INTEGRATED MANAGEMENT OF *BROMUS SPECIES* IN GRAIN ONLY WINTER WHEAT PRODUCTION OF THE SOUTHERN GREAT PLAINS

By

HANNAH CAROL LINDELL

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Thesis Approved:

Dr. Misha Manuchehri

Thesis Advisor

Dr. Emi Kimura

Dr. Todd Baughman

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Abstract: *Bromus spp.* including rescuegrass, cheat, and downy brome are difficult to manage winter annual grass weeds in southern Great Plains winter wheat. Producers can manage *Bromus spp.* in herbicide-tolerant wheat, but control in non-herbicide tolerant wheat often is poor. Studies evaluating *Bromus spp.* management using a combination of planting date delay, competitive wheat cultivar selection, and two common herbicides, were conducted throughout Oklahoma and Texas in 2019-2020 and 2020-2021. Visual *Bromus* spp. control was evaluated eight to nine weeks after herbicide treatment, collection of *Bromus spp*. and wheat biomass at heading, wheat head counts, and grain yield. Herbicide treatment decreased *Bromus spp*. biomass at five of the eight site years. Pyroxsulam at Marshall 2020 reduced rescuegrass biomass 80% compared to sulfosulfuron and nontreated check. Sulfosulfuron at Tipton 2020 and 2021, and Burkburnett 2020 reduced rescuegrass biomass 93%, 77%, and 75%, respectively, compared to nontreated. Pyroxsulam and sulfosulfuron reduced biomass of downy brome and cheat 98% compared to nontreated at Lahoma 2021. Delaying planting date reduced *Bromus spp.* biomass by 51%, 73%, and 87% at Marshall 2020 and 2021, and Lahoma 2021, respectively, compared to the optimal timing. A planting date by herbicide interaction occurred only at Burkburnett 2020. Herbicide treatment following the optimal and mid-planting dates reduced downy brome biomass by 86% and 94%, respectively, compared to nontreated. For grain yield, planting date affected Tipton 2020 and 2021, and Lahoma 2020. The late planting date resulted in 18%, 46%, and 21% less grain, respectively, than the optimal timing. For both years at Marshall, herbicide treatment affected grain yield. Pyroxsulam and nontreated treatments produced the least amount of grain for 2020 (~3,115 kg ha^{-1}) compared to sulfosulfuron, and pyroxsulam reduced 2021 yield 11% compared to nontreated. Herbicide treatment also increased Tipton 2020 yield ~9% compared to nontreated. Relative to planting date by cultivar interaction, cultivar yield varied at location across four site years as delayed planting decreased yield. Overall, herbicide treatments and/or a delay in planting by two to six weeks after the optimal timing provided a reduction in *Bromus spp.* biomass but resulted in decreased wheat biomass and grain yield.

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CHAPTER I

LITERATURE REVIEW

Winter Wheat Production

Winter wheat (*Triticum aestivum* L.) is the number one agricultural production commodity in Oklahoma, ranking third in the United States with approximately 1.69 to 1.78 million ha sown in the past three years. In 2021, 1.2 million ha was harvested for grain only production with an average yield of 2,620 kg ha^{-1} (NASS USDA 2021a). In 2020, 1.72 million ha were planted for all purposes with 1.05 million ha harvested for grain (NASS USDA 2020a). The top three cultivars harvested in 2020 and 2021 in Oklahoma were Gallagher, Smith's Gold, and Doublestop CL Plus (NASS USDA 2021b). Winter wheat production in Texas ranks the state at number two in the United States with 1.82 to 2.23 million ha sown in the past three years (NASS USDA 2021a). Approximately 810,000 ha were harvest in 2021 with an average yield of 2,490 kg ha^{-1}, and roughly 829,000 ha were harvested in 2020 with a yield of 2,017 kg ha^{-1}. Of those hectares harvested during 2019 and 2020, Gallagher, TAM 111, TAM 112, and TAM 114 were the top four cultivars planted in Texas (NASS USDA 2020c).

Winter wheat production in Oklahoma and Texas is unique, as many systems utilize the crop for forage and/or grain. Dual-purpose systems increase the diversity of a producer's income for the year by grazing wheat with cattle through the winter, removing cattle in late winter, and then harvesting for grain in the summer. Dual-purpose producers in Oklahoma commonly sow wheat from late August to mid-September and can be sown as late as December (Krenzer 2021). Whereas grain only production planting occurs from mid-October to November with harvest occurring in mid-June (Lollato 2017). Dual-purpose Texas Rolling Plains producers begin sowing from September to early-October, while grain only sowing occurs from October to early December (Darapuneni 2016). However, grain only producers generally sow from October to early November for highest yields (Kimura et al. 2017; Morgan 2011). Because of the diversity in income winter wheat offers Oklahoma and Texas, many producers use continuous wheat systems, growing wheat in the same field year after year. These monoculture systems fail to break up pest cycles and increase selection pressure for herbicide resistant weed biotypes that can quickly take over fields; thus, creating ecological and economic loss (Glowicka-Woloszyn et al. 2020; Wozniak 2019). For example, *Bromus species (spp.)* are adapted to winter annual grass crops like monoculture wheat systems and production practices in the region support their ability to thrive.

Winter annual grasses, such as *Bromus spp.* compete with regionally adapted wheat cultivars, resulting in reduced forage and grain yield and quality. During optimum wheat planting periods, especially for forage or dual-purpose wheat, prime germination for winter annual grass weed *spp.* also occur. This creates a challenge for many wheat producers in the southern Great Plains of Oklahoma and the Rolling Plains region of

Texas. While there are effective herbicide options for some annual grass weed *spp.*, herbicide resistant weed biotypes have increased over the years due to increases in selection pressure. An increase in selection pressure is partly attributed to decreased cultural and mechanical weed control and overuse of single herbicide active ingredients and sites of action, which is enhanced with the use of herbicide tolerant wheat and monoculture practices. Additionally, several *Bromus spp.* are not herbicide resistant but are herbicide tolerant, meaning that they simply respond poorly to herbicides.

***Bromus* Biology**

The grass family *Poaceae* are highly influential as a source of food around the world consisting of nearly 785 genera and 250,000 *spp.*; approximately 11,000 *spp.* being weeds (Chen et al. 2006; Watson and Dallwitz 1992). With *Poaceae* mainly characterized with abundant genetic makeup and adaptability from one *spp.* to the next, invasive grass weed *spp.* are recognized as major ecosystem-altering species (Kern et al. 2020). In agriculture, *Bromus spp.* cause losses in grain and forage yields, delayed harvesting operations, additional seed cleaning expenses, and grain quality discounts such as dockage and/or foreign material. When *Bromus* seed remains, dockage in harvested grain can exceed 40% and can cause difficulty in marketing (Ratlilff and Peeper 1987).

Bromus is a large genus of cool-season grass *spp.* with as many as 160 documented annuals and perennials (Acedo and Llamas 2001; Fortune et al. 2008). From those documented *spp.*, most cool-season annual grasses are found in winter cropping systems, rangelands, and pastures within the southern Great Plains; seeding in late summer and germinating in fall. Cool-season annual grasses require a temperature between 10-20°C for optimum germination; with a reduction in germination at temperatures above 25°C (Butler et al. 2017). *Bromus* seedlings also have higher tolerance to cold conditions with rapid growth response to warm temperatures following germination (Griffith et al., 2014). Under rare circumstances, germination of *Bromus spp.* such as downy brome (*Bromus tectorum* L.) may occur in the spring while other winter annual grass *spp.* are already established (Menalled et al. 2008).

Immediate control and removal of *Bromus spp.* can be correlated to reduced competition and higher crop yield response (Ratliff 1985). Cheat (*Bromus secalinus*) primarily found in eastern hard red winter wheat producing areas, and downy brome in western parts of the United States, have been the most common, difficult-to-control *Bromus spp.* of the southern Great Plains in past years (Driver et al. 1993; Peeper 1984). Downy brome, a highly competitive cool-season annual weed, grows actively throughout fall and winter, initiating early growth in spring after overwintering, dwindling resources for winter crops (Menalled et al. 2008). Similar growth habits are observed for cheat, which at one time was documented to infest approximately 1.4 million hectares of harvested winter wheat in Oklahoma (Ratliff and Peeper 1987). Cheat can cause yield reductions up to 19% at a density of 89 plant m^{-2} (Fast et al. 2009). Similarly, Stahlman and Miller (1990) observed a yield reduction of up to 20% from 65 downy brome plants per m^2. Infestation of winter annual grasses such as *Bromus spp.* can be the difference between profit and loss especially during low price wheat years.

Two other economically critical *Bromus spp.* in the region are Japanese brome (*Bromus japonicus* Houtt.), and rescuegrass (*Bromus catharticus* Vahl.). Rescuegrass has recently become one of the most difficult to-manage grasses in winter wheat within the southern Great Plains. Producers have claimed yield losses up to 50 and 70% and have noticed increasing price discounts at the elevator due to rescuegrass infestations. Rescuegrass competes with crops by germinating first thus maturing earlier than other winter *Bromus spp.*, reducing crop yield and quality in dual-purpose and grain only systems. Additionally, rescuegrass responds poorly to herbicides.

Although rescuegrass is one of the most relevant *Bromus spp.* in Oklahoma and north Texas today, little literature on rescuegrass biology has been published due to most research looking at cheat and downy brome impacts on crop-weed competition. Introduced in the United States around the early 1800s from Argentina as a weak perennial grazing grass (Trew 1957), rescuegrass maximum emergence occurs from mid-September to mid-October (Djibril et al. 1985). Under favorable conditions, a single native rescuegrass panicle can produce an estimated 379 seeds (Abbott et al. 2007).

Prevention

Producers in the southern Great Plains can reduce the presence of persistent weed populations within their systems by taking preventative actions. One key option producers can use to stop weed infestations from occurring in predominantly clean fields at the beginning of the season is to sow weed-free seed. Weed infested crop seed can cause issues in winter wheat systems and create long-term problems, requiring intensive control methods. Purchase and use of weed-free seed from a certified seed retailer is highly recommended for prevention or reinfestation of *Bromus spp.* into fields.

At harvest, weed seed is mature and can be transported and dispersed along ditches and within fields when lodged in equipment. Producers can decrease the probability of spreading weed *spp.* into a clean field by sanitizing tillage and harvest equipment used in a heavily infested field. Producers can properly clean equipment by (1) removing loose residue that has attached or lodged itself to the equipment, (2) blowing off any small foreign material with an air compressor, and (3) pressure washing entire equipment implements after every use in a new field (Bopp 2012). On the other hand, producers in the region often hire out custom harvesters in hopes to efficiently harvest all acres of wheat before wheat is no longer within that prime quality threshold. Custom harvesters offer producers the ability of an income increase (Sahs and Bir 2020) but does not assure clean equipment from one job to the next. One method to employ with custom harvesters is to harvest clean fields first, harvesting weed infested fields last.

Further attentive preventative actions such as keeping irrigation lines and channels clean prevent increases in introduced weed *spp.* to clean fields. Dastgheib (1989) discovered weed seeds ability to successfully germinate after drifting through irrigation equipment, rivers, streams, and drainage channels for long distances. Additionally, since animals can transport weed seeds, not allowing livestock to graze from infested fields and move onto cleaner fields can prevent spread of new or resistant weed *spp.* (Manuchehri et al. 2021).

Plants that survive inadequate management pass on genetic resistance from generation to generation causing selection for mutant genotypes (Powles and Shaner 2001). Continuous, non-integrated management practices do not suffice and will result in resistant *spp.* reproducing in fields, likely not being detected until their populations reach 30% of total weed populations (Mahmood 2014). Recommendations to producers to continuously scout fields, identify any new weed emergence or resistance, as well as avoid consecutive applications of one herbicide in a single growing season is vital.

Management

Rescuegrass and other *Bromus spp.* pose a threat for continuous winter wheat systems that struggle to compete with weeds for essential nutrients. Early growth habits of *Bromus spp.*, particularly rescuegrass, can cause winter wheat to undergo early stress related growth. Thorough use of integrated management tactics such as cultural, chemical, and mechanical methods can adequately control and/or suppress weed populations without harm to producers on an economic and environmental level (Neely et al. 2016). In the Pacific Northwest, wheat systems with intense weed management methods such as an application of a herbicide with a high rate of nitrogen have been correlated to increased weed control and wheat yield (Young et al. 1994).

Weed management strategies that incorporate multiple integrated tactics sufficiently aid in control of *Bromus spp.* but have not yet been optimized. Integrating multiple practices, such as delaying planting of winter wheat, careful selection of a competitive wheat cultivar, and proper use of an effective herbicide can provide long-term weed management of *Bromus spp.* Ample weed control also may reduce dockage and increase grain yield (Ratliff and Peeper 1987). Integrated management also can be altered year after year which can restrict selection pressure and weed resistance from occurring and obtaining highly sustainable field conditions (Harker and O'Donovan. 2013). Producers can then begin to use other mechanical, cultural, and chemical methods to prolong *Bromus spp.* management and feasibly prevent further selection pressure.

Cultural Weed Control

Crop Rotation

Crop rotation practices in continuous winter wheat systems are not commonly utilized in Oklahoma and north Texas but will allow improved weed management in the long-run by breaking up pest cycles, including weeds. Common summer crops producers can rotate to include corn (*Zea mays* L.), sorghum (*Sorghum bicolor* (L.) *Moench ssp. Bicolor*), soybean [*Glycine max* (L.) *Merr.],* sesame (*Sesamum indicum* L.), cotton (*Gossypium hirsutum* L.), and sometimes canola (*Brassica napus* L.) in the southern Great Plains (Bushong et al. 2011; Manuchehri et al. 2021). Rotation of crops from a winter annual to a summer annual not only break up weed cycles but also support the use of different herbicide sites of action. For example, winter canola is sometimes used in winter wheat rotations as it allows the use of sethoxydim, clethodim, and quizalofop-P-ethyl (quizalofop) to manage *Bromus* seedlings (Lyon et al. 2015). Lyon et al. (2015) examined the effect of *Bromus spp.* following summer crop rotations over multiple years after winter wheat in the Pacific Northwest and found that summer systems disrupt growth patterns and deplete overall *Bromus spp.* in the soil seed bank. When favorable growing conditions are disrupted and seedbanks are reduced, producers can more easily control and reduce *Bromus spp.* populations.

Weed *spp.* are distinguished by their ability to evolve rapidly to their environment and circumstances. Diverse crop rotations can further prevent weed selection pressure by allowing various planting dates and competitive cultivar selection. Later planted summer crops allow enough time for adequate *Bromus spp.* emergence and growth during spring months to be managed with nonselective herbicides or tillage (Lyon et al. 2015). For example, conventionally tilled double-crop grain sorghum immediately after wheat harvest, followed by soybean planted in April reduced dockage of cheat by 78 and 87% and increased subsequential wheat yield by 32 and 42% in Billings and Ponca City, OK (Stone et al. 2006).

Planting Date and Cultivar Selection

Competition for essential growth factors between crop and weed *spp.* are correlated to overall crop fitness (van Heemst 1985). Early emerging *Bromus spp.*, such as rescuegrass are more aggressive than other weed *spp.* as they compete with wheat during its critical weed free period, which takes place for several weeks immediately after sowing (Welsh 1999). *Bromus spp*. emerging later in the winter wheat growing season has significantly less effect on wheat yield due to shade (Blackshaw 1993). When *Bromus spp.* populations are managed prior to planting, fewer plants will emerge and compete with wheat in-season.

Early sown wheat requires intensive weed management for the majority of *Bromus spp.* that emerge simultaneously. Whereas late planted wheat holds opportunity for partial management of *Bromus spp*. prior to planting with the use of tillage or a non-selective herbicide. Less *Bromus spp*. throughout the growing season results in more effective herbicide treatments, increased yield, and little contaminated seed at harvest. Over time, producers would require less aggressive control methods due to fewer *Bromus spp*. in the soil seedbank. A study conducted in Pakistan looking at planting delay in wheat identified weed biomass and density was significantly reduced following late sown wheat on December 15 compared to an October 15 planting date (Subhan 2003).

However, planting too late may result in emergence of wheat before harsh cold fronts, killing off seedlings before green-up takes place (Barrett 1978). Conversely, in Texas, early sown wheat has been revealed to break winter dormancy earlier in spring, resulting in greater potential for late spring freeze injury (Miller 1992). Planting date of wheat may also effect severity of pathogen infestation and injury to crop. Winter wheat yield response to planting date and spring inoculation of wheat streak mosaic rymovirus (WSMV) in Stillwater, OK detected decreased yield and increased symptoms of WSMV in November sown wheat compared to August and October due to maturity stage of crop (Hunger et al 1992). Producers must determine a planting date that will result in adequate growing conditions without yield loss occurring. The selection of an early-maturing wheat cultivar may salvage wheat yields when a delay in planting is used as a weed management strategy.

Over the years, wheat breeders have genetically bred wheat cultivars to be hardier against pests. Cultivars also have been bred for vigorous vegetative growth to support the use of dual-purpose systems in Oklahoma and Texas. Early canopy coverage is not only beneficial for winter forage but also suppressed early emerging weeds. Selection of a competitive wheat cultivar with vigorous canopy coverage characteristics achieves competitive fitness of crop with *Bromus spp.* (Mwendwa et al. 2020).

Fertility Management

Soil fertility management is another key practice producers can use in the southern Great Plains to ensure competitive crops against weeds. Nitrogen (N) and Phosphorus (P) are essential for plant growth and help determine a plant's ability to produce strong root structures, photosynthesize, and efficiently uptake water and nutrients (Li et al. 2003). Alternative methods of weed control using N in wheat have been evaluated by various researchers in the southern Great Plains. Sexsmith and Pittman (1963) discovered that an early spring application of N during a fallow season increased germination of wild oat, reducing the amount of available seed for the next season. After similar findings, Phillips et al. (1999) applied urea ammonium nitrate (UAN) at an average rate of 6.7 lb. N acre^{-1} on wheat beginning to flower and before cheat began to flower, discovering cheat seed reduced by 54.9%. Exploration of N application rates of 34, 67, and 101 kg N ha^{-1} on winter wheat to suppress grass weed species barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] and green foxtail *[Setaria viridis* (L.) P Beauv.] in North Platte, Nebraska observed a decrease in overall weed yield as N rates increased (Valenti and Wicks 1992).

Soil characteristics play a key role in the types of a *Bromus spp.* found in specific regions. Under high soil moisture conditions, downy brome growth patterns can be altered by the change in N, P, and potassium (K) (Belnap et al. 2016). Specific soil pH levels also can increase winter wheat's ability to better compete with *Bromus spp.* via herbicide-soil residual interaction. For example, sulfonylurea herbicides may have a higher chance of weed control in alkaline soils compared to acidic soils due to slower herbicide degradation at higher pH levels (Brown 1990; Driver et al. 1993)

Chemical Weed Control

Most products labelled and used for grass weed control in Oklahoma and Texas winter wheat are acetolactate synthase (ALS) inhibitors. Application of an ALS in the fall, when plants are rapidly growing, is the most common and practical herbicide site of action used in winter wheat (Reddy et al. 2013). ALS herbicides pyroxsulam, propoxycarbazone-sodium, and sulfosulfuron provided successful downy brome control in northwest Kansas when applied in the fall (Reddy et al. 2013). The same study discovered little to no crop injury or effect on grain yield. Blackshaw and Hamman (1998) and Geier et al. (2011) also recommended an ALS herbicide is most sufficient when sprayed POST in the fall compared to spring for control of *Bromus spp*. The use of an ALS inhibiting herbicide may support successful rescuegrass and other *Bromus spp*. control, but it is a short-term management option that will increase selection pressure of resistant biotypes when used continuously and not integrated with other strategies. Even though grass weed *spp.* may show symptoms of stunting of new leaf development after treatment of an ALS herbicide, they can sometimes still produce viable seed at maturity, especially if applied later than the desired fall application window (UC IPM 2021).

Metribuzin, a photosystems II inhibitor (WSSA Group 5), is another herbicide option producers can use. Durutan (1975) conducted a study to evaluate metribuzin application timing in winter wheat in Oregon and concluded that metribuzin applied at the 3- to 4-tiller stage provided the highest wheat yield along with the greatest cheat control out of five application timings (PRE, one leaf, three leaf-tillering, three to four tiller, and early joint). They also found that PRE and at spike applications caused the most damage to wheat, anywhere from 15 to 37% injury. Experiments conducted in Oklahoma indicated hard red winter wheat cultivars had reduced stand up to 45% when metribuzin was applied in the spring, between tillering and jointing, at 0.6 kg ha^{-1} and reduced yield up to 75% when applied at 1.1 kg ha^{-1} (Runyan et al. 1982). The use of herbicides for control of rescuegrass and other *Bromus spp.* is an important tool; however, selection of appropriate herbicides is vital. Moreover, rotation of herbicide active ingredients and sites of action is critical to reducing selection pressure for herbicide resistance.

Herbicide resistance is a challenge when it comes to current herbicide options. As early as 2009, Oklahoma documented cross-resistant cheat to all ALS herbicides including imazamox, propoxycarbazone-sodium, pyroxsulam, and sulfosulfuron (Heap 2021a). In the United States, no rescuegrass biotypes have been documented to be herbicide resistant. However, biotypes resistant to the EPSP synthase inhibitor, glyphosate (WSSA Group 9), were first reported in Buenos Aires, Argentina in 2017 (Heap 2021b; Yanniccari et al 2021). Multiple resistant downy brome biotypes to acetyl CoA carboxylase (ACCase, WSSA Group 1) inhibitors, ALS inhibitors, and photosystem II inhibitors have been reported in Oregon under intense crop production (Park and Mallory-Smith 2005). Japanese brome biotypes resistant to ALS herbicides imazamox, propoxycarbazone-sodium, pyroxsulam, and sulfosulfuron also have been documented in Kansas (Heap 2021c).

Herbicide-tolerant winter wheat systems such as CoAXium® and Clearfield® currently provide control of many *Bromus spp.* Clearfield® winter wheat cultivars are tolerant to Group 2 herbicide, imazamox, which controls or suppresses over 50 broadleaf weeds and over 30 grassy weeds (Anonymous 2019). CoAXium® wheat cultivars that contain the AXigen trait, a wheat system recently developed by the Colorado Wheat Research Foundation, Albaugh Chemical, and Limagrain, are tolerant to the Group 1 herbicide, quizalofop, which controls and/or suppresses many grass weed *spp*. CoAXium® and Clearfield® systems allow producers to control many grass weeds with a single application in the fall or spring or a split application in the fall and spring.

With recent documentation of Group 2 resistant cheat in Oklahoma, imazamox used in Clearfield® systems is now ineffective, leaving wheat growers with only one option – to spray quizalofop in CoAXium® wheat. Except for WSSA group 1 resistant Italian ryegrass (Heap 2021d), quizalofop herbicide is efficacious on most winter annual grasses in the southern Great Plains (Vipan et al. 2020), including *Bromus spp.* However, crop tolerance has been a challenge, especially following late spring applications in Oklahoma. Finally, without proper stewardship, development of herbicide resistant biotypes other winter annual grasses to quizalofop will occur. Therefore, it is critical this system is used for less than two consecutive seasons and is integrated with other weed management tools.

The lack of consistent, effective management strategies for *Bromus spp*., especially rescuegrass, is a serious production problem facing many southern Great Plains winter wheat producers. Although there are some herbicides that offer short-term solutions, long-term and integrated strategies are needed for sustainable and profitable wheat production in the southern Great Plains. To improve management of rescuegrass and other *Bromus spp.* in the southern Great Plains, a study was conducted at four locations in Oklahoma and Texas to evaluate the impact of cultivar selection, planting date, and herbicide treatment on *Bromus spp.* populations.

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CHAPTER II

INTEGRATED MANAGEMENT OF *BROMUS SPECIES* IN GRAIN ONLY WINTER WHEAT PRODUCTION OF THE SOUTHERN GREAT PLAINS

Introduction

As of 2021, Oklahoma and Texas are ranked third and second, respectively, in the nation for winter wheat production, with wheat being the number one cash crop produced in Oklahoma (~1.2 million ha harvested) and number six cash crop produced in Texas (~810,000 ha harvested) (NASS USDA 2021a). Oklahoma and Texas winter wheat is unique in the sense that many producers can utilize the system for forage and/or grain purposes, increasing diversity of income for the year. Producers will place cattle out to graze wheat through mid-fall and winter, removing cattle prior to wheat jointing, and harvesting grain in summer; known as dual-purpose systems. Because of the economic diversity winter wheat systems provide, Oklahoma producers can either sow wheat for dual-purpose from August to mid-October or grain only from mid-October to November (Lollato 2017). As for Texas winter wheat, dual-purpose wheat is sown from September to early-October, whereas grain only wheat is sown from October to early December (Darapuneni 2016). During optimum planting periods especially for dual-purpose, prime germination for winter annual grass weed *spp.* also occur, creating a challenge for many producers.

Due to the diverse crop-to-graze benefits winter wheat provides, many producers grow wheat season-to-season within the same field, creating monoculture systems. Winter annual grass weeds, such as *Bromus species (spp.)* adapt and thrive in monoculture systems, which fail to break up pest cycles.

Ratliff and Peeper (1987) observed dockage in harvested grain exceeding 40% in *Bromus* infested fields. *Bromus spp*. primarily found in Oklahoma and Texas winter wheat include cheat (*Bromus secalinus* L.), Japanese brome (*Bromus japonicus* Houtt.), rescuegrass (*Bromus catharticus* Vahl.), and occasionally downy brome (*Bromus tectorum* L.). Cheat has been documented to infest approximately 1.4 million hectares of harvested winter wheat in Oklahoma and can cause yield reductions up to 19% at a density of 89 plant m^{-2} (Fast et al. 2009; Ratliff and Peeper 1987). Japanese brome seeds can germinate over a wide range of environmental conditions with high levels of germination occurring during fall months (Haferkamp et al. 1994). Rescuegrass is the first winter annual grass weed *spp.* to emerge in winter wheat systems with maximum emergence occurring from mid-September to mid-October, thus maturing earlier than other winter *Bromus spp.* (Djibril et al. 1985). Producers have claimed yield losses up to 50 and 70% in rescuegrass infested fields, as well as poor response to herbicides. Finally, downy brome grows actively throughout fall and winter, growing rapidly in the spring which dwindles resources for wheat and reduces yield up to 20% when approximately 65 plants m^{-2} are present (Menalled et al. 2008; Stahlman and Miller 1990).

Immediate control and removal of *Bromus spp.* like these can be correlated to reduced competition and higher crop yield response (Ratliff 1985) and quality. Despite many regionally adapted wheat cultivars available to producers in Oklahoma and Texas, *Bromus spp.* can still compete with wheat. *Bromus spp.* may cause grain and forage yield loss, delayed harvest operations, additional seed cleaning, and grain quality discounts such as dockage and/or foreign material. Effective control of *Bromus spp*. with the use of a herbicide may be an option. Although, cross-resistant cheat to ALS herbicides imazamox, propoxycarbazone-sodium, pyroxsulam, and sulfosulfuron exists in Oklahoma (Heap 2021a) leaving producers with few management options.

An increase in selection pressure also is partly attributed to decreased cultural and mechanical weed control as well as overuse of single herbicide active ingredients and sites of action, which is enhanced using herbicide tolerant wheat cultivars. Additionally, some *Bromus spp.*, like rescuegrass, are not herbicide resistant but simply respond poorly to herbicides (herbicide tolerant). Continuous, non-integrated management practices will result in resistant *spp.* reproducing in fields, likely not being detected until their populations reach 30% of total weed populations (Mahmood 2014).

The lack of consistent, effective management strategies of *Bromus spp*. is a serious production problem facing many southern Great Plains winter wheat producers. Although there are some herbicides that offer control in the short-term, long-term, integrated strategies are needed. To improve management of rescuegrass and other *Bromus spp.* in the region, a study was conducted at four locations over two growing seasons in Oklahoma and Texas to evaluate the impact of wheat cultivar selection, planting date, and herbicide treatment on *Bromus spp.* populations.

Materials and Methods

Study Area

Field experiments were located in Lahoma (36°23'08.6"N 98°06'46.4"W; elevation of 380m), Marshall (36°15'54.1"N 97°62'57.3"W; elevation of 321m), and Tipton (34°30'7.19"N 99°08.6"W; elevation of 394m), Oklahoma during 2019-2020 and 2020-2021 winter wheat growing seasons. Texas locations included Burkburnett (34°04'34.8"N 98°34'3.59"W; elevation of 323m) during the 2019-2020 season and Thornberry (34°3'29"N 98°23'21'W; elevation of 305m) during the 2020-2021 season. Soil type at the Marshall location primarily consisted of two soil types; 2019-20 growing season location was on a Kirkland silt loam (Fine, mixed, superactive, thermic Udertic Paleustoll) and the 2020-21 growing season was on a Kirkland silty clay loam (Fine, mixed, superactive, thermic Udertic Paleustolls), with an average pH of 5.3 and organic matter (OM) of 1.8% throughout both growing seasons. Lahoma primarily consisted of a Grant silt loam (Fine-silty, mixed, superactive, thermic Udic Argiustolls) with an average pH of 5.9 and OM of 1.5%. The Tipton location consisted of Tipton loam (Fine-loamy, mixed, superactive, thermic Pachic Argiustolls) with an average soil pH of 6.2 and OM of 1.3%. As for the Texas locations, Burkburnett soil type consisted of a Frankirk loam (Fine, mixed, superactive, thermic Typic Argiustolls) with a pH of 6.8 and OM of 1.2% and Thornberry soil consisted of a Winters loam (Fine, mixed, superactive, thermic Typic Paleustalfs) with a pH of 5.0 and OM of 1.4%. Field trial growing seasons are referred to as the year harvest of grain occurred. Winter wheat was sown at Lahoma and Marshall from early October to mid-November whereas the sowing window occurred from late

October to mid-December at the three most southern locations (Table 2.3). In-season rainfall and average monthly temperature are listed in (Table 2.1 and 2.2).

Field Trial Design and Method

Experimental design was a three-way factorial structure, arranged as a split-plot design with four replications. Trial independent variables included planting date, winter wheat cultivar, and herbicide. Main plots consisted of three planting dates, subplots represented one of two wheat cultivars, and sub-sub-plots two included herbicide treatments plus a nontreated control. Individual sub-sub plots were 2.2 m wide by 10 m in length. Three planting dates were used to represent optimal, mid-, and late planting dates (Table 2.3) for grain only production in Oklahoma and Texas. Optimal planting date represented the optimal time to sow grain only wheat for specific regions, the mid-planting date was approximately a two-to-three week delay from the optimal planting, and the late planting date was approximately a five-to-six week delay from the optimal planting date. Optimal winter wheat planting window for Northern Oklahoma is from early October to mid-November whereas that for southern Oklahoma and North central Texas falls between late-October and mid-December (Lollato 2017). Two high-yielding winter wheat cultivars were selected; one with early canopy coverage and low forage yielding characteristics during spring ('Showdown') and one with prompt-low-competitive early canopy coverage and high forage yielding characteristics during spring ('Green Hammer') (OGI 2021). Wheat was planted using a Kincaid Great Plains Grain Drill (Kincaid Equipment Manufacturing Corporation, Haven, KS) with 19 cm row spacing at a seeding rate of 67 kg ha^{-1}. Immediately after each sowing for each planting date, a burndown application of glyphosate at 0.86 kg ae ha^{-1} with ammonium sulfate

(AMS) at 2.85 kg ha^{-1} was sprayed to ensure a weed-free field prior to wheat emergence.

Proper field maintenance entails field fertility needs such as nitrogen (N), phosphorus (P), and potassium (K) and fungicide application at flag leaf stage. Soil samples were collected from each field location prior to planting each year, by obtaining 20 to 30 soil cores from 0 to 6 in in depth throughout one acre, thoroughly mixed, and analyzed at Oklahoma State University Soil, Water and Forage Analytical Laboratory (SWFAL) for pH, OM, and N-P-K analysis. Based on SWAFL results, application of N-P-K before planting and tillage were conducted at five site years. Three site years required split applied N-P-K.

Herbicide treatments included two common acetolactate synthase (ALS) inhibiting herbicides and a nontreated control (Table 2.3). Each herbicide treatment included a non-ionic surfactant (NIS) at 0.25% vol/vol plus liquid urea-ammonium nitrate (UAN) at 30% vol/vol. Treatments consisted of pyroxsulam (Powerflex® HL, 18.4 g ai ha^{-1}, Corteva, 974 Centre Road Wilmington, DE 19805
USA) or sulfosulfuron (Outrider®, 35.2 g ai ha^{-1}, Valent U.S.A. LLC, 2600 Norris Canyon Road, San Ramon, CA 94583) applied at the 2- to 3-leaf stage of *Bromus spp*. at each site and planting date. Herbicides were sprayed at the recommended labelled rate using water as the carrier with a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at 3 mph, using Turbo TeeJet® 11002 nozzles.

Weed Control, Biomass Measurements, and Grain Yield

Visual control estimates of *Bromus spp.* (Table 2.4) were evaluated approximately four to six weeks and eight to nine weeks after treatment (WAT) using a scale of 0 to 100 percent, where 0 equaled no weed control and 100 equaled complete control. Additionally, *Bromus spp*. densities were recorded in two 0.10 m^2 quadrats; one at front of plot and one at end of plot. Near the end of the winter wheat growing season when wheat and *Bromus spp.* were headed out, biomass of crop and weeds were collected from one 0.25 m^2 quadrat between the 2nd and 3rd row of crop from left side. Biomass samples were separated by species in the field. Samples were then dried in ovens at 60°C for five days, weighed in grams (g), and recorded. Wheat head counts also were recorded. Wheat was harvested in June or July of each year (Table 2.3) with a Wintersteiger (Wintersteiger Inc, Salt Lake City, UT) small plot combine (Table 2.3). Post-harvest seed dockage was assessed from 150 g subsamples per individual plot harvested and separated by hand for *Bromus spp*., miscellaneous weed *spp.* and wheat.

Statistical Analysis

Due to significant site year by treatment interactions, all site years were analyzed independently. Fixed effects included experimental site-year, planting date, winter wheat cultivar, and herbicide treatment while random effects included replication. A univariate analysis was performed on all responses in order to test for stable variance (Version 9.4, SAS Institute Inc., SAS Campus Drive, NC). No data sets were transformed, as transformation did not increase stabilization. Data sets were analyzed using PROC MIXED with the pdmix 800 macro described by Saxton (1998) and treatments were separated by Fisher's Protected LSD at an α level of 0.05. Responses are referenced in an ANOVA table (Table 2.5) for Lahoma, Marshall, and Tipton, OK and Burkburnett and Thornberry, TX during the 2019-20 and 2020-21 winter wheat growing seasons.

Results and Discussion

Marshall and Tipton

Rescuegrass Visual Control

Results are discussed by location because of varying *Bromus spp.* infestations. Planting date affected visual control of rescuegrass for ratings eight to nine weeks after treatment (WAT) at Marshall 2020 and 2021, and Tipton 2020 (Table 2.6). Winter wheat sown mid- and late at Marshall 2020 displayed 23% and 32% greater visual control of rescuegrass, respectively, compared to the optimal planting. At Marshall 2021, visual control was similar for mid- and late plantings (87% and 85%, respectively) and was greater than control following the optimal timing (78%). Rescuegrass at Tipton 2020 was controlled 57%, 69%, and 91% following optimal, mid- and late planting dates, respectively, with control increasing as planting delayed. In addition to planting date, at Marshall 2020 (Table 2.6), pyroxsulam provided 56% visual control of rescuegrass, an increase of 20% compared to sulfosulfuron. Near northeast Kansas, Reddy et al. (2013) also observed an increase in *Bromus spp.* control to pyroxsulam compared to sulfosulfuron applied in the fall POST where there was a 9% increase in visual control of downy brome following pyroxsulam compared to sulfosulfuron.

A planting date by herbicide interaction occurred at Tipton 2021 (Table 2.6). Pyroxsulam and sulfosulfuron applied at the optimal and late planting date provided similar visual control ($p>0.05$) with no difference between the two herbicides. Sulfosulfuron combined with mid- planting controlled rescuegrass 95%, increasing control 17% compared to pyroxsulam. Additionally, control following sulfosulfuron between mid- and late planting increasing control over 20% compared to the optimal planting date. Similar control was observed with pyroxsulam at the optimal and mid-planting while the late planting increased control 15% compared to optimal planting. Conversely to Marshall 2020 and Reddy et al. (2013), at the mid-planting, sulfosulfuron visually increased control 17% compared to pyroxsulam. Although visual control varied by herbicide at Marshall 2020 and Tipton 2021 dependent on environmental factors, a study conducted in North Dakota observed sulfosulfuron and pyroxsulam resulted in similar *Bromus spp.* visual control of 59 and 54%, respectively (Ostlie and Howatt 2013). Therefore, producers need to consider herbicide label recommendations as well as region and timing of application.

Rescuegrass Biomass at Heading

Dependent environmental factors, herbicide treatment affected rescuegrass biomass at Marshall 2020 and Tipton 2020 and 2021 variously (Table 2.7). Pyroxsulam decreased rescuegrass biomass by 75% and 80% compared to sulfosulfuron and nontreated, respectively, at Marshall 2020. Krenzer stated rescuegrass has been difficult to manage with sulfosulfuron (Lyon et al. 2002). Although, rescuegrass biomass at Tipton 2020 was reduced by 93% after an application of sulfosulfuron compared to the nontreated. Rescuegrass biomass following pyroxsulam was similar to the nontreated (~11 g $0.25m^{-2}$). Similar trends were present the following year at Tipton 2021 where rescuegrass biomass was similar following no treatment and pyroxsulam; however, sulfosulfuron reduced rescuegrass biomass by 67% and 77% compared to pyroxsulam and the nontreated, respectively. Dependent on region sulfosulfuron may have greater suppression of rescuegrass in Oklahoma winter wheat (G. Strickland, personal communication). Therefore, producers need to consider herbicide label recommendations as well as region and timing of application.

While the effects of herbicide treatment on rescuegrass biomass were variable, manipulating planting date demonstrated to be an effective management strategy for consistently reducing rescuegrass competition at Marshall during both growing seasons (Table 2.7). During the 2020 season, 51% more rescuegrass biomass was collected following the optimal planting date compared to the mid- and late plantings. For Marshall 2021, rescuegrass biomass was similar for mid- and late plantings (~1.3 g $0.25m^{-2}$), while the optimal planting had ~71% more biomass. A similar study on chickweed (*Stellaria media* L.), field poppy (*Papaver rhoes* L.), and common oat (*Avena sativa* L.) biomass in Denmark discovered a 40% decrease in overall weed biomass as planting date of wheat was delayed to latest sowing date (Rasmussen 2004). Delaying planting date can allow producers to eliminate early flushes of rescuegrass by either the use of a non-selective herbicide or tillage.

Wheat Biomass at Heading

Dependent on growing season, planting date affected wheat biomass for Marshall and Tipton (Table 2.8). Delaying wheat planting at Marshall from the optimal to mid-timing resulted in an increase in wheat biomass of 21% during the 2020 growing season while late planted wheat produced similar biomass to the optimal and mid-plantings with 155g 0.25 m^{-2}. Wheat biomass increasing 9% and 17% as planting date delayed to mid and late planting dates, respectively, relative to the optimal timing at Tipton 2020. It is not common to expect an increase in wheat biomass as planting date is delayed; however, Marshall and Tipton received consistent rainfall and warmer than typical average temperatures throughout the 2020 growing season (Table 2.1). Optimal planting date did not record increased biomass due to early flush of rescuegrass after sowing of winter wheat. During the 2021 growing season, there was greater wheat biomass following the optimal timing compared to mid- and late plantings for Marshall and Tipton. Wheat biomass following the optimal planting at Marshall was 37% and 54% greater than biomass for mid- and late plantings, respectively. In addition, the mid-planting resulted in 1.5 times more wheat biomass compared to the late planting. For Tipton 2021, wheat biomass at mid- and late plantings produced similar biomass (~131g $0.25m^{-2}$); however, wheat biomass at the optimal timing increased 26% and 20% compared to mid- and late planting dates, respectively. Similar findings by Wajid et al. (2004) revealed that wheat biomass sown at the recommended timing significantly increased final biomass of wheat compared to a late planting date. Optimal planting window allows producers to sow wheat during optimal soil temperatures of 12 to 25°C (Austin and Jones 1975). As planting date delayed, soil temperatures fell towards or below the optimal range, resulting in less wheat stand occurring.

The only case where herbicide affected wheat biomass was at Marshall 2021 ($p<0.0001$). An application of pyroxsulam reduced wheat biomass by 17% compared to sulfosulfuron and the nontreated (Table 2.7). Wheat biomass following an application of sulfosulfuron was similar to wheat biomass from the nontreated control (~134 g $0.25m^{-2}$). Pyroxsulam may increase crop injury after application prior, during, or after a severe cold snap (Anonymous 2011) as observed in Oklahoma and Texas in February 2021 (Table 2.2). Application of pyroxsulam following the optimal, mid-, and late plantings occurred on December 25th, February 4th, and March 31st, respectively. Minimum temperature for those three days were 1.4, 1.1, and 3.3 °C. Below freezing temperatures also occurred within a one-to-two week after herbicide application for mid- and late plantings with minimum temperatures of -26 and -0.55 °C, respectively.

Wheat Head Count

During the Tipton 2020 and Marshall 2021 growing seasons, planting date affected winter wheat head counts (Table 2.9). Following optimal and mid-plantings at Tipton, number of wheat head count were similar (~83) and 24% greater than heads produced at the late timing. At Marshall 2021, number of wheat heads decreased as planting date delayed. Delaying planting from optimal to mid- resulted in 23% less wheat heads. An additional delay from mid- to the late planting date resulted in 13% less wheat heads. Similar findings within the Midwest observed wheat heads per square feet decreased as planting date decreased from an August to a September and October planting date due to response to environment and stage of plant development when growth ceased (Dahlke et al 1993). Dahlke et al. (1993) recommended as planting date delayed, an increase in seeding rate can be beneficial in increasing yield components such as head counts.

A planting date by cultivar interaction occurred at Tipton 2021 with Green Hammer at the mid-planting producing 30% more wheat heads 0.25 m^{-2} compared to Showdown (Table 2.8). Green Hammer at the mid-planting also produced 30% more wheat heads than Green Hammer at the late planting. Following the optimal and late plantings, both cultivars produced similar total number of wheat heads 0.25 m^{-2} (~62.5). Dahlke et al. (1993) study also observed a cultivar affect when planting date was delayed. Cultivar Cardinal had higher yields than Merrimac when sown during September and

October due to heavier kernel weight. There were also instances where Merrimac had greater yields than Cardinal cultivar when planting date delayed after 3 October. Selection of cultivars with adaptable yield components to varying conditions is critical but uncertain.

Wheat Yield

The main effects of planting date, cultivar selection, and/or herbicide treatments were significant on winter wheat yield (Table 2.10). At Tipton 2020, late planting (2,494 kg ha^{-1}) decreased grain yield up to 15% compared to optimal and mid-plantings (~3,009 kg ha^{-1}). In 2021 at Tipton, yield decreased as planting date delayed. Following the optimal planting date, yield was 25% and 46% greater than mid- and late plantings, respectively. Similar findings in Garden City, KS observed wheat cultivar TAM 107 yield declining as planting date delayed every month from 1 October to 1 April (October representing optimum yield) with November and December grain yield decreasing by 23 and 41% compared to October (Witt 1996). At Marshall 2020 or 2021, planting date did not affect yield. Dependent on region, delaying planting date can decrease grain yield due to soil temperatures falling towards or below the optimal range, resulting in less wheat stand and insufficient yield components.

At Marshall 2020, an application of sulfosulfuron increased wheat yield up to 20% compared to pyroxsulam and nontreated (~ 3,114 kg ha^{-1}). Kelley and Peeper (2003) also observed a grain yield increase after an application of sulfosulfuron (MON 37500) POST compared to nontreated by 69%. Tipton 2020 observed slightly different trends with pyroxsulam and sulfosulfuron increasing yield by ~9% compared to the nontreated. At Marshall 2021, there was an 11% decrease in yield following pyroxsulam relative to the nontreated control. Zuger et al. (2017) discovered similar yield trends where a spring application of pyroxsulam HL POST at 18.4 g ai ha^{-1} reduced grain yield by 15% compared to wheat without the spring application. A crop rotation study conducted in Georgia also observed wheat yield loss (9% to 10%) following POST application of pyroxsulam compared to sulfosulfuron and nontreated; however, pyroxsulam was applied at four times the recommended rate (74 g ai ha^{-1}) (Grey et al 2012). Pyroxsulam may increase crop injury after application which can decline grain yield due to insufficient crop growth.

At Tipton 2020, a cultivar effect impacted grain yield while a planting date by cultivar interaction occurred at Marshall 2021. At Tipton 2020, 7% more grain was produced for cultivar Showdown compared to Green Hammer. A similar trend occurred at Altus, OK during the 2020-2021 Oklahoma State University Wheat Cultivar Trials where Showdown yielded ~17% more than Green Hammer (OSU 2021). Conversely, at Marshall 2021, an increase in yield of 24% and 31% followed Green Hammer compared to Showdown at mid- and late planting, respectively. Both cultivars yielded an average of ~3,836 kg ha^{-1} at the optimal planting date, which was an increase in grain yield up to 33% and 76% compared to mid- and late planting dates, respectively. Finally, at Marshall 2021, 74% more grain was collected at the mid-planting date compared to the late. It is uncertain why one cultivar yielded greater than the other did. Although, Green Hammer cultivar is a progeny of the three-way cross, OK Bullet/TAM 303 sister//Shocker and OK Bullet is characterized as a tall, semi-dwarf (OGI 2021). Studies conducted in the Pacific Northwest observed semi-dwarf cultivars produced highest grain yield across planting dates of August, September, and October compared to non-semi-dwarf cultivars

(Donaldson et al. 2001). Selection of semi-dwarf cultivars can be beneficial to increased grain yield dependent on region and cultivar adaptability.

Lahoma

Downy Brome and Cheat Visual Control

At Lahoma in 2020 and 2021, planting date affected visual control of downy brome and cheat eight to nine WAT (Table 2.11). in 2020, *Bromus spp.* visual control increased 11% at the mid-planting compared to the optimal and increased 14% at the late planting compared to the mid-planting. In 2021, similar *Bromus spp.* visual control (~98.5%) was recorded for mid- and late plantings and was 23% greater than control for the optimal planting. Massee (1976) observed similar trends in Idaho when downy brome was purposely planted with winter wheat across three planting dates (September 20, October 3, and October 19), downy brome germination declined at later planting dates. Although a planting date effect was consistent in both years, herbicide treatment only affected *Bromus spp.* visual control in 2020. Pyroxsulam controlled *Bromus spp.* 88% compared to sulfosulfuron with 82% control. Field studies over 3 years in Kansas comparing pyroxsulam with other acetolactate synthase inhibitors (sulfosulfuron) observed consistent visual control over 97% following an application of pyroxsulam while sulfosulfuron recorded inconsistent control (30 to 81%) (Geier et al. 2011). Application of pyroxsulam may allow producers greater visual control of *Bromus spp*. as a short-term solution but delaying sowing of winter wheat can result in greater decline in the long-term.

Wheat and Bromus spp. Biomass at Heading

Delaying planting affected wheat biomass for Lahoma 2020 and 2021 growing seasons (Table 2.12). Optimal planting in 2020 resulted in up to 24% greater wheat biomass compared to mid- and late plantings (~179.5g 0.25 m^{-2}). In 2021, biomass for optimal and mid-plantings were similar (~202.9 g 0.25 m^{-2}) and were 55.1 g 0.25 m^{-2} greater than late planted wheat biomass. A herbicide by cultivar interaction also occurred for wheat biomass at Lahoma 2020 where sulfosulfuron decreased Showdown wheat biomass 23% and 22% compared to pyroxsulam and nontreated, respectively (Table 2.12). Showdown wheat biomass following pyroxsulam was 23% greater than Green Hammer following pyroxsulam. Showdown and Green Hammer treated with sulfosulfuron revealed uniform biomass (~187.4g 0.25 m^{-2}). Nontreated Showdown and Green Hammer resulted in similar trends (~209.6g 0.25 m^{-2}). Uncertain why Showdown cultivar resulted in greater biomass than Green Hammer after an application of pyroxsulam other cultivar competitiveness studies in Pakistan observed variation in cultivar response to herbicide application and weed density. Khaliq et al. (2014) observed variation among wheat cultivars after herbicide application might be due to morpho-physiological differences in cultivar, accounting for variable weed competitiveness. Application of pyroxsulam or sulfosulfuron can suppress and reduce *Bromus spp.* stand, increasing competitive ability of winter wheat.

For downy brome and cheat biomass, planting date and herbicide treatment affect occurred in 2021 (Table 2.12). A reduction in downy brome biomass occurred as planting date was delayed. Downy brome biomass at the mid- and late planting dates was reduced 87% and 80%, respectively, compared to the optimal planting. Fewer *Bromus spp.*

emergence occurred as planting date delayed allowing adequate control with an application of a non-selective herbicide (glyphosate) immediately after planting because of maximum emergence of weeds occurring prior to later planting dates. Downy brome and cheat biomass were low ($\leq$ 0.4 g m^{-2}) and 97 to 98% less, respectively, after an application of pyroxsulam or sulfosulfuron than biomass in nontreated controls. Herbicide application substantially suppress downy brome and cheat in winter wheat systems. In Oregon, fluazifop-P, quizalofop-P, sethoxydim, and clethodim applications to downy brome in greenhouse studies revealed excellent control of weed biomass compared to nontreated *spp.* (Ball et al. 2007)

Winter Wheat Yield

In 2020, delay in planting date from optimal to mid- or late planting decreased grain yield up to 21% (Table 2.13). In 2021, grain yield decreased when a delay in planting occurred across all herbicide treatments (pyroxsulam, sulfosulfuron, nontreated) with the optimal planting date following pyroxsulam or sulfosulfuron resulting in the greatest yields (~6,057 kg ha^{-1}). A planting date by cultivar interaction also occurred for winter wheat yield in 2021 (Table 2.13). Showdown sown at the optimal planting date produced 15% more grain than Green Hammer sown at the optimal timing and also yielded 17% and 61% more grain compared to mid- and late planting dates, respectively. Overall, main effects and herbicide and cultivar interactions for planting date occurred dependent on-site year with the optimal planting date resulting in greatest grain yield. The application of pyroxsulam or sulfosulfuron can increase grain yield but proper planting date selection is pertinent for the Lahoma region. Reddy et al. (2013) observed that herbicide alone is very important to maximize yield potential. Proper cultivar selection may also increase grain yield dependent on planting date. Khaliq et al. (2014) study in Pakistan also verified that cultivar selection is critical for increased yield potential.

Burkburnett and Thornberry

Bromus spp. Visual Control and Biomass

Delaying winter wheat planting affected visual control of *Bromus spp.* at Burkburnett in 2020 (Table 2.14). Similar control was recorded (~62.5%) following optimal and mid-planting dates, while visual control was 26% greater following the late planting. At Burkburnett 2020, herbicide treatment affected rescuegrass biomass, while a planting date by herbicide and a planting date by cultivar interaction for downy brome biomass occurred (Table 2.15). Sulfosulfuron reduced rescuegrass biomass 75% compared to nontreated, while pyroxsulam observed little difference compared to nontreated and sulfosulfuron (~2.7g 0.25 m^{-2}). Downy brome biomass was 89% less following pyroxsulam applied at the late planting compared to the optimal and mid-planting dates. At the optimal planting, pyroxsulam and sulfosulfuron reduced downy brome biomass 69% and 86%, respectively, compared to the nontreated control. A similar trend occurred at the mid-planting date where downy brome biomass was 94% greater following no herbicide treatment compared to pyroxsulam and sulfosulfuron applications. A three-year study in Kansas discovered similar findings with pyroxsulam applied POST in the fall where downy brome was visually controlled 84 to 99% and was similar to or greater than sulfosulfuron (Geier 2011). The nontreated late planting date provided 86% less downy brome biomass compared to nontreated plots at the optimal and mid-planting dates. Downy brome biomass also was similar (~6.7g 0.25 m^{-2}) at the late planting date following nontreated, pyroxsulam, and sulfosulfuron treatments. While pyroxsulam and sulfosulfuron offer sufficient suppression of *Bromus spp.,* delaying planting date also offers extra suppression and another long-term solution to producers.

Showdown and Green Hammer sown at the optimal time resulted in the greatest amount of downy brome biomass (~44.5g 0.25 m^{-2}) while the late plantings of both cultivars resulted in the least (~7g 0.25 m^{-2}). Unsure as to why, but the mid-planting date resulted in a varietal effect on downy brome biomass with 43% less in Green Hammer compared to Showdown. In the Rolling Plains competitive ability of cultivars may increase grain yield at certain planting dates, but overall, later planting dates decrease grain yield because of insufficient stand of wheat sown into soils with temperatures below the optimum wheat emergence temperature range.

Wheat Biomass and Head Counts

A cultivar effect resulted in Green Hammer producing 24% more biomass than Showdown at Burkburnett in 2020 (Table 2.15). A planting date by herbicide interaction also occurred with sulfosulfuron applied at the optimal and mid-planting dates increasing wheat biomass 56% and 47%, respectively, compared to nontreated. All herbicide treatments following late planted wheat produced similar wheat biomass (~93.7g 0.25 m^{-2}). For Thornberry 2021, the optimal planting date resulted in 49% and 79% more biomass compared to mid- and late planting dates, respectively. The mid-planting date produced 60% more wheat biomass than the late planting date.

At Burkburnett 2020, herbicide treatment affected winter wheat head counts, while planting date affected Thornberry 2021 head counts (Table 2.16). Following pyroxsulam and sulfosulfuron at Burkburnett, wheat head counts increased up to 29%

compared to nontreated wheat. For Thornberry 2021, planting date trends for wheat head counts matched wheat biomass. Similar to findings by Musick et al. (1980), optimal and mid-planting dates resulted in 77% and 44% more heads $0.25m^{-2}$, respectively, than heads for the late planting. Head counts also increased 54% from the optimal to mid-planting. At mid- and late planting dates at Thornberry 2021, wheat stand was extremely minimal, resulting in less biomass and fewer wheat heads compared to the optimal planting date. Minimal wheat stand can be attributed to unfavorable environmental conditions and extreme infestations of rattail fescue [*Vulpia myuros* (L.) *C.C. Gmel]*.

Wheat Yield

As planting date delayed, Burkburnett 2020 grain yield varied dependent on herbicide application (Table 2.17). At the optimal planting, nontreated wheat yielded 44% and 18% less than pyroxsulam and sulfosulfuron treated wheat, respectively. Conversely, following the late planting, pyroxsulam and sulfosulfuron reduced grain yield up to 26% compared to the nontreated. Burkburnett had substantial summer annual weed *spp.* suppression at the late planting date. An increase in *Bromus spp.* was observed for nontreated plots because pyroxsulam and sulfosulfuron suppressed those *spp*. allowing growth for summer annuals which interfered with crops ability to grow successfully. Grain yield following sulfosulfuron applied at mid-planting was greatest (1,768 kg ha^{-1}) compared to pyroxsulam and nontreated (~1,239 kg ha^{-1}). Herbicide application following a planting window relatively close to the optimal timing can suppress *Bromus spp.* adequately without decreasing yield due to fewer emergence of summer annual weed *spp.* and possibly crop growth stage at application of herbicide.

At Burkburnett 2020 and Thornberry 2021, grain yield varied dependent on planting date by cultivar interaction. At Burkburnett 2020, Showdown sown at the optimal timing resulted in 359 kg ha^{-1} more grain than Green Hammer. While grain yield for Showdown was 387 kg ha^{-1} less than Green Hammer at the mid- planting date. Grain yield also declined from the optimal to mid- planting date for Showdown cultivar by 16%. However, Green Hammer sown at the mid- planting date resulted in 31% greater yield compared to the optimal planting date. At Thornberry 2021, Showdown and Green Hammer at the optimal planting date resulted in over 94% and 93%, respectively, greater grain yield compared to mid- and late planting dates. At the optimal planting date alone, yield increased 354 kg ha^{-1} following sowing of Green Hammer compared to Showdown. It is unclear why Showdown and Green Hammer resulted in variation of yield increase and decrease dependent on planting date across Burkburnett and Thornberry.

Delaying planting date of wheat allows producers to control early emerging rescuegrass and *Bromus spp.* but creates the possibility for grain yield loss or lack of forage in dual-purpose systems. Delaying planting date also provides producers the chance to avoid severe weather anomalies such as drought, freeze, and excessive flooding. Along with planting date, selection of competitive winter wheat cultivars for a particular region may determine how well the crop yields and competes with weeds. Wheat cultivar competitiveness to *weed spp*. trials in Canada discovered cultivar CDC Ptarmigan (soft white winter wheat grown for the ethanol feedstock market, medium height, high yield, fair winter hardiness) controlled and suppressed monocot weed spp. greater than less competitive cultivars (Beres et al. 2010).

The use of acetolactate synthase inhibiting herbicides pyroxsulam and sulfosulfuron can provide effective control of rescuegrass and other *Bromus spp. but* may alter successful crop growth. Environmental conditions, such as air temperature (Olson et al. 2000), soil organic matter and pH (Moyer and Hamman 2001), and precipitation (Shinn et al. 1998) can alter efficacy of sulfonylurea herbicides (sulfosulfuron). A wide range of weather conditions occurred throughout all site years; from warm and humid to severely cold, this likely resulted in varying effects of sulfosulfuron and pyroxsulam.

Winter wheat cultivar selection, time of wheat planting, and herbicide treatment are important strategies for rescuegrass and *Bromus spp.* control. Producers in the southern Great Plains have the option to integrate these tools with their existing weed management plans, either individually, together, or in a sequential manner. Treatments of pyroxsulam and sulfosulfuron and/or a delay in planting by two to six weeks after the optimal time did provide a reduction in rescuegrass and *Bromus spp*. biomass but also resulted in decreased wheat biomass and grain yield. Producers will need to evaluate their *Bromus spp*. infestations and decide if they can take on short-term yield decreases in order to make a long-term investment in weed management.

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Tables

Table 2.1. Monthly average weather data at Lahoma, Marshall, and Tipton, OK, and Burkburnett, TX during the 2019-20 winter wheat growing season.

Month	Lahoma 2020			Marshall 2020			Tipton 2020			Burkburnett 2020		
	Temperature ºC		Rainfall in	Temperature ºC		Rainfall in	Temperature ºC		Rainfall in	Temperature ºC		Rainfall in
	Min	Max		Min	Max		Min	Max		Min	Max	
October	-7[a]	28	0.8[b]	-7	28	1.7	-6	11	0.0			
November	-11	24	1.2	-12	24	1.9	-10	26	1.1	-8	27	2.2
December	-6	22	1.5	-9	22	1.3	-8	24	0.4	-6	24	0.6
January	-7	20	1.5	-6	22	2.4	-6	22	2.1	-4	24	2.9
February	-10	24	1.2	-11	25	0.8	-17	26	0.9	-11	28	2.0
March	-3	27	3.0	-4	32	3.8	-2	35	3.8	1	34	5.0
April	-3	30	1.0	-2	31	0.8	-2	34	1.4	-1	33	0.4
May	2	34	1.9	3	33	3.1	5	41	8.8	6	39	4.4
June	11	39	0.0	16	37	0.0	18	34	0.0	16	32	0.0
July												
Average	-4	28	1.3	-3	28	1.8	-3	31	2.1	-1	30	2.2
Total			12.1			15.8			18.5			17.4

[a] All Oklahoma and Texas max and min temperature data collected from the Oklahoma Mesonet (mesonet.org) and Texas Mesonet (texmesonet.org)

[b] Rainfall was determined from planting date to harvest date.

Table 2.2. Monthly average weather data at Lahoma, Marshall, and Tipton, OK, and Thornberry, TX during the 2020-21 winter wheat growing season.

Month	Lahoma 2021 Temperature ºC		Lahoma 2021 Rainfall in	Marshall 2021 Temperature ºC		Marshall 2021 Rainfall in	Tipton 2021 Temperature ºC		Tipton 2021 Rainfall in	Thornberry 2021 Temperature ºC		Thornberry 2021 Rainfall in
	Min	Max		Min	Max		Min	Max		Min	Max	
October	-3[a]	34	2.2[b]	-2	28	3.3						
November	-6	27	1.6	-5	26	0.7	-4	28	0.4	-3	29	0.4
December	-12	20	1.8	-15	23	2.2	-8	23	1.9	-6	26	1.4
January	-7	18	1.5	-7	18	2.3	-6	22	0.5	-7	22	0.6
February	-25	21	0.2	-27	22	0.2	-22	25	0.3	-22	28	0.8
March	-4	27	4.6	-4	27	5.6	-4	31	0.9	1	29	1.3
April	-3	27	2.2	-3	28	2.7	-1	31	2.9	1	31	4.5
May	5	30	4.2	4	19	3.6	6	33	4.5	8	32	4.8
June	12	39	4.5	12	37	0.8	14	36	3.7	13	36	0.8
July	17	33	0.3									
Average	-3	28	2.3	-5	25	2.4	-3	29	2	-2	29	1.8
Total			23.1			21.5			15.3			14.7

[a] All Oklahoma and Texas max and min temperature data collected from the Oklahoma Mesonet (mesonet.org) and Texas Mesonet (texmesonet.org)

[b] Rainfall was determined from planting date to harvest date.

Table 2.3. Agronomic practices at Lahoma, Marshall, and Tipton, OK and Burkburnett and Thornberry, TX during the 2019-20 and 2020-21 winter wheat growing seasons.

Growing season	Location	Plant timing	Planting date	Herbicide application date	Harvest date
2019-20	Lahoma	Optimal[a]	Oct 17	Dec 20[b]	Jun 8[c]
		Mid-	Nov 5	Jan 14	Jun 8
		Late	Nov 18	Feb 7	Jun 18
2019-20	Marshall	Optimal	Oct 8	Nov 14	Jun 5
		Mid-	Oct 22	Nov 25	Jun 5
		Late	Nov 14	Jan 13	Jun 5
2019-20	Tipton	Optimal	Oct 31	Dec 12	Jun 3
		Mid-	Nov 22	Jan 24	Jun 3
		Late	Dec 11	Mar 11	Jun 11
2019-20	Burkburnett	Optimal	Nov 1	Dec 12	Jun 3
		Mid-	Nov 23	Jan 15	Jun 3
		Late	Dec 12	Mar 11	Jun 11
2020-21	Lahoma	Optimal	Oct 9	Dec 1	Jul 7
		Mid-	Nov 11	Feb 2	Jul 7
		Late	Nov 30	Mar 31	Jul 7
2020-21	Marshall	Optimal	Oct 5	Dec 25	Jun 23
		Mid-	Nov 10	Feb 5	Jun 23
		Late	Nov 30	Mar 31	Jun 23
2020-21	Tipton	Optimal	Nov 13	Jan 19	Jun 16
		Mid-	Dec 4	Mar 4	Jun 16
		Late	Dec 18	Mar 25	Jun 16
2020-21	Thornberry	Optimal	Nov 12	Jan 20	Jun 23
		Mid-	Dec 4	Apr 1	Jun 23
		Late	Dec 18	Apr 22	Jun 23

[a] Optimal planting date represents the optimal window winter wheat can be sown with mid- occurring two to three weeks after optimal and late occurring two to three weeks after mid-.

[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 2- to 3- leaf stage of winter wheat and *Bromus spp*. for each planting date.

[c] Harvest date of wheat grain when kernel moisture was between 9 to 12% .

Table 2.4. Visual control ratings and stand counts of *Bromus spp*., as well as crop and weed biomass collection dates at Lahoma, Marshall, and Tipton, OK and Burkburnett and Thornberry, TX during the 2019-20 and 2020-21 winter wheat growing seasons.

Growing season	Location	Plant timing	Visual control and stand counts			Biomass collection
2019-2020	Lahoma	Optimal[a]	January 20[b]	February 11	June 8	May 12[c]
		Mid-	February 11	March 21	June 8	May 14
		Late	March 21	April 2	June 8	May 19
2019-2020	Marshall	Optimal	December 20	January 14	June 5	Apr 16
		Mid-	January 9	January 31	June 5	May 7
		Late	February 19	March 24	June 5	May 8
2019-2020	Tipton	Optimal	January 15	February 14	June 3	April 21
		Mid-	February 24	March 20	June 3	May 11
		Late	April 17	May 11	June 11	May 13
2019-2020	Burkburnett	Optimal	January 15	February 8	June 3	Apr 21
		Mid-	February 24	March 20	June 3	May 11
		Late	April 17	May 11	June 11	May 13
2020-21	Lahoma	Optimal	January 12	March 8	July 7	May 7
		Mid-	March 8	March 30	July 7	May 15
		Late	April 27	May 26	July 7	May 20
2020-2021	Marshall	Optimal	March 2	March 30	June 23	May 13
		Mid-	March 10	March 30	June 23	May 14
		Late	April 27	May 26	June 23	May 20
2020-2021	Tipton	Optimal	March 1	March 25	June 15	April 30
		Mid-	April 1	April 30	June 15	May 5
		Late	April 19	May 17	June 15	May 17
2020-2021	Thornberry	Optimal	March 1	April 1	*	May 4
		Mid-	Apr 22/May 4[d]	June 11	*	June 11
		Late	May 9	June 10	*	June11

[a] Optimal planting date represents the optimal window winter wheat can be sown with Mid- occurring two to three weeks after optimal and Late occurring two to three weeks after Mid-.

[b] Visual control and stand counts of *Bromus spp.* approximately four to six and eight to nine WAT, and at harvest. Stand counts were not recorded.

[c] Biomass collection of wheat and *Bromus spp.* at heading.

[d] Visual control was conducted on April 22nd and weed stand counts were conducted on May 4th.

[*] Ratings did not take place.

Table 2.5. ANOVA table for Lahoma, Marshall, and Tipton, OK and Burkburnett and Thornberry, TX during the 2019-20 and 2020-21 winter wheat growing seasons.

	Lahoma		**Marshall**		**Tipton**		**Burkburnett**	**Thornberry**
Growing season	20	21	20	21	20	21	20	21
				Weed control				
Planting date (P)	***	NS	***	*	***	***	***	ND
Herbicide (H)	*	NS	***	NS	NS	NS	NS	ND
Cultivar (C)	NS	NS	NS	NS	NS	NS	NS	ND
P x H	NS	NS	NS	NS	NS	***	NS	ND
P x C	NS	NS	NS	NS	NS	NS	NS	ND
H x C	NS	NS	NS	NS	NS	NS	NS	ND
P x H x C	NS	NS	NS	NS	NS	NS	NS	ND
				Weed biomass				
Planting date (P)	NS	*	***	***	NS	NS	***	ND
Herbicide (H)	NS	***	***	NS	***	*	***	ND
Cultivar (C)	NS	NS	NS	NS	NS	NS	NS	ND
P x H	NS	*	NS	NS	NS	NS	***	ND
P x C	NS	NS	**	NS	NS	NS	*	ND
H x C	NS	NS	NS	NS	NS	NS	NS	ND
P x H x C	NS	NS	NS	NS	NS	NS	NS	ND

				Wheat biomass				
Planting date (P)	***	***	**	***	***	*	NS	***
Herbicide (H)	NS	NS	NS	***	NS	NS	*	NS
Cultivar (C)	NS	NS	NS	NS	NS	NS	**	*
P x H	NS	NS	NS	*	NS	NS	**	NS
P x C	NS	NS	NS	NS	NS	NS	NS	NS
H x C	**	NS	NS	NS	NS	NS	NS	NS
P x H x C	NS	NS	NS	NS	NS	NS	NS	NS
				Wheat head count				
Planting date (P)	***	***	NS	***	**	NS	NS	***
Herbicide (H)	NS	NS	NS	NS	NS	NS	**	NS
Cultivar (C)	NS	NS	NS	NS	NS	NS	**	NS
P x H	NS	NS	NS	NS	NS	NS	NS	NS
P x C	NS	NS	NS	NS	NS		*	NS
H x C	**	NS	NS	NS	NS	NS	NS	NS
P x H x C	NS	NS	NS	NS	NS	NS	NS	NS
				Wheat yield				
Planting date (P)	***	***	NS	***	***	***	***	***
Herbicide (H)	NS	**	***	*	*	NS	***	NS
Cultivar (C)	NS	NS	NS	***	*	NS	NS	**
P x H	NS	**	NS	NS	NS	NS	***	NS

P x C	NS	**	NS	**	NS	NS	***	*
H x C	NS	NS	NS	NS	NS	NS	NS	NS
P x H x C	NS	NS	NS	NS	NS	NS	NS	NS

*, **, *** represents 0.05, 0.01, and <0.0001, respectively.

NS: Not significant.

ND: No data.

Table 2.6. Visual control of rescuegrass eight to nine weeks after herbicide treatment for Marshall and Tipton, OK during the 2019-20 and 2020-21 winter wheat growing seasons.

	Marshall 2020	Marshall 2021	Tipton 2020	Tipton 2021	
	% Visual control[a]				
Planting date					
Optimal[b]	28 b	78 b	57 c		
Mid-	51 a	87 a	69 b		
Late	60 a	85 a	91 a		
Herbicide					
pyroxsulam[c]	56 a				
sulfosulfuron	36 b				
Planting date*herbicide				P[c]	S
Optimal				73 cd [d]	66 d
Mid-				78 bc	95 a
Late				86 ab	89 a

[a] Visual rating of rescuegrass control on a scale of 0 to 100% as compared to nontreated plots. 0 represents no control, 100 represents complete control.

[b] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[c] Pyroxsulam (P) sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron (S) at 35.2 g ai ha^{-1}. All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

[d] Means within a column for each site year followed by a common letter were similar according to Fisher's protected LSD at $P < 0.05$.

Table 2.7. Rescuegrass biomass collected at heading (g 0.25 m^{-2}) at Marshall and Tipton, OK during the 2019-20 and 2020-21 winter wheat growing seasons.

	Marshall 2020	Marshall 2021	Tipton 2020	Tipton 2021
	g 0.25 m^{-2}			
Planting date				
Optimal[a]	45.4 a	4.4 a		
Mid	22.2 b	1.3 b		
Late	26.6 b	1.2 b		
Herbicide				
Nontreated	47.5 a		13.7 a	4.5 a
pyroxsulam[b]	9.4 b		8.3 a	3.1 a
sulfosulfuron	37.2 a		1.0 b	1.0 b

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[b] 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 at 30% vol/vol.

Table 2.8. Winter wheat biomass collected at heading (g 0.25 m^{-2}) at Marshall and Tipton, OK during the 2019-20 and 2020-21 winter wheat growing seasons.

	Marshall 2020	Marshall 2021	Tipton 2020	Tipton 2021
	g 0.25 m^{-2}			
Planting date				
Optimal[a]	135 b[b]	180 a	156 c	153 a
Mid	170 a	114 b	171 b	132 b
Late	155 ab	83 c	188 a	129 b
Herbicide				
Nontreated		133 a		
Pyroxsulam[c]		111 b		
sulfosulfuron		134 a		

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[b] Means within a column for each site year followed by a common letter were similar according to Fisher's protected LSD at $P < 0.05$.

[c] Pyroxsulam 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 non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

Table 2.9. Winter wheat head counts (0.25 m^{-2} quadrat) for Marshall and Tipton, OK during the 2019-20 and 2020-21 winter wheat growing seasons.

	Marshall 2021	Tipton 2020	Tipton 2021	
	# of wheat heads			
Planting date				
Optimal[a]	78 a	80 a		
Mid-	60 b	85 a		
Late	52 c	65 b		
Planting date*cultivar			SD[b]	GH
Optimal			73 ab[c]	63 bc
Mid-			56 c	80 a
Late			58 bc	56 c

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[b] Two winter wheat cultivars (SD: Showdown; GH: Green Hammer) comparing competitive ability with early and late canopy coverage.

[c] Means within a column for each site year followed by a common letter were similar according to Fisher's protected LSD at $P < 0.05$.

Table 2.10. Grain yield (kg ha^{-1}) for Marshall and Tipton, OK during the 2019-20 and 2020-21 winter wheat growing seasons.

	Marshall 2020	Marshall 2021	Tipton 2020	Tipton 2021
	kg ha^{-1}			
Planting date				
Optimal[a]			2,963 a	4,856 a
Mid-			3,055 a	3,663 b
Late			2,494 b	2,630 c
Herbicide				
Nontreated	2,998 b	2,812 a	2,663 b	
pyroxsulam[b]	3,231 b	2,494 b	2,915 a	
sulfosulfuron	3743 a	2,681 ab[c]	2,934 a	
Cultivar				
Showdown[d]			2,939 a	
Green Hammer			2,736 b	
Planting date * cultivar		SD[d] GH		
Optimal		3,804 a 3,869 a		
Mid-		2,610 c 3,456 b		
Late		911 e 1,324 d		

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[b] Pyroxsulam sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron at 35.2 g ai ha^{-1}, and nontreated check. All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

[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] Two winter wheat cultivars (SD: Showdown; GH: Green Hammer) comparing competitive ability with early and late canopy coverage.

Table 2.11. Visual control of downy brome and cheat eight to nine weeks after herbicide treatment for Lahoma, OK during the 2019-20 and 2020-21 winter wheat growing seasons.

	Lahoma 2020	Lahoma 2021
	% Visual control[a]	
Planting date		
Optimal[b]	74 c	76 b
Mid-	83 b	98 a
Late	96 a	99 a
Herbicide		
pyroxsulam[c]	88 a	
sulfosulfuron	82 b	

[a] Visual rating of rescuegrass control on a scale of 0 to 100% as compared to nontreated plots. 0 represents no control, 100 represents complete control.

[b] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[c] Pyroxsulam 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 non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

Table 2.12. Wheat, downy brome, and cheat biomass collected at heading (g 0.25 m^{-2}) at Lahoma, Oklahoma during the 2019-20 and 2020-21 winter wheat growing seasons.

	Lahoma 2020		Lahoma 2021		
	Wheat		*Wheat*	*Downy brome*	*Cheat*
	g 0.25 m^{-2}				
Planting date					
Optimal[a]	233.7 a		207.5 a	10.8 a	
Mid-	171.5 b		198.3 a	1.4 b	
Late	187.6 b		152.4 b	2.8 b	
Herbicide					
nontreated				14.3 a	13.4 a
pyroxsulam[b]				0.4 b	0.2 b
sulfosulfuron				0.4 b	0.2 b
Herbicide * cultivar	SD[c]	GH			
nontreated	220.2 a	198.9 ab[d]			
pyroxsulam	221.6 a	170.2 b			
sulfosulfuron	171.3 b	203.4 ab			

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[b] Pyroxsulam (P) sprayed at a rate of 18.4 g ai $ha^{-1,}$ sulfosulfuron (S) at 35.2 g ai ha^{-1}, and nontreated (NT). All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

[c] Two winter wheat cultivars (SD: Showdown; GH: Green Hammer) comparing competitive ability with early and late canopy coverage.

[d] Means within a column for each site year followed by a common letter were similar according to Fisher's protected LSD at $P < 0.05$.

Table 2.13. Grain yield (kg ha^{-1}) for Lahoma, OK during the 2019-20 and 2020-21 winter wheat growing seasons.

	Lahoma 2020	Lahoma 2021		
	kg ha^{-1}			
Planting date				
Optimal[a]	3,982 a			
Mid-	3,409 b			
Late	3,155 b			
Planting date*herbicide		NT	P[b]	S
Optimal		4,576 b	6,031 a	6,082 a
Mid-		4,910 b	5,101 b	5,073 b
Late		2,426 c	2,223 c	2,516 c
Planting date*cultivar		SD[c]		GH
Optimal		6,029 a		5,096 b
Mid-		5,034 b		5,022 b
Late		2,326 c		2,450 c

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[b] Pyroxsulam (P) sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron (S) at 35.2 g ai ha^{-1}, and nontreated (NT) check. All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

[c] Two winter wheat cultivars (SD: Showdown; GH: Green Hammer) comparing competitive ability with early and late canopy coverage.

Table 2.14. Visual control of *Bromus spp.* eight to nine weeks after herbicide treatment for Burkburnett, TX during the 2019-20 winter wheat growing season.

	Burkburnett 2020
	——% visual control[a] ——
Planting date	
Optimal[b]	62 b
Mid-	63 b
Late	88 a

[a] Visual rating of rescuegrass control on a scale of 0 to 100% as compared to nontreated plots. 0 represents no control, 100 represents complete control.

[b] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

Table 2.15. Wheat, rescuegrass, and downy brome biomass collected at heading (g 0.25 m^{-2}) at Burkburnett, TX during the 2019-20 winter wheat growing season.

		Burkburnett 2020		Thornberry 2021	Burkburnett 2020			
		Wheat			*Rescuegrass*		*Downy brome*	
				g 0.25 m^{-2}				
Planting date								
Optimal[a]				68 a				
Mid-				35 b				
Late				14 c				
Herbicide								
Nontreated					8 a[d]			
pyroxsulam[b]					6 ab			
sulfosulfuron					2 b			
Cultivar								
Showdown[c]		68 b						
Green Hammer		90 a						
Planting date*herbicide	NT	P[b]	S			NT	P	S
Optimal	44 b	73 ab	101 a			91 a	28 b	13 bc
Mid-	46 b	79 ab	87 a			81 a	18 bc	5 c
Late	105 a	91 a	85 a			12 c	3 c	5 c

Planting date*cultivar	SD[c]	GH
Optimal	43 a	46 a
Mid-	44 a	25 b
Late	5 c	9 c

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[b] Pyroxsulam (P) sprayed at a rate of 18.4 g ai $ha^{-1,}$ sulfosulfuron (S) at 35.2 g ai ha^{-1}, and nontreated (NT). All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

[c] Two winter wheat cultivars (SD: Showdown; GH: Green Hammer) comparing competitive ability with early and late canopy coverage.

[d] 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.

Table 2.16. Winter wheat head counts (0.25 m^{-2} quadrat) for Burkburnett and Thornberry, TX during the 2019-20 and 2020-21 winter wheat growing seasons.

	Burkburnett 2020	Thornberry 2021
	——— # of wheat heads ———	
Planting date		
Optimal[a]		35 a
Mid-		16 b
Late		9 c
Herbicide		
Nontreated	30 b	
pyroxsulam[b]	40 a	
sulfosulfuron	42 a	

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[b] Pyroxsulam sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron at 35.2 g ai ha^{-1}, and nontreated check. All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

[c] Two winter wheat cultivars (SD: Showdown; GH: Green Hammer) comparing competitive ability with early and late canopy coverage.

[d] Means within a column for each site year followed by a common letter were similar according to Fisher's protected LSD at $P < 0.05$

Table 2.17. Grain yield (kg ha^{-1}) for Burkburnett and Thornberry, TX during the 2019-20 and 2020-21 winter wheat growing seasons.

	Burkburnett 2020			Thornberry 2021	
	kg ha^{-1}				
Planting date*herbicide	NT	P[b]	S		
Optimal[a]	765 f[d]	1,386 b	1,700 a		
Mid-	1,112 cde	1,366 bc	1,768 a		
Late	1,202 bcd	891 ef	942 def		
Planting date*cultivar	SD[c]		GH	SD	GH
Optimal	1,463 a		1,104 bc	1,337 b	1,691 a
Mid-	1,222 b		1,609 a	91 c	183 c
Late	1,062 bc		962 c	78 c	124 c

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[b] Pyroxsulam (P) sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron (S) at 35.2 g ai ha^{-1}, and nontreated (NT) check. All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

[c] Two winter wheat cultivars (SD: Showdown; GH: Green Hammer) comparing competitive ability with early and late canopy coverage.

[d] Means within a column for each site year followed by a common letter were similar according to Fisher's protected LSD at $P < 0.05$

APPENDICES

Table A.1. Visual control of rescuegrass four to six weeks after herbicide treatment for Marshall and Tipton, OK during the 2019-20 and 2020-21 winter wheat growing seasons.

	Marshall 2020	Marshall 2021	Tipton 2020	Tipton 2021
	% visual control[a]			
Planting date				
Optimal[b]	33 b	48 b		46 b
Mid-	50 a	41 c		81 a
Late	38 b	71 a		90 a
Herbicide				
pyroxsulam[c]	50 a	57 a		
sulfosulfuron	31 b	50 b		
Cultivar				
Showdown[d]			51 b	
Green Hammer			58 a	

Planting date*herbicide	P[c]	S
Optimal	49 b	36 c
Mid-	33 c	33 c
Late	84 a	93 a

[a] Visual rating of rescuegrass control on a scale of 0 to 100% as compared to nontreated plots. 0 represents no control, 100 represents complete control.

[b] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[c] Pyroxsulam (P) sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron (S) at 35.2 g ai ha^{-1}. All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

[d] Two winter wheat cultivars (SD: Showdown; GH: Green Hammer) comparing competitive ability with early and late canopy coverage.

Table A.2. Visual control of rescuegrass at harvest for Marshall and Tipton, OK during the 2019-20 and 2020-21 winter wheat growing seasons

	Marshall 2020	Marshall 2021	Tipton 2020	
	% visual control[a]			
Planting date				
Optimal[b]	67 b		98 a	
Mid-	87 a		99 a	
Late	82 a		92 b	
Herbicide				
pyroxsulam[c]	87 a	83 a	94 b	
sulfosulfuron	71 b	75 b	99 a	
Planting date*herbicide			P[c]	S
Optimal			98 a	98 a
Mid-			98 a	99 a
Late			85 b	98 a

[a] Visual rating of rescuegrass control on a scale of 0 to 100% as compared to nontreated plots. 0 represents no control, 100 represents complete control.

[b] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[c] Pyroxsulam (P) sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron (S) at 35.2 g ai ha^{-1}. All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

Table A.3. Rescuegrass stand count (0.10 m^{-2}) four to six weeks after herbicide treatment at Marshall and Tipton, OK for 2019-20 and 2020-21 winter wheat growing seasons.

	Marshall 2020	Marshall 2021	Tipton 2020	Tipton 2021		
	——	——	0.10 m^{-2}	——	——	——
Planting date						
Optimal[a]		1.0 a	11.8 a		6.0 a	
Mid-		0.9 a	3.0 b		1.8 b	
Late		0.4 b	1.6 b		1.6 b	
Herbicide						
Nontreated	30.4 a					
pyroxsulam[b]	23.6 b					
sulfosulfuron	32.1 a					
Cultivar						
Showdown[c]			4.5 b			
Green Hammer			6.5 a			
Planting date*herbicide				NT	P[b]	S
Optimal				4.4 bc[d]	8.0 a	5.5 b
Mid-				1.1 d	1.8 d	1.9 d
Late				2.8 cd	1.0 d	1.4 d
Planting date*cultivar	SD[c]	GH				

Optimal	41.8 b	52.7 a		
Mid-	26.7 c	26.0 c		
Late	14.6 d	10.6 d		
Herbicide*cultivar			SD	GH
Nontreated			0.7 b	0.9 ab
pyroxsulam			0.4 b	1.2 a
sulfosulfuron			0.9 ab	0.4 b

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[b] Pyroxsulam (P) sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron (S) at 35.2 g ai ha^{-1} and nontreated (NT). All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

[c] Two winter wheat cultivars (SD: Showdown; GH: Green Hammer) comparing competitive ability with early and late canopy coverage.

[d] Means within a column for each site year followed by a common letter were similar according to Fisher's protected LSD at $P < 0.05$.

Table A.4. Rescuegrass stand count (0.10 m^{-2}) eight to nine weeks after herbicide treatment at Marshall and Tipton, OK for 2019-20 and 2020-21 winter wheat growing seasons.

	Marshall 2020	Marshall 2021	Tipton 2020	Tipton 2021
	0.10 m^{-2}			
Planting date				
Optimal[a]	39.0 a	0.5 b	12.3 a	3.8 a
Mid-	25.9 b	1.3 a	3.0 b	2.2 b
Late	6.6 c	0.5 b	4.9 b	0.7 c
Herbicide				
Nontreated	26.1 a			
pyroxsulam[b]	26.0 a			
sulfosulfuron	19.4 b			

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[b] Pyroxsulam (P) sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron (S) at 35.2 g ai ha^{-1} and nontreated (NT). All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

Table A.5. Seed dockage subsamples (per 150 g) at Marshall and Tipton, OK during the 2019-20 winter wheat growing season.

	Marshall 2020		Marshall 2020		Tipton 2020		
	Wheat		*Rescuegrass*				
	per 150 g						
Planting date*herbicide					NT	P[b]	S
Optimal[a]					0.6 a	0.5 a	0.06 b
Mid-					0.6 a	0.2 b	0.05 b
Late					0.08 b	0.05 b	0.02 b
Planting date*cultivar	SD[c]	GH	SD	GH	SD	GH	
Optimal	146.4 b [d]	143.8 c	3.6 b	6.3 a	0.5 a	0.2 b	
Mid-	148.8 a	148.1 ab	1.3 c	1.9 bc	0.4 a	0.2 b	
Late	146.7 ab	148.3 ab	3.1 bc	1.7 bc	0.06 b	0.04 b	
Herbicide*cultivar			SD	GH	SD	GH	
Nontreated			3.5 b	6.4 a	0.6 a	0.3 bc	
pyroxsulam[b]			0.4 c	0.3 c	0.3 b	0.1 cd	
sulfosulfuron			4.1 b	3.1 b	0.04 d	0.05 d	

[a] Optimal planting date represents the recommended window for sowing grain-only wheat in the region. Mid- occurred two to three weeks after the first planting date and late occurred two to three weeks after second planting date.

[b] Pyroxsulam (P) sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron (S) at 35.2 g ai ha^{-1} and nontreated (NT). All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

[c] Two winter wheat cultivars (SD: Showdown; GH: Green Hammer) comparing competitive ability with early and late canopy coverage.

[d] Means within a column for each site year followed by a common letter were similar according to Fisher's protected LSD at $P < 0.05$.

Table A.6. Seed dockage subsamples (per 150 g) at Marshall and Tipton, OK during the 2020-21 winter wheat growing season.

	Marshall 2021	Tipton 2021	Marshall 2021	Tipton 2021
	Wheat		*Rescuegrass*	
	——— per 150 g ———			
Planting date				
Optimal[a]	149.76 a	149.42 a	0.22 b	0.28 b
Mid-	149.56 a	148.7 b	0.36 b	0.65 a
Late	148.51 b	148.77 b	0.62 a	0.25 b
Herbicide				
Nontreated		148.21 b		0.61 a[c]
pyroxsulam[b]		149.32 a		0.41 ab
sulfosulfuron		149.36 a		0.15 b

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[b] Pyroxsulam 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 non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

[c] Means within a column for each site year followed by a common letter were similar according to Fisher's protected LSD at $P < 0.05$.

Table A.7. Visual control of downy brome and cheat four to six weeks after herbicide treatment for Lahoma, OK during the 2019-20 and 2020-21 winter wheat growing seasons.

	Lahoma 2020	Lahoma 2021
	% visual control[a]	
Planting date		
Optimal[b]	25 c	33 b
Mid-	36 b	38 a
Late	83 a	90 a
Herbicide		
pyroxsulam[c]	51 a	
sulfosulfuron	44 b	
Cultivar		
Showdown[d]	51 a	
Green Hammer	44 b	

[a] Visual rating of rescuegrass control on a scale of 0 to 100% as compared to nontreated plots. 0 represents no control, 100 represents complete control.

[b] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[c] Pyroxsulam 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 non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

[d] Two winter wheat cultivars (SD: Showdown; GH: Green Hammer) comparing competitive ability with early and late canopy coverage.

Table A.8. Downy brome and cheat counts (0.10 m^{-2}) four to six weeks after herbicide treatment at Lahoma, OK for 2019-20 and 2020-21 winter wheat growing seasons.

	Lahoma 2020			Lahoma 2021
	0.10 m^{-2}			
Planting date				
Optimal[a]				7 a
Mid-				2 b
Late				2 b
Planting date * herbicide	NT	P[b]	S	
Optimal	26 abc[c]	29 ab	29 ab	
Mid-	15 cde	20 bcd	33 a	
Late	11 def	2 ef	1 f	

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[b] Pyroxsulam (P) sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron (S) at 35.2 g ai ha^{-1} and nontreated (NT). All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

[c] Means within a column for each site year followed by a common letter were similar according to Fisher's protected LSD at $P < 0.05$.

Table A.9. Downy brome and cheat counts (0.10 m^{-2}) eight to nine weeks after herbicide treatment at Lahoma, OK for 2019-20 and 2020-21 growing seasons.

	Lahoma 2020		Lahoma 2021	
	——— 0.10 m^{-2} ———			
Planting date				
Optimal[a]	22.0 a			
Mid-	7.0 b			
Late	6.3 b			
Herbicide				
Nontreated[b]	21.7 a			
pyroxsulam	6.9 b			
sulfosulfuron	6.8 b			
Planting date * herbicide		NT	P[b]	S
Optimal		47.2 a	3.6 b	2.9 b
Mid-		1.9 b	0.9 b	0.6 b
Late		2.1 b	0.2 b	0.5 b

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[b] Pyroxsulam (P) sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron (S) at 35.2 g ai ha^{-1} and nontreated (NT). All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

Table A.10. Winter wheat head counts (0.25 m^{-2} quadrat) for Lahoma, OK during the 2019-20 and 2020-21 winter wheat growing seasons.

		Lahoma 2020		Lahoma 2021
	———————	——— # of wheat heads ———	———	———————
Planting date				
Optimal[a]		108 a		110 a
Mid-		81 b		120 a
Late		86 b		63 b
Herbicide * cultivar	SD[c]		GH	
Nontreated	104 a[d]		90 abc	
pyroxsulam[b]	103 a		78 c	
sulfosulfuron	81 bc		97 ab	

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[b] Pyroxsulam sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron at 35.2 g ai ha^{-}1, and nontreated check. All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

[c] Two winter wheat cultivars (SD: Showdown; GH: Green Hammer) comparing competitive ability with early and late canopy coverage.

[d] Means within a column for each site year followed by a common letter were similar according to Fisher's protected LSD at $P < 0.05$.

Table A.11. Seed dockage subsamples (per 150 g) at Lahoma, OK during the 2020-21 winter wheat growing season.

	Lahoma 2021		
	Wheat		*Cheat*
	per 150 g		
Planting date			
Optimal[a]	147.95 b		
Mid-	149.27 a		
Late	147.26 b		
Herbicide			
Nontreated			1.18 a
pyroxsulam[b]			0.11 b
sulfosulfuron			0.07 b
Herbicide * cultivar	SD[c]	GH	
Nontreated	148.59 a	145.80 b	
pyroxsulam	148.58 a	148.34 a	
sulfosulfuron	148.97 a	148.68 a	

[a] Optimal planting date represents the recommended window for sowing grain-only wheat in the region. Mid- occurred two to three weeks after the first planting date and late occurred two to three weeks after second planting date.

[b] Pyroxsulam (P) sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron (S) at 35.2 g ai ha^{-1} and nontreated (NT). All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

[c] Two winter wheat cultivars (SD: Showdown; GH: Green Hammer) comparing competitive ability with early and late canopy coverage.

Table A.12. Visual control of *Bromus spp.* four to six weeks after herbicide treatment and at harvest for Burkburnett, TX during the 2019-20 winter wheat growing season.

	Burkburnett 2020	
	—— % visual control[a] ——	
	Three to four weeks after treatment	
Planting date		
Optimal[b]	23 b	
Mid-	69 a	
Late	79 a	
	Harvest	
Planting date * herbicide	P	S
Optimal	59 c[c]	78 b
Mid-	82 ab	89 a
Late	88 a	90 a

[a] Visual rating of rescuegrass control on a scale of 0 to 100% as compared to nontreated plots. 0 represents no control, 100 represents complete control.

[b] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

[c] Means within a column for each site year followed by a common letter were similar according to Fisher's protected LSD at $P < 0.05$.

Table A.13. *Bromus spp.* counts (0.10 m^{-2}) four to six weeks after treatment at Burkburnett and Thornberry, TX for 2019-20 and 2020-21 winter wheat growing seasons.

	Burkburnett 2020	Thornberry 2021
	—— 0.10 m^{-2} ——	
Planting date		
Optimal[a]	207 a	4 b
Mid-	62 b	5 b
Late	9 c	12 a

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

Table A.14. *Bromus spp.* counts (0.10 m^{-2}) eight to nine weeks after treatment at Burkburnett, TX for 2019-20 winter wheat growing season.

	Burkburnett 2020
	——— 0.10 m^{-2} ———
Planting date	
Optimal[a]	194 a
Mid-	103 b
Late	13 c

[a] Optimal planting date represents optimal window for sowing. Mid occurred two to three weeks after first planting date and Late occurred two to three weeks after second planting date.

Table A.15. Seed dockage subsamples (per 150 g) at Burkburnett, TX during the 2019-20 winter wheat growing season.

	Burkburnett 2020					
	Wheat	*Rescuegrass*	*Downy brome*			*Cheat*
	per 150 g					
Planting date						
Optimal[a]	140.41 b					3.26 a
Mid-	137.79 b					1.37 b
Late	147.66 a					0.79 b
Herbicide						
Nontreated	136.62 b	2.41 a[c]				
pyroxsulam[b]	143.63 a	0.82 ab				
sulfosulfuron	145.60 a	0.14 b				
Planting date*herbicide			NT	P[b]	S	
Optimal			8.64 ab	0.85 c	0.43 c	
Mid-			12.52 a	3.81 bc	1.98 c	
Late			0.04 c	0.04 c	0.02 c	

[a] Optimal planting date represents the recommended window for sowing grain-only wheat in the region. Mid- occurred two to three weeks after the first planting date and late occurred two to three weeks after second planting date.

[b] Pyroxsulam (P) sprayed at a rate of 18.4 g ai ha^{-1} and sulfosulfuron (S) at 35.2 g ai ha^{-1} and nontreated (NT). All herbicide treatments were applied using water as the carrier and included a non-ionic surfactant at 0.25% vol/vol and a urea-ammonium nitrate at 30% vol/vol.

[c] Means within a column for each site year followed by a common letter were similar according to Fisher's protected LSD at $P < 0.05$.

VITA

Hannah Carol Lindell

Candidate for the Degree of

Master of Science

Thesis: INTERGRATED MANAGEMENT OF *BROMUS SPP*. IN GRAIN ONLY WINTER WHEAT PRODUCTION OF THE SOUTHERN GREAT PLAINS

Major Field: Plant and Soil Sciences

Biographical:

Education:

Completed the requirements for the Master of Science in Plant and Soil Science at Oklahoma State University, Stillwater, Oklahoma in December 2021.

Completed the requirements for the Bachelor of Science in Agricultural Food Systems at Washington State University, Pullman, Washington in May 2019.

Experience:

2019-2020 – Graduate Research Assistant – Oklahoma State University

2016-2019 – Laboratory, Greenhouse, and Field Assistant – Washington State University

2015-2016 – Undergraduate Research Internship – Washington State University

Professional Memberships:
Western Society of Weed Science
Weed Science Society of America
American Society of Agronomy
Crop Science Society of America