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Integrated management of cheat (*Bromus secalinus* L.) and downy brome (*Bromus tectorum* L.) in Oklahoma grain-only winter wheat

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Abstract

In Oklahoma, downy brome and cheat are difficult-to-control winter annual grasses. In the past, cheat infested most of the winter wheat hectares harvested in Oklahoma. Biotypes that are cross-resistant to acetolactate synthase–inhibiting herbicides have left growers with minimal management options for conventional and herbicide-tolerant systems. Field trials near Lahoma, Oklahoma, in 2019–2020 and 2020–2021 evaluated integrated management of cheat and downy brome using three strategies: planting date (optimal, delayed, and late), cultivar selection (high and low competitiveness), and herbicide choice (no herbicide, sulfosulfuron at 35.2 g ai ha^{-1} and pyroxsulam at 18.4 g ai ha^{-1}). Visual control, weed species present, wheat biomass at heading, and grain yield data were collected. In 2019–2020, 8 to 9 wk after treatment, visual control increased by 15% with the delayed planting compared with the optimal planting date and 14% with the late planting date. In 2020–2021, similar control (~99%) was recorded for delayed and late plantings with 23% greater control than the optimal timing. Due to a lack of weed coverage, weed biomass in 2019–2020 had no response to planting date, cultivar, or herbicide treatment. Downy brome biomass during 2020–2021 was approximately 90% lower with delayed to late planting dates than the optimal planting date. In the same year, downy brome and cheat biomass were low (≤0.4 and 0.2 g m^{-2}) and 98% less after an herbicide application than a nontreated area. Wheat grain yield at the optimal planting date was greater than yields from delayed and late plantings in 2019–2020. A delay in planting from the optimal date to delayed or late timings decreased wheat yield by 14% and 21%, respectively. In 2020–2021, wheat yield from the late planting was reduced by 57% compared with the optimal planting yield. Delaying the planting date and the use of a common herbicide can suppress cheat and downy brome, but a decline in wheat yield may occur.

Introduction

From 2020 to 2022, Oklahoma was ranked second or third in the nation for winter wheat production; winter wheat was the number-one cash crop produced on 991,000 ha harvested in Oklahoma during 2022 (USDA-NASS 2022). Oklahoma winter wheat is unique because producers use it for both forage and grain purposes, thereby increasing the diversity of their products and their income for the year. When using the land for forage and grain, producers will place cattle out to graze wheat through mid-fall and winter, remove the cattle before wheat jointing, and harvest the grain in summer. This is known as a dual-purpose system. Because of the flexibility winter wheat systems provide, Oklahoma producers can either sow wheat for dual purposes from August to mid-October or as seed for a grain-only purpose from mid-October to November (Lollato 2017). Due to the diverse benefits dual-purpose winter wheat provides, many producers grow wheat season-to-season within the same field in a monoculture.

Additionally, in these continuous winter annual grass crop systems, winter annual grass weeds, such as downy brome (*Bromus tectorum* L.), form monospecific stands that adapt and thrive (Menalled et al. 2008). Persistence of winter annual grass weeds becomes common as continuous monoculture systems fail to break up pest cycles through lack of herbicide availability, cultural efforts, and use of crop rotation to hinder weed growth cycles.

Considering the unique and economically important resource of Oklahoma winter wheat in the state and region, the consistency of infestations with weeds from the *Bromus* species

Table 1. Key agronomic study dates during the 2019–2020 and 2020–2021 winter wheat growing seasons

Growing season	Plant timing[a]	Planting date	Herbicide application date[b]	Biomass collection[c]	Harvest date[d]
2019–2020	Optimal	October 17	December 20	May 12	June 8
	Delayed	November 5	January 14	May 14	June 8
	Late	November 18	February 7	May 19	June 18
2020–2021	Optimal	October 9	December 1	May 7	July 7
	Delayed	November 11	February 2	May 15	July 7
	Late	November 30	March 31	May 20	July 7

[a]The optimal planting date represents the optimal window for sowing grain-only wheat to maximize grain yield and quality. The delayed timing occurred 2 to 3 wk after the optimal date, whereas the late planting date occurred 2 to 3 wk after the delayed date.
[b]Application timing of pyroxsulam sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron at 35.2 g ai ha^{-1} at the 2- to 3-leaf stage of winter wheat and cheat for each planting date. All herbicide treatments were applied using water as the carrier and included a nonionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate solution at 30% vol/vol.
[c]Biomass collection of wheat and cheat at heading.
[d]Harvest date of wheat grain when kernel moisture was between 9% and 12%.

contributes to significant direct and indirect losses. Ratliff and Peeper (1987) observed dockage in harvested grain exceeding 40% in cheat-infested (*B. secalinus* L.) wheat fields. Other economically critical *Bromus* species found in Oklahoma winter wheat include not only cheat but also Japanese brome (*B. japonicus* Thunb.), rescuegrass (*B. catharticus* Vahl.), and occasionally, downy brome. At one time, cheat infested approximately 1.4 million ha of harvested winter wheat in Oklahoma (Ratliff and Pepper 1987) and reduced grain yield by up to 19% at a density of 89 plants m^{-2} (Fast et al. 2009). Downy brome densities can exceed 400 plants m^{-2}, and may cause crop failure (Reddy et al. 2013).

Despite many regionally adapted wheat cultivars available to producers in Oklahoma and the region, cheat can still compete with wheat, causing grain and forage yield loss, delayed harvest operations, additional seed cleaning, and grain quality discounts for dockage, foreign material, or both. Immediate control and removal of *Bromus* species, like cheat, can be correlated to reduced competition and higher crop yield response (Ratliff 1985) and quality. Cheat and downy brome have unique qualities that contribute to their weediness and persistence, such as an ability to germinate over a wide range of environmental conditions (Haferkamp et al. 1994). Downy brome grows rapidly in the spring, which reduces resources for wheat during heading, and thereby reducing yields by up to 20% (Menalled et al. 2008; Stahlman and Miller 1990).

Many *Bromus* species have evolved resistance to herbicides. As early as 2009, Oklahoma documented cheat that was cross-resistant to all herbicides that inhibit acetolactate synthase (ALS; categorized as Group 2 herbicides by the Weed Science Society of America), including imazamox, propoxycarbazone-sodium, pyroxsulam, and sulfosulfuron (Heap 2021). Quizalofop-resistant (CoAXium®) and imazamox-resistant (Clearfield®) winter wheat systems provide control of many winter annual grass species, including *Bromus* species, but they are not a tool for sustainable management of species that are resistant to WSSA Group 1 and Group 2 herbicides, such as cheat and downy brome (Heap 2024). Although reports of downy brome resistance are correlated with the Pacific Northwest, there is concern that Clearfield and CoAXium technologies may cause resistance in Oklahoma.

With recent documentation of ALS cross-resistant cheat in Oklahoma, imazamox is now ineffective in many regions, leaving wheat growers with only one option: to spray quizalofop onto quizalofop-resistant wheat. However, without proper stewardship (crop and herbicide rotations) of the technology, continued development of grass weed biotypes that are resistant to WSSA Group 1 herbicides will occur. Some wheat fields where our study was located still have susceptible cheat populations, which allows for the continued reliance on certain herbicides. Herbicide-only management practices that fail to integrate other practices will result in the further selection of herbicide-resistant species, likely not being detected until their populations reach 30% of total weed populations (Mahmood et al. 2014). Nevertheless it is still critically necessary that winter wheat systems use integrated weed management rather than relying on herbicides alone.

The lack of consistent, effective management strategies for cheat and downy brome is a serious production problem facing many winter wheat producers in the southern Great Plains. To improve management of cheat and downy brome in the region, a study was conducted in Lahoma, Oklahoma, over two growing seasons, to evaluate the effects of wheat cultivar selection, planting date, and herbicide treatment on ALS-susceptible cheat and downy brome populations.

Materials and Methods

Field experiments were located near Lahoma, OK (36.23086°N, 98.06464°W; elevation 380 m), during the 2019–2020 and 2020–2021 winter wheat growing seasons. The soil was primarily a Grant silt loam (fine-silty, mixed, superactive, thermic Udic Argiustolls) with an average pH of 5.9 and organic matter content of 1.5%. Field trial growing seasons are referred to as the year grain harvest occurred. Winter wheat was sown from early October to mid-November (Table 1). In-season rainfall and average monthly temperature are listed in Table 2.

The experimental design was a three-way factorial treatment structure (three planting dates × two cultivars × three herbicides), arranged as a split-plot design with 18 treatments with four replications. Main plots consisted of three planting dates, subplots represented one of two wheat cultivars, and sub-subplots included two herbicide treatments plus a nontreated control. Individual sub-subplots were 2.2 m wide by 10 m in length. N-P-K fertilizer was applied as indicated by soil test results. Fungicide was applied at wheat flag leaf emergence. Soil samples were collected from 1 acre (0.405 ha) of each field location prior to planting each year by obtaining 20 to 30 soil cores from 0 to 15 cm in depth. Samples were thoroughly mixed and analyzed at the Oklahoma State University Soil, Water and Forage Analytical Laboratory (SWFAL) in Stillwater for pH, organic matter, and N-P-K analysis. Based on SWAFL results, N-P-K was applied either prior to planting or split into two applications: prior to planting and prior to green-up in the late winter/early spring.

Three planting dates were used to represent optimal, delayed, and late plantings (Table 1) for grain-only winter wheat production in Oklahoma. The optimal planting date occurred from

Table 2. Monthly average weather data from Lahoma, OK, during the 2019–2020 and 2020–2021 winter wheat growing season.[a,b]

	2019–2020			2020–2021		
	Temperature			Temperature		
Month	Min	Max	Rainfall	Min	Max	Rainfall
	——C——		mm	—— C ——		mm
October	−7	28	20	−3	34	55
November	−11	24	30	−6	27	41
December	−6	22	38	−12	20	46
January	−7	20	38	−7	18	38
February	−10	24	30	−25	21	5
March	−3	27	76	−4	27	117
April	−3	30	25	−3	27	56
May	2	34	48	5	30	107
June	11	39	0	12	39	114
July	—	—	—	17	33	8
Average	−4	28	34	−3	28	59
Total			305			587

[a]Maximum and minimum temperature data were obtained from Mesonet, Oklahoma's Weather Network(mesonet.org).
[b]Rainfall was determined from planting date to harvest date.

Table 3. Visual control of cheat and downy brome 8 to 9 wk after herbicide treatment during the 2019–2020 and 2020–2021 winter wheat growing seasons

	2020	2021
	———% Visual control[a]———	
Planting date[b]		
Optimal	74 c[c]	76 b
Delayed	83 b	98 a
Late	96 a	99 a
Herbicide[d]		
Pyroxsulam	84	90
Sulfosulfuron	82	91

[a]Visual rating of cheat control was based on a scale of 0% to 100% as compared to nontreated plots, where 0% represents no control, and 100% represents complete control.
[b]The optimal planting date represents the optimal window for sowing grain-only wheat to maximize grain yield and quality. The delayed timing occurred 2 to 3 wk after the optimal date, and the late planting date occurred 2 to 3 wk after the delayed date.
[c]Means within a column for each site year followed by a common letter were similar according to Fisher's protected LSD at $P < 0.05$.
[d]Pyroxsulam was sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron at 35.2 g ai ha^{-1}. All herbicide treatments were applied using water as the carrier and included a nonionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate solution at 30% vol/vol.

October to mid-November (Lollato et al. 2017), representing the optimal time to sow grain-only wheat for north central Oklahoma. The delayed planting date was approximately 2 to 3 wk after the optimal date, and the late planting date was approximately 5 to 6 wk after the optimal planting. Two high-yielding winter wheat cultivars were selected: 'Showdown', which has early canopy coverage and low forage-yielding characteristics during spring; and 'Green Hammer', which has low-competitive early canopy coverage and high forage-yielding characteristics during spring (Anonymous 2021). Fields were prepped with a disk and field cultivator, undercutting 10 cm below the soil surface and churning the topsoil with multiple shanks and teeth to smooth out the field. Wheat was seeded at a soil depth of 1.9 cm and a rate of 67 kg ha^{-1} using a grain drill with 19-cm row spacing. Immediately after each sowing for each planting date, a burndown application of glyphosate at 0.86 kg ae ha^{-1} with ammonium sulfate at 2.85 kg ha^{-1} was sprayed to ensure a weed-free field before wheat emergence.

Herbicide treatments included two common ALS-inhibiting herbicides and a nontreated control (Table 2). Each herbicide treatment included a nonionic surfactant at 0.25% vol/vol plus liquid urea-ammonium nitrate at 30% vol/vol. Treatments consisted of pyroxsulam (18.4 g ai ha^{-1}, PowerFlex® HL; Corteva Agriscience, Wilmington, DE) or sulfosulfuron (35.2 g ai ha^{-1}, Outrider®; Valent U.S.A., San Ramon, CA) applied at the 2- to 3-leaf stage of cheat and downy brome at each site and planting date. Herbicides were sprayed at the recommended labeled rate using water as the carrier with a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at 1.6 kph, using Turbo TeeJet® 11002 nozzles (Spraying Systems Co., Glendale Heights, IL). As previously mentioned, ALS cross-resistant cheat has been confirmed in Oklahoma, however, a susceptible biotype was present at this site for both cheat and downy brome. Downy brome has recorded ALS resistance in Oregon and Montana, but not Oklahoma.

Visual control estimates of cheat and downy brome (Table 3) were evaluated approximately 8 to 9 wk after treatment using a scale of 0% to 100%, where 0% = no weed control and 100% = complete control. At the heading of wheat stage, downy brome, cheat, and wheat biomass was collected from a single square-meter quadrat between the second and third row of the crop from the west side of each plot. Biomass samples were separated by species in the field. Samples were dried in an oven at 60 C for 5 d, weighed, and recorded. Wheat was harvested in June or July of each year (Table 2) with a small-plot combine (Model Classic Plus; Wintersteiger, Salt Lake City, UT).

Due to significant site year-by-treatment interactions, all site years were analyzed independently. Fixed effects included planting date, winter wheat cultivar, and herbicide treatment, with replication considered a random effect. Observations of fixed-effect interactions were also included. A univariate analysis was performed on all responses to test for stable variance with SAS software (version 9.4; SAS Institute Inc., Cary, NC). No data sets were transformed because transformation did not increase stabilization. Data sets were analyzed using the GLIMMIX procedure, and treatments were separated by Fisher's protected LSD at an α level of 0.05.

Results and Discussions

There were no significant effects of wheat cultivar on visual control of cheat or downy brome; the biomass of cheat, downy brome, and wheat; or wheat grain yield. There were also no significant interactions between wheat cultivar and planting date; wheat cultivar and herbicide; or wheat cultivar, planting date, and herbicide. Consequently, data were averaged across cultivars within planting dates and herbicide treatments. Data for cultivar selection will not be discussed in the following results. It is critical to note that only two cultivars were assessed.

Cheat and Downy Brome

Visual Control

Weed species data are presented by year to account for differences observed across total species and population variations. In 2020, planting date affected cheat and downy brome visual control 8 to 9 wk after treatment (Table 3). A delay in planting allowed for a longer window to apply glyphosate as a burndown treatment to control emerged *Bromus* species before sowing wheat, ultimately reducing the amount of cheat and downy brome vegetation observed. Visual cheat and downy brome control increased by 9%

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Table 4. Wheat, downy brome, and cheat biomass collected at heading during the 2019–2020 and 2020–2021 winter wheat growing seasons.[a]

	2019–2020			2020–2021		
	Wheat	Downy brome	Cheat	Wheat	Downy brome	Cheat
	g m^{-2}					
Planting date[b]						
Optimal	935 a	17.6	11.2	830 a	43.2 a	13.6
Delayed	686 b	11.2	28.8	793 a	5.6 b	11.6
Late	750 b	22.8	17.6	608 b	4.0 b	30.8
Herbicide						
Nontreated	838	21.6	21.2	698	50.0 a	54.0 a
Pyroxsulam[c]	783	3.6	8.4	757	1.6 b	0.8 b
Sulfosulfuron[c]	750	26.8	28.8	776	1.6 b	0.8 b

[a]Means within a column for each site year followed by a common letter were similar according to Fisher's protected LSD at $P < 0.05$.
[b]The optimal planting date represents the optimal window for sowing grain-only wheat to maximize yield and quality. The delayed timing occurred 2 to 3 wk after the optimal date, and the late planting date occurred 2 to 3 wk after the delayed date.
[c]Pyroxsulam was sprayed at a rate of 18.4 g ai ha^{-1}, sulfosulfuron at 35.2 g ai ha^{-1}. All herbicide treatments were applied using water as the carrier and included a nonionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate solution at 30% vol/vol.

Table 5. Grain yield obtained from the 2019–2020 and 2020–2021 winter wheat growing seasons.[a]

	2019–2020	2020–2021
	kg ha^{-1}	
Planting date[b]		
Optimal	3,980 a	4,870 a
Delayed	3,410 b	4,400 ab
Late	3,160 b	2,080 b

[a]Means within a column for each site year followed by a common letter were similar according to Fisher's protected LSD at $\alpha < 0.05$.
[b]The optimal planting date represents the optimal window for sowing grain-only wheat to maximize grain yield and quality. The delayed timing occurred 2 to 3 wk after the optimal planting date, and the late planting date occurred 2 to 3 wk after the delayed date.

at the delayed planting compared with the optimal, and it increased by 13% at the late planting compared with the delayed planting. In 2021, similar visual control (~99%) was recorded for delayed and late plantings and was 23% greater than visual control following the optimal planting.

The effects of planting date on cheat and downy brome were similar to those reported by Koscelny et al. (1991). Wheat plots planted in September, October, and November at the Lahoma location averaged 84, 71, and 11 plants m^{-2}, respectively. Massee (1976) observed similar trends in Idaho when downy brome was purposely planted with winter wheat on three planting dates (September 20, October 3, and October 19), with downy brome germination declining as planting date was delayed. Delaying planting not only reduces weeds that are present, but it creates fewer instances of weed-crop competition due to a reduced ability of weeds to compete with a later-planted crop (Melander 1995).

Biomass

In both years, cheat and downy brome biomass collected at the wheat heading stage averaged 2.6% and 2.75% of total biomass, respectively. Cheat and downy brome biomass during the 2020 growing season was unaffected by any management strategy (Table 4). This may result from inadequate rainfall before the optimal planting date, which delayed overall cheat and downy brome emergence (Table 1). Additionally, weed biomass was highly variable from plot to plot in 2020, with some plots having no biomass (data not shown). In 2021, planting date also did not create significant differences in cheat biomass, but it did for downy brome. Delayed and late planting dates reduced downy brome biomass by 87% and 91%, respectively, compared with the optimal planting (Table 4). Sufficient rainfall around the optimal planting encouraged downy brome emergence and control with preplant burndown glyphosate prior to the delayed and late planting dates (Table 1). Koscelny et al. (1991) conducted an experiment in the Lahoma area and documented similar cheat biomass values as well as a similar trend of cheat biomass peaking that averaged 390, 499, and 54 kg ha^{-1} at wheat planting dates of September 21, October 11, and November 2, respectively.

In 2021, there was an herbicide effect for both cheat and downy brome biomass, in which pyroxsulam or sulfosulfuron use resulted in biomass reduction of 98% and 97%, respectively, compared with nontreated controls (Table 4). Cheat and downy brome biomass in 2020 were not affected by herbicide application. Herbicide efficacy may be limited by cheat and downy brome's delayed asynchronous emergence, allowing late-emerging individuals to escape the timing of herbicide applications. Although herbicide application successfully controlled susceptible cheat and downy brome populations at the research location in 2021, populations of *Bromus* species can still create problems of herbicide control with a cheat that is cross-resistant to the ALS herbicides imazamox, propoxycarbazone-sodium, pyroxsulam, and sulfosulfuron (Heap 2021).

Winter Wheat

Biomass

Wheat biomass is presented by year to account for differences observed across temperature and environmental variations. A delay in planting did affect wheat biomass in 2020 and 2021 (Table 4). Optimal-time planting in 2020 resulted in up to 26% greater wheat biomass compared with delayed and late plantings. Biomass for optimal and delayed plantings were similar, with 33% greater biomass than late-planted wheat in 2021. Similar findings by Wajid et al. (2004) revealed that wheat biomass following a recommended sowing timing significantly increased the final biomass of wheat compared with that of a late planting date. Planting within a recommended planting window allows producers to sow wheat during optimal soil temperatures of 12 to 25 C (Edwards 2008). As planting date is delayed, soil temperatures fall below the optimal range, resulting in less wheat emergence.

Grain Yield

Even though optimal planting dates improved wheat biomass in both years, end-of-season grain yield was variable. In 2020, grain yield was reduced from optimal planting to delayed or late planting, evidenced as a decrease in grain yield by up to 21% (Table 5). In 2021, increased wheat biomass was observed for optimal and delayed plantings compared with late-planted wheat; only the optimal timing yielded more grain than the late timing, with 57% more grain harvested from the optimal planting. It is important to note that during the 2021 growing season, a severe freeze occurred in early February, which prolonged crop stress. A severe freeze during the winter, multiple freezes in the spring, or both, can result in severe wheat injury depending on the wheat growth stage at time of the event or events (Barret 1978;

Miller 1992). Additionally, significant stripe rust (*Puccinia striiformis* f. sp. *tritici*) followed by leaf rust [*P. triticina* (*P. recondite* Roberge ex Desmaz. f. sp. *tritici*)] infection during wheat recovery from the freeze-reduced growth for late-planted wheat.

The use of ALS-inhibiting herbicides pyroxsulam and sulfosulfuron can provide effective control of cheat and downy brome but they may affect crop growth. Environmental conditions such as air temperature (Olson et al. 2000), soil organic matter, pH (Moyer and Hamman 2001), and precipitation (Shinn et al. 1998) can alter the efficacy of sulfonylurea herbicides (e.g., sulfosulfuron). A wide range of weather conditions occurred throughout the 2 site-years evaluated in our study. This likely explains the varying herbicide effects.

Winter wheat cultivar selection, herbicide treatment, and wheat planting time can be important strategies for cheat and downy brome management in winter wheat crops. Producers in Oklahoma and the southern Great Plains have the option of integrating these tools with their existing weed management plans, either individually, together, or in a sequential manner. Treatments with pyroxsulam and sulfosulfuron can control or suppress cheat and downy brome growth when proper stewardship and favorable conditions occur. In our studies, herbicides did not negatively affect wheat biomass or yield, but weed control was inconsistent. Producers who use ALS-inhibiting herbicides to control cheat or downy brome also need to be aware that continued use of this chemistry without incorporating other management strategies will continue to increase selection pressure for ALS-resistant cheat and downy brome biotypes. Finally, delaying planting by 2 to 6 wk after the optimal planting time provided control of cheat and downy brome, but it also decreased wheat biomass and grain yield. If choosing to incorporate a delay in planting as a cheat and downy brome management strategy, producers will need to evaluate their weed infestations and decide whether they can afford possible short-term yield decreases to make a long-term investment in *Bromus* species seed bank management.

Practical Implications

Weed management is critically necessary for winter wheat producers in the southern Great Plains. Timing of wheat planting is a key technique for managing downy brome and cheat. Downy brome and cheat are early emerging winter annual grasses that primarily germinate from mid-September to mid-October. This coincides with the optimal sowing window of dual-purpose and grain-only production in Oklahoma. This overlap creates management problems for wheat producers, because delaying wheat planting allows the producer to control early emerging downy brome and cheat, resulting in yield loss. We recommend a planting date of early to mid-November, 2 to 6 wk after the beginning of the optimal sowing window used by grain-only producers with high infestations of cheat and downy brome in Oklahoma. Weather conditions may further allow producers to delay the sowing of winter wheat while mitigating the yield loss from downy brome. In addition to planting date, producers can use common ALS-inhibiting herbicides such as pyroxsulam or sulfosulfuron to suppress downy brome and cheat.

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