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Combined effects of spring-planted cover crops and residual herbicide on weed suppression and subsequent wheat yield in the semiarid Central Great Plains

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Abstract

Cover crops (CCs) are a component of the integrated weed management strategies for controlling herbicide-resistant weed biotypes. A field study was conducted at Kansas State University Agricultural Research Center near Hays, KS, from 2021 to 2024 to determine the effect of spring-planted CCs in combination with residual herbicide on weed suppression during fallow phase and subsequent wheat yield in a no-till winter wheat (*Triticum aestivum* L.)–grain sorghum [*Sorghum bicolor* (L.) Moench]–fallow rotation in the semiarid Central Great Plains (CGP). The study site had a natural seedbank of glyphosate-resistant (GR) kochia [*Bassia scoparia* (L.) A.J. Scott] and Palmer amaranth (*Amaranthus palmeri* S. Watson). A mixture of CCs (oats [*Avena sativa* L.]–barley [*Hordeum vulgare* L.]–spring peas [*Pisum sativum* L.]) was spring-planted in no-till sorghum stubbles and terminated at the oats heading stage. Four treatments were tested: (1) weedy fallow (no CC and no herbicide), (2) chemical fallow (no CC but glyphosate + flumioxazin/pyroxasulfone + dicamba), (3) CC terminated with glyphosate, and (4) CC terminated with glyphosate + flumioxazin/pyroxasulfone. Across 3 yr, CC at termination reduced total weed density by 78% to 99% and total weed biomass by 93% to 99% compared with weedy fallow. Weed suppression by the CC terminated with glyphosate plus flumioxazin/pyroxasulfone continued for at least 90 d with reduced total weed density of 52% to 80% and total weed biomass reduction by 70% compared with weedy fallow across 3 yr. No differences in subsequent wheat grain yield between CC treatments and chemical fallow were recorded in 2021 to 2022 and 2022 to 2023; however, in 2023 to 2024, chemical fallow and CC terminated with glyphosate + flumioxazin/pyroxasulfone had greater wheat yield than CC terminated with glyphosate only. These results suggest that integration of spring-planted CC with residual herbicide may help suppress GR *B. scoparia* and *A. palmeri* in the CGP.

Introduction

Winter wheat (*Triticum aestivum* L.)–grain sorghum [*Sorghum bicolor* (L.) Moench]–fallow (W-S-F) is a dominant 3-yr crop rotation in the semiarid Central Great Plains (CGP) (Holman et al. 2022). In this crop rotation, there is a 11- to 12-mo fallow period between sorghum harvest (October to November) and the subsequent winter wheat planting (October). Weed control during this fallow period is generally achieved with the use of herbicides. However, repeated and extensive use of glyphosate for weed control resulted in the widespread evolution of glyphosate-resistant (GR) weeds, including kochia [*Bassia scoparia* (L.) A. J. Scott], Palmer amaranth (*Amaranthus palmeri* S. Watson), and horseweed [*Erigeron canadensis* L.; syn. *Conyza canadensis* (L.) Cronquist] in this region (Dhanda et al. 2025b; Heap 2025; Jha et al. 2016; Kumar et al. 2019a, 2019b, 2020; Westra et al. 2019). Furthermore, multiple herbicide–resistant (MHR) *B. scoparia* and *A. palmeri* populations have also become evident in recent years (Dhanda et al. 2025b; Heap 2025; Kumar et al. 2019a, 2019b). Ecologically based integrated weed management strategies are needed for effective control of these GR or MHR weed populations.

Cover crops (CCs) are grown for a variety of agroecosystem services, including increased crop yields, enhanced organic carbon sequestration, reduced wind and water erosion, weed suppression, increased nutrient cycling, enhanced soil microbial activities, and reduced soil compaction (Blanco-Canqui et al. 2011, 2013; Kumar et al. 2020; Simon et al. 2022; Van Eerd et al. 2023). The magnitude of these benefits is highly variable based on CC species selection, planting and termination timings, method of termination, and the duration of cover cropping (Van Eerd et al. 2023). Integration of CCs in a crop rotation depends on several factors such as prevailing weather, availability of planting equipment, soil moisture, and the overall goal of cover cropping (Blanco-Canqui et al. 2011, 2013).

Actively growing CCs can suppress weed seedlings through direct competition for available resources or by releasing allelochemicals; whereas CC residue/mulch left on the soil surface after termination acts as a physical barrier for weed seed germination and seedling emergence (Silva and Bagavathiannan 2023; Teasdale and Mohler 1993). Several studies have shown that CCs can suppress weeds in semiarid environments (Dhanda et al. 2025a; Mesbah et al. 2019; Obour et al. 2022; Petrosino et al. 2015). For instance, Obour et al. (2022) reported that replacing the fallow phase of a W-S-F rotation with spring-planted CCs reduced weed biomass by 86% to 99% compared with weedy fallow. Weed suppression primarily depends on CC biomass, which is largely influenced by CC species, termination timing, and available soil water (MacLaren et al. 2019). For instance, Petrosino et al. (2015) reported that CCs accumulating >1,000 kg ha^{-1} of biomass at the time of termination was effective for weed suppression in the semiarid CGP. However, greater CC biomass can result in reduced soil water availability for the subsequent cash crop and can negatively impact cash crop yield, especially in dry years (Holman et al. 2018; Nielsen et al. 2016). Holman et al. (2022) reported that replacing fallow with CCs increased the cost of production by 16% to 97% in W-S-F rotation. To facilitate the adoption of CCs and to improve the net returns, the U.S. Department of Agriculture–Natural Resources Conservation Service (USDA-NRCS) provides some financial support to growers under the Environmental Quality Incentives Program (USDA-NRCS 2024).

Soil-residual herbicides play an important role in managing GR weed populations in the CGP region (Whalen et al. 2020). Several studies have shown the benefits of combining soil-residual herbicides with CCs for season-long weed suppression (Dhanda et al. 2025a; Perkins et al. 2021). For instance, Perkins et al. (2021) reported that fall-planted cereal rye (*Secale cereale* L.) + hairy vetch (*Vicia villosa* Roth) CCs in combination with preemergence herbicides (flumioxazin, pyroxasulfone, pyroxasulfone + flumioxazin, and/or acetochlor) reduced early-season density of *A. palmeri* and waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer.] in soybean [*Glycine max* (L.) Merr.]. Whalen et al. (2020) also reported that CCs terminated with glyphosate plus 2,4-D in combination with residual herbicides (sulfentrazone plus chlorimuron) resulted in 73% to 84% control of *A. tuberculatus* compared with 44% to 65% with no residual herbicide. Limited information exists regarding the integration of spring-planted CCs in combination with soil-residual herbicides for weed control during the fallow phase and the impact on subsequent winter wheat grain yield in a W-S-F rotation. Therefore, the main objectives of this study were to determine (1) the combined effects of spring-planted CCs and soil-residual herbicide on weed suppression (density and biomass) during the fallow period and (2) the impact on subsequent winter wheat yield.

Materials and Methods

Study Design and Treatments

A field study was conducted at Kansas State University Agricultural Research Center near Hays, KS (KSU-ARCH) (38.85196°N, 99.34279°W) from spring of 2021 to fall of 2024. The study site had been under no-till W-S-F rotation for >10 yr and had a natural infestation of GR *B. scoparia* and *A palmeri*. Each experimental year included all three phases of the crop rotation (W-S-F). The soil type at the study site was Roxbury silt loam (fine-silty, mixed, superactive, mesic Cumulic Haplustolls) with a pH of 6.9 and 1.6% organic matter. 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. The CC was terminated at the oats heading stage (corresponds to Zadoks 53 to 57) every year. The study was under a randomized complete block design with four replications. Each year, four treatments were established: (1) weedy fallow, (2) chemical fallow (standard grower practice in the CGP region), (3) CC terminated with glyphosate (GLY) (Roundup PowerMax®, Bayer Crop Science, St Louis, MO) at 1,260 g ae ha^{-1}, and (4) CC terminated with GLY at 1,260 g ha^{-1} plus a premix of flumioxazin/pyroxasulfone (FLU/PYR) (Fierce® EZ, Valent USA, Walnut Creek, CA) at 106/134 g ai ha^{-1}. The CC was not planted in weedy fallow control plots, and no herbicides were applied to control weeds, whereas in chemical fallow, no CC was planted, but these plots were treated with GLY at 1,260 g ha^{-1} plus a premix of FLU/PYR at 106/134 g ha^{-1} plus dicamba (Clarity®, BASF Corporation, Research Triangle Park, NC) at 560 g ae ha^{-1} at the same time as CC termination. Despite the presence of GR *A. palmeri* and *B. scoparia* at the study site, GLY was used in chemical fallow to control winter annuals and some grass weeds that growers typically apply in the region. Additionally, GLY is a cost-effective and commonly used herbicide for CC termination in the region. During the 2021 to 2022 experimental period, weedy fallow treatment was not present, and there were only three treatments. The plot size was 45-m long and 13-m wide. In 2022 to 2023 and 2023 to 2024, the initial chemical fallow plot was subdivided into two plots to have both weedy fallow and chemical fallow treatments (each 45-m long and 6.5-m wide) for comparison of weed suppression. Before winter wheat planting, all plots were sprayed in late September with GLY at 1,260 g ha^{-1} plus dicamba at 560 g ha^{-1}. Winter wheat variety ‘Joe’ was planted at a seeding rate of 67 kg ha^{-1} in rows spaced 19.1 cm apart. Because of low rainfall, winter wheat did not germinate in the fall of 2022; therefore, spring wheat variety ‘WestBred 9717’ was planted in the 2022 to 2023 growing season at a seeding rate of 112 kg ha^{-1}. Details for CC planting and termination dates and planting and harvesting dates for winter wheat in each experimental year are given in Table 1. Weather data, including monthly precipitation and air temperature over the 3-yr study period, were obtained from the Kansas State University Mesonet weather station (https://mesonet.k-state.edu) located approximately 400 m from the study site (38.8495°N, 99.3446°W) (Figure 1).

Data Collection

The aboveground CC biomass was measured by manually harvesting samples from two randomly placed 1-m^2 quadrats per plot just before CC termination. The samples were then oven-dried at 72 C for 4 d to determine the dry biomass. Weed density for each species was recorded at CC termination, 30, 60, and 90 d after CC termination (DATe) (except 2021 to 2022, when data were not collected at 60 DATe). Similarly, the aboveground weed biomass was manually harvested and oven-dried at 72 C for 4 d to obtain total weed dry biomass. Data for CC biomass, weed density, and weed biomass were averaged from both quadrats in each plot at each evaluation timing. The relative abundance of each weed species in each plot was calculated following the method outlined by Thomas (1985) using Equation 1. Relative density is the number of plants for each species within the quadrat per plot divided by the total number of plants in that sampled quadrat multiplied by 100. Relative frequency is the proportion of quadrats in which the

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Table 1. Planting and termination dates for cover crop and planting and harvesting dates for grain sorghum and wheat during 2020–2022, 2021–2023, and 2022–2024 seasons at Kansas State University Agricultural Research Center near Hays, KS.

Crop	Operation	2020–2022	2021–2023	2022–2024
Grain sorghum	Planting	June 14, 2020	June 9, 2021	June 2, 2022
	Harvesting	Oct 18, 2020	Nov 4, 2021	Oct 26, 2022
Cover crop	Planting	March 9, 2021	March 16, 2022	March 3, 2023
	Termination	June 24, 2021	June 23, 2022	June 13, 2023
Wheat	Planting	October 7, 2021	April 10, 2023[a]	October 2, 2023
	Harvesting	July 11, 2022	July 6, 2023	July 10, 2024

[a]Winter wheat planted on September 30, 2022, did not germinate; therefore, spring wheat was planted.

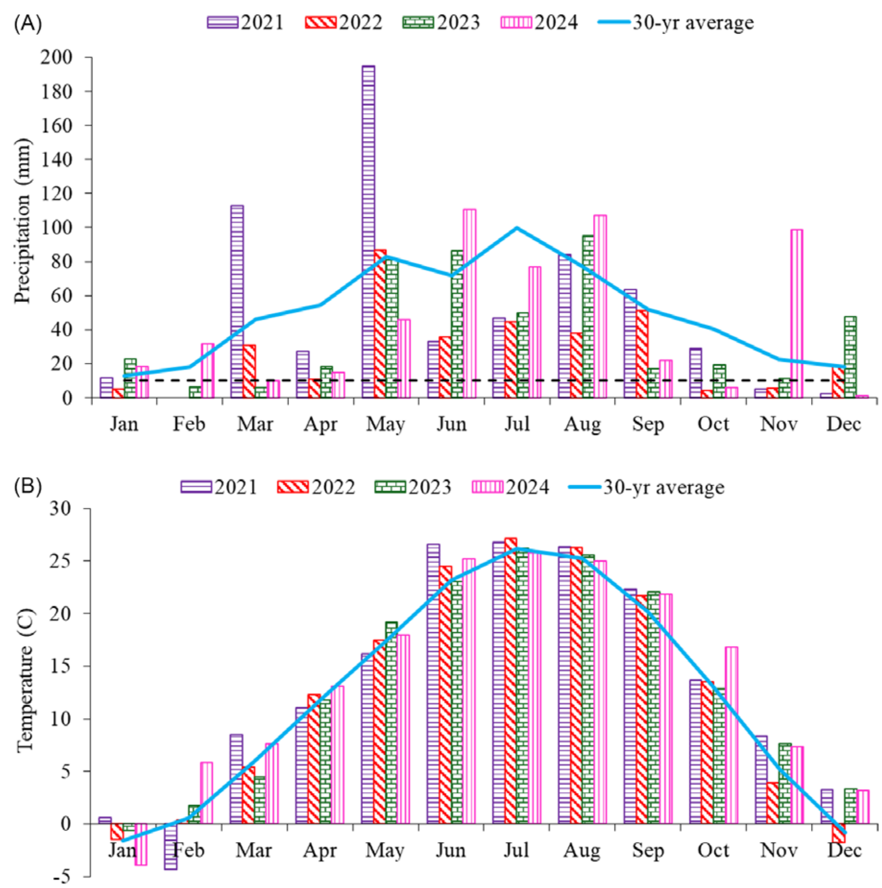

Figure 1. Total monthly precipitation (A) and average monthly air temperature (B) from 2021 to 2024 and 30-yr average at Kansas State University Agricultural Research Center near Hays, KS. The horizontal dashed line in A represents a 10-mm precipitation.

species was present, divided by the frequency of all species in that sampled quadrat, multiplied by 100 (Thomas 1985).

$$\text{Relative abundance} = \frac{\text{Relative density} + \text{Relative frequency}}{2} \quad [1]$$

Statistical Analyses

Data were subjected to ANOVA using the PROC MIXED procedure in SAS v. 9.3 (SAS Institute, Cary, NC). Data were checked for the homogeneity of variance and normality of the residuals using PROC UNIVARIATE. Data for weed density and biomass were log transformed to improve the normality of the residuals and homogeneity of variance; however, back-transformed data are presented with mean separation based on the transformed data. For CC biomass data, year was treated as fixed effect, while replication was treated as a random effect. For total weed density and total weed dry biomass data, CC treatment, year, evaluation timing, and their interactions were considered fixed effects, whereas replication and their interactions were considered random effects. For wheat yield, CC treatment, year, and their interactions were treated as fixed effects, whereas replication and their interactions were considered random effects. Data for total weed density, total weed dry biomass, and wheat yield were analyzed separately for each year because of significant year by treatment interaction ($P < 0.01$). Treatment by evaluation timing interaction for total weed density and total weed dry biomass was significant ($P < 0.001$); therefore, data were sorted by evaluation timings

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Table 2. Total weed density and mean relative abundance of weed species observed in the cover crop (CC) treatments at 0, 30, and 90 d after CC termination (DATe) in 2021–2022 at Kansas State University Agricultural Research Center near Hays, KS.[a]

Treatments[b]	Total weed density	Mean relative abundance				
		Bassia scoparia	*Amaranthus palmeri*	Grass	*Mollugo verticillata*	*Erigeron canadensis*
	plants m^{-2}	%				
At 0 DATe						
Chemical fallow	74 a	43	23	14	13	7
CC + GLY	1 b	100	0	0	0	0
CC + GLY + FLU/PYR	2 b	100	0	0	0	0
At 30 DATe						
Chemical fallow	57 a	14	41	14	9	22
CC + GLY	15 b	31	45	4	4	15
CC + GLY + FLU/PYR	13 b	27	48	0	2	24
At 90 DATe						
Chemical fallow	6 a	54	39	2	1	4
CC + GLY	4 a	28	70	0	0	2
CC + GLY + FLU/PYR	4 a	32	66	0	0	2

[a]Means followed by the same letter within a column at each timing are not different according to Fisher's protected LSD at $P < 0.05$.
[b]CC + GLY indicates cover crop terminated with glyphosate only and CC + GLY + FLU/PYR indicates cover crop terminated with glyphosate plus a premix of flumioxazin/pyroxasulfone.

using PROC SORT with evaluation timing treated as a repeated measure. Treatment means were separated using Fisher's protected LSD test ($P < 0.05$).

Results and Discussion

The total amount of precipitation received during the spring-planted CC growing season (March to June) was 332, 164, and 184 mm in 2021, 2022, and 2023, respectively (Figure 1). No difference was recorded in aboveground CC dry biomass at the time of termination in 2021 and 2022; however, significantly higher CC biomass was recorded in 2023 and was 1,240, 1,290, and 4,060 kg ha^{-1} in 2021, 2022, and 2023, respectively. Although cumulative precipitation in 2021 was high, it was not uniformly distributed. A few major events led to waterlogging and poor CC growth, resulting in lower CC biomass that year.

Total Weed Density and Weed Biomass

Bassia scoparia, *A. palmeri*, *E. canadensis*, Venice mallow (*Hibiscus trionum* L.), carpetweed (*Mollugo verticillata* L.), and grasses (mainly tumble windmillgrass [*Chloris verticillata* Nutt.]) were the major weeds at the study site across 3 yr. Among all weeds, *B. scoparia* and *A. palmeri* were the dominant weed species based on their relative abundance, across 3 yr (Tables 2–4).

The 2021 Growing Season

Bassia scoparia and *A. palmeri* were two dominant weed species in 2021 across all treatments and evaluation timings with a relative abundance of 14% to 100% and 23% to 70%, respectively (Table 2). Before termination or 0 DATe, CC reduced total weed density by 97% to 99% compared with chemical fallow. At this evaluation, no herbicide was applied in chemical fallow plots. CC terminated with GLY and GLY plus FLU/PYR reduced total weed density by 74% to 77% and 33% compared with chemical fallow at 30 and 90 DATe, respectively. Consistent with total weed density, CC at 0 DATe reduced the total weed dry biomass by 97% compared with chemical fallow (Table 5). Similarly, at 30 DATe, CC terminated with GLY and GLY plus FLU/PYR reduced total weed dry biomass by 40% to 44% compared with chemical fallow. However, there was no difference in total weed dry biomass between CC treatments and chemical fallow at 90 DATe. These results indicated that over time, CC residue degraded and was no longer able to suppress weeds. Osipitan et al. (2018) conducted a meta-analysis and reported that CCs significantly reduced total weed density and biomass at termination and provided early-season weed suppression.

The 2022 Growing Season

Bassia scoparia was the dominant weed in 2022 with a relative abundance of 54% to 100% across all treatments and evaluation timings (Table 3). This dominance could be attributed to low precipitation during the growing season and early emergence ability of *B. scoparia* compared with *A. palmeri*. Only 135 mm was received from CC termination to 90 DATe in 2022 compared with 225 mm in 2021 (Figure 1). As *B. scoparia* is drought tolerant, it thrived under these conditions; however, lower precipitation probably limited the germination of *A. palmeri*. Before termination, CC reduced total weed density by 94% compared with weedy fallow (Table 3). At 30 DATe, CC terminated with GLY and GLY plus FLU/PYR and chemical fallow resulted in a 65% to 95% reduction in total weed density compared with weedy fallow. At 60 DATe, CC terminated with GLY plus FLU/PYR provided 88% to 89% reduction in total weed density compared with weedy fallow or chemical fallow. Similarly, at 90 DATe, CC terminated with GLY plus FLU/PYR resulted in 80%, 72%, and 60% reduction in total weed density compared with weedy fallow, chemical fallow, and CC terminated with GLY only, respectively (Table 3). These results indicate the importance of CCs in combination with residual herbicide for reducing the total weed density as compared with chemical fallow. Obour et al. (2022) also reported 82% reduction in total weed density with a spring-planted CC mixture (oat–triticale×*Triticosecale* Wittm. ex A. Camus [*Secale* × *Triticum*]–peas) compared with weedy fallow. Consistent with total weed density, CC reduced total weed dry biomass by 93% to 95% before termination compared with weedy fallow (Table 5). The CC reduced sunlight penetration to the soil, suppressing weed seed germination and weed seedling emergence, competitiveness for resources, ultimately lowering weed biomass (Silva and Bagavathiannan 2023; Webster et al. 2016). At 60 DATe, CC terminated with GLY plus FLU/PYR reduced total weed biomass

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Table 3. Total weed density and mean relative abundance of weed species observed in the cover crop (CC) treatments at 0, 30, 60, and 90 d after CC termination (DATe) in 2022–2023 at Kansas State University Agricultural Research Center near Hays, KS[a]

Treatments[b]	Total weed density	Mean relative abundance				
		Bassia scoparia	*Amaranthus palmeri*	*Hibiscus trionum*	Grass	*Erigeron canadensis*
	plants m^{-2}	%				
At 0 DATe						
Weedy fallow	630 a	94	6	0	0	0
Chemical fallow	604 a	100	0	0	0	0
CC + GLY	36 b	76	24	0	0	0
CC + GLY + FLU/PYR	35 b	93	7	0	0	0
At 30 DATe						
Weedy fallow	120 a	100	0	0	0	0
Chemical fallow	37 b	54	5	11	10	21
CC + GLY	42 b	92	0	0	0	8
CC + GLY + FLU/PYR	6 b	89	0	0	0	11
At 60 DATe						
Weedy fallow	44 a	84	0	0	0	16
Chemical fallow	40 a	87	0	0	0	13
CC + GLY	30 ab	88	13	0	0	0
CC + GLY + FLU/PYR	5 b	100	0	0	0	0
At 90 DATe						
Weedy fallow	85 a	92	0	0	0	8
Chemical fallow	61 a	100	0	0	0	0
CC + GLY	43 ab	100	0	0	0	0
CC + GLY + FLU/PYR	17 b	100	0	0	0	0

[a]Means followed by the same letter within a column at each timing are not different according to Fisher's protected LSD at $P < 0.05$
[b]CC + GLY indicates cover crop terminated with glyphosate only and CC + GLY + FLU/PYR indicates cover crop terminated with glyphosate plus a premix of flumioxazin/pyroxasulfone.

Table 4. Total weed density and mean relative abundance of weed species observed in the cover crop (CC) treatments at 0, 30, 60, and 90 d after CC termination (DATe) in 2023–2024 at Kansas State University Agricultural Research Center near Hays, KS[a]

Treatments[b]	Total weed density	Mean relative abundance				
		Bassia scoparia	*Amaranthus palmeri*	*Hibiscus trionum*	Grass	*Erigeron canadensis*
	plants m^{-2}	%				
At 0 DATe						
Weedy fallow	116 a	100	0	0	0	0
Chemical fallow	104 a	92	7	0	1	0
CC + GLY	25 b	91	7	0	1	0
CC + GLY + FLU/PYR	23 b	75	23	0	2	0
At 30 DATe						
Weedy fallow	67 a	62	35	0	3	0
Chemical fallow	2 c	41	59	0	0	0
CC + GLY	39 b	68	28	2	2	0
CC + GLY + FLU/PYR	12 c	75	23	0	2	0
At 60 DATe						
Weedy fallow	52 a	67	27	0	6	0
Chemical fallow	22 b	82	10	0	3	5
CC + GLY	49 a	50	47	0	3	0
CC + GLY + FLU/PYR	32 b	90	9	0	1	0
At 90 DATe						
Weedy fallow	56 a	47	26	0	27	0
Chemical fallow	16 b	85	0	0	15	0
CC + GLY	61 a	49	34	0	16	0
CC + GLY + FLU/PYR	27 b	100	0	0	0	0

[a]Means followed by the same letter within a column at each timing are not different according to Fisher's protected LSD at $P < 0.05$.
[b]CC + GLY indicates cover crop terminated with glyphosate only and CC + GLY + FLU/PYR indicates cover crop terminated with glyphosate plus a premix of flumioxazin/pyroxasulfone.

by 98%, 92%, and 82% compared with weedy fallow, chemical fallow, and CC terminated with GLY only, respectively. Similarly, at 90 DATe, CC terminated with GLY plus FLU/PYR reduced total weed dry biomass by 70%, 36%, and 44% compared with weedy fallow, chemical fallow, and CC terminated with GLY only, respectively. A low reduction in total weed dry biomass under CC terminated with GLY only over time indicated that only CC was insufficient to suppress weeds and highlighted a need for residual herbicide with CC. Wiggins et al. (2016) also reported that CC alone was not enough for season-long control of GR *A. palmeri* and suggested integrating residual herbicides to complement the suppressive effect of CC.

Table 5. Total weed dry biomass in the cover crop (CC) treatments at 0, 30, 60, and 90 d after CC termination during 2021 to 2024 growing seasons at Kansas State University Agricultural Research Center near Hays, KS[a]

Treatments[b]	Total weed biomass			
	0	30	60	90
	g m^{-2}			
2021–2022				
Weedy fallow				
Chemical fallow	34 a	62 a		68 a
CC + GLY	1 b	37 b		73 a
CC + GLY + FLU/PYR	1 b	35 b		59 a
2022–2023				
Weedy fallow	58 a	95 a	116 a	125 a
Chemical fallow	53 a	16 b	24 b	58 b
CC + GLY	4 b	5 bc	11 b	66 b
CC + GLY + FLU/PYR	3 b	1 c	2 c	37 c
2023–2024				
Weedy fallow	194 a	224 a	500 a	626 a
Chemical fallow	115 a	3 c	58 c	170 c
CC + GLY	6 b	79 b	188 b	303 b
CC + GLY + FLU/PYR	2 b	11 c	58 c	188 c

[a]Means followed by the same letter within a column at each timing are not different according to Fisher's protected LSD at $P < 0.05$.
[b]CC + GLY indicates cover crop terminated with glyphosate only and CC + GLY + FLU/PYR indicates cover crop terminated with glyphosate plus a premix of flumioxazin/pyroxasulfone.

The 2023 Growing Season

Bassia scoparia, *A. palmeri*, and grass weeds (mainly *C. verticillata*) were dominant in 2023 across all treatments and evaluation timings with a relative abundance of 41% to 100%, 0% to 59%, and 0% to 27%, respectively (Table 4). Before termination, CC reduced total weed density by 78% to 80% compared with weedy fallow (Table 4). At 30 DATe, CC terminated with only GLY reduced total weed density by 42% compared with weedy fallow; however, CC terminated with GLY plus FLU/PYR and chemical fallow resulted in 82% to 97% reduction in total weed density compared with weedy fallow. At 90 DATe, both weedy fallow and CC terminated with GLY only had statistically similar total weed density, and CC terminated with GLY plus FLU/PYR and chemical fallow had 52% to 71% lower total weed density than weedy fallow. Consistent with total weed density, CC before termination resulted in 97% to 99% total weed dry biomass reduction compared with weedy fallow (Table 5). At 30 DATe, CC terminated with GLY only resulted in 65% reduction in total weed dry biomass compared with weedy fallow; however, CC terminated with GLY plus FLU/PYR increased the total biomass reduction to 95%, which was similar to chemical fallow. A similar trend was observed at 60 and 90 DATe. It is important to note that at 90 DATe, there was no difference in total weed density between weedy fallow and CC terminated with GLY only; however, the same CC treatment reduced total weed biomass by 52% compared with weedy fallow. These results indicate the suppressive action of CC on weed growth that would ultimately reduce the weed seed production (Baraibar et al. 2018).

Wheat Yield

During the 2022 to 2023 wheat growing season, particularly in October and November 2022, only 10 mm of precipitation was received (Figure 1), which led to poor germination and eventual failure of winter wheat; therefore, spring wheat was planted in the spring of 2023. Wheat grain yield was greater in 2021 to 2022 and ranged from 2,789 to 3,073 kg ha^{-1} compared with 2022 to 2023 and 2023 to 2024, where wheat grain yield ranged from 570 to 952 kg ha^{-1} (Table 6). The greater winter wheat grain yield in 2021 to 2022 compared with 2023 to 2024 might be due to higher precipitation in 2021 to 2022 at critical wheat stages, including the jointing stage (March to April) and booting to heading stages (April to May) (Figure 1). There were no significant differences in wheat yield between CC treatments and chemical fallow in 2021 to 2022 and 2022 to 2023; however, in 2023 to 2024, chemical fallow and CC terminated with GLY plus FLU/PYR resulted in greater yield followed by CC terminated with GLY only, and the least yield was recorded in weedy fallow. Holman et al. (2022) reported that fallow replacement in a W-S-F rotation with spring-planted CCs had no significant effect on wheat yield when conditions were either extremely dry with poor yields or very wet with above-average yields.

Table 6. Spring-planted cover crop (CC) effect on winter wheat yield over three growing seasons at Kansas State University Agricultural Research Center near Hays, KS[a]

Treatments[b]	Wheat yield		
	2021–2022	2022–2023[c]	2023–2024
	kg ha^{-1}		
Weedy fallow		589 b	570 c
Chemical fallow	2789 a	763 a	952 a
CC + GLY	3031 a	808 a	724 b
CC + GLY + FLU/PYR	3073 a	876 a	886 a

[a]Means followed by the same letter within a column are not different according to Fisher's protected LSD at $P < 0.05$
[b]CC + GLY indicates cover crop terminated with glyphosate only and CC + GLY + FLU/PYR indicates cover crop terminated with glyphosate plus a premix of flumioxazin/pyroxasulfone.
[c]In 2022–2023, because of low rainfall, winter wheat did not germinate; therefore, spring wheat was planted.

Results from this study indicate that integrating a spring-planted CC mixture after grain sorghum in the W-S-F rotation and terminating it with GLY plus FLU/PYR herbicide can provide weed suppression up to 90 DATe. Before termination (mid- to late June), spring-planted CC reduced total weed density by 78% to 99% and total weed biomass by 93% to 99% compared with weedy fallow. It is critical for early-emerging weeds like *B. scoparia* and *A. palmeri* which can start emerging in March-May (Dhanda et al. 2024; Dille et al. 2017; Kumar et al. 2018). With time, CC residue started to degrade and at 90 DATe, CC terminated with GLY plus FLU/PYR reduced total weed density by 52 to 80% and total weed dry biomass by 70% compared with weedy fallow across years. No differences in wheat grain yield between CC treatments and chemical fallow were recorded in 2021 to 2022 and 2022 to 2023; however, in 2023 to 2024, chemical fallow and CC terminated with GLY plus FLU/PYR had greater yield than CC terminated with GLY only. It is important to note that under the low wheat yield scenario observed in the present study, net returns could become negative. This is because the reduced returns from wheat yield may not be sufficient to offset the costs of CC seed and planting, as highlighted in our previous study (Dhanda et al. 2025a). Future studies should focus on integrating other weed control methods along with CCs to control late-emerging weeds.

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