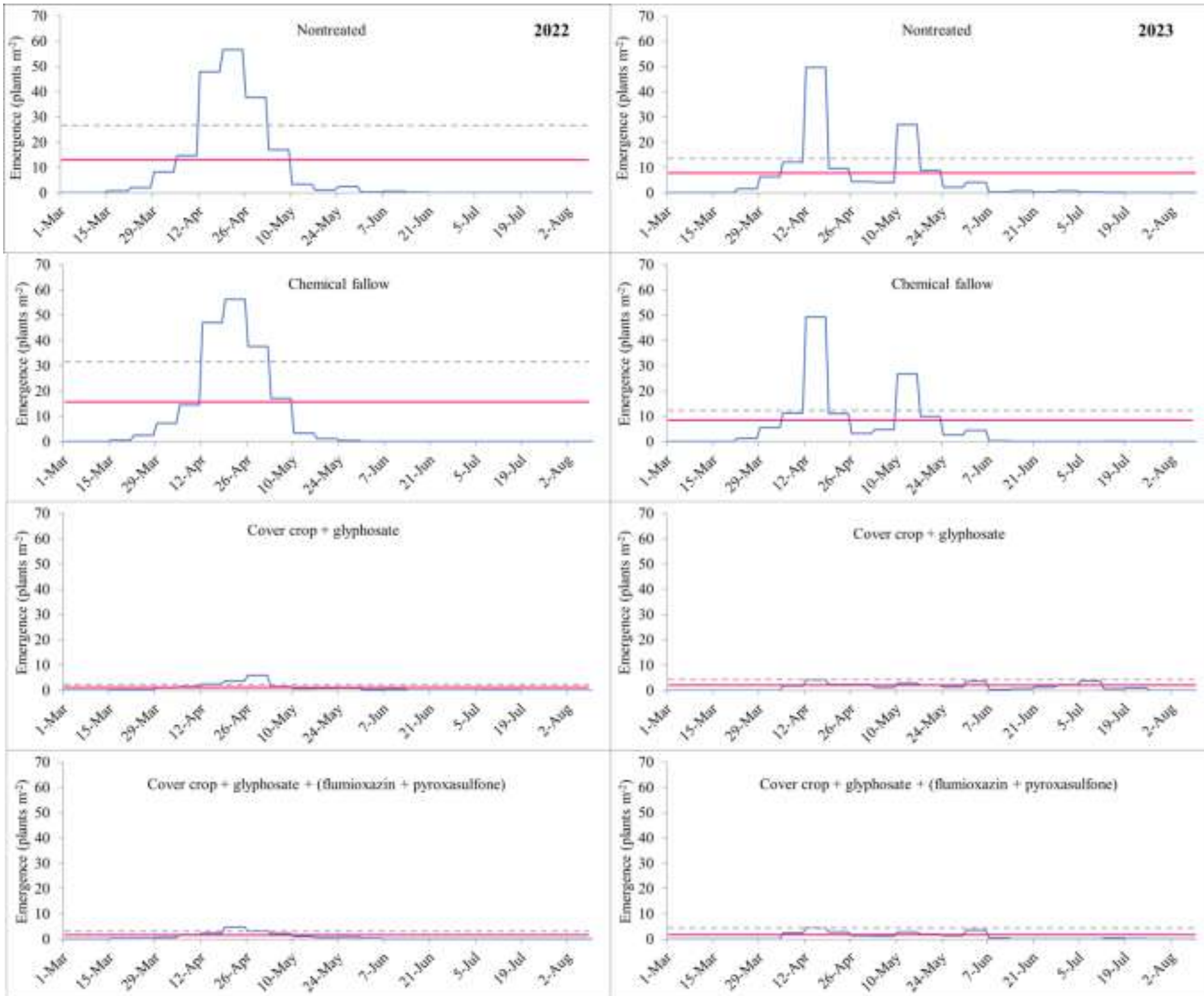

Figure 4. Daily emergence of glyphosate-resistant *Bassia scoparia* under different spring-planted cover crop treatments in 2022 and 2023. The horizontal solid line for each treatment represents the daily mean emergence and the dashed line represents the mean plus the standard deviation for each treatment.

https://doi.org/10.1017/wsc.2024.71 Published online by Cambridge University Press

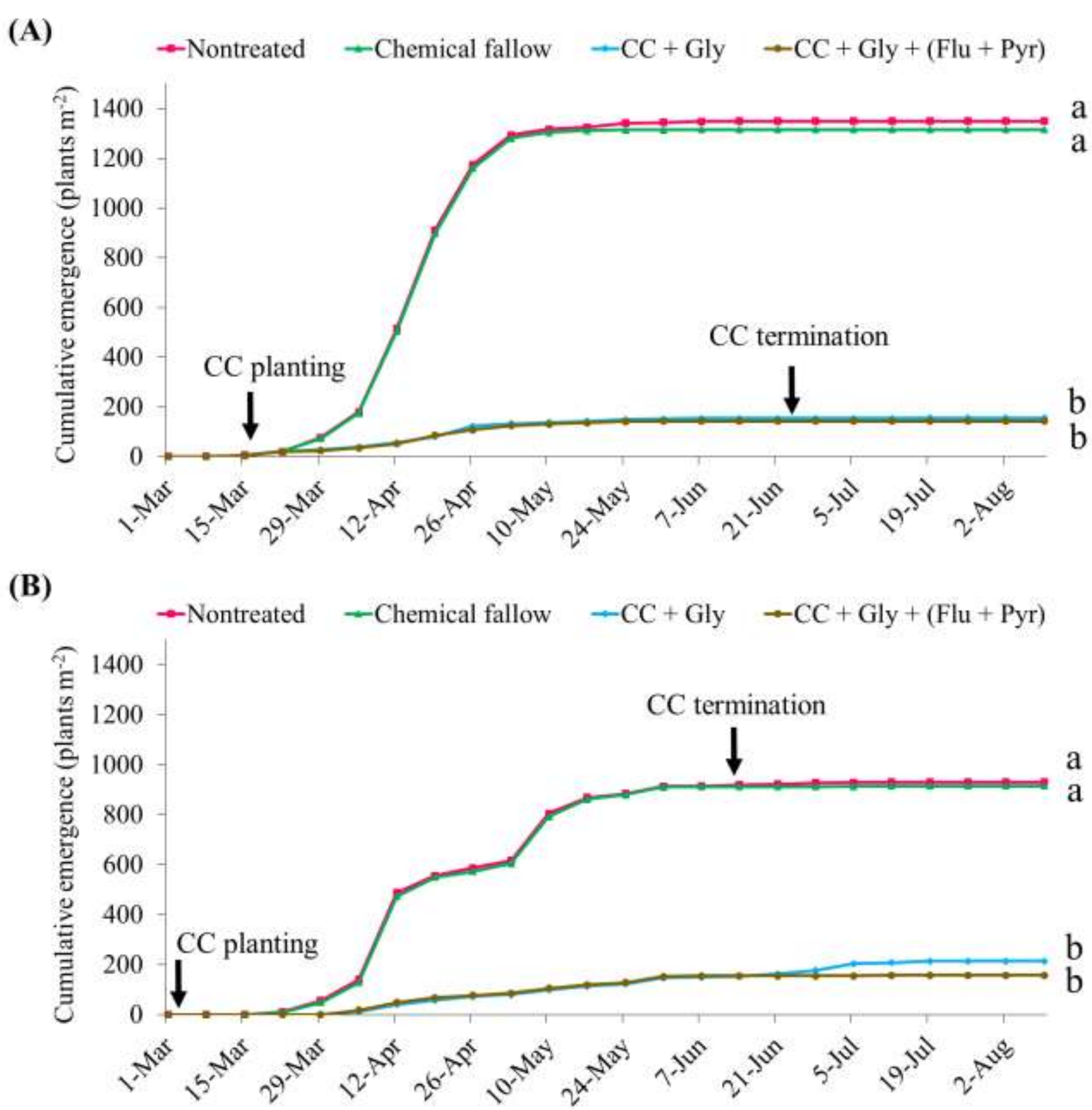

Figure 5. Cumulative emergence of glyphosate-resistant *Bassia scoparia* under different spring-planted cover crop (CC) treatments in 2022 (A) and 2023 (B). Arrows indicate the dates for planting and termination of spring-planted CC. Means for the cumulative emergence at the end of the line followed by the same letters are not significantly different based on Fisher's Protected LSD test. CC + Gly indicates CC terminated with glyphosate only and CC + Gly + (Flu + Pyr) indicates CC terminated with glyphosate plus a premix of flumioxazin and pyroxasulfone.