WINTER WHEAT VARIETAL TOLERANCE TO METRIBUZIN TANK-MIXED WITH PYROXASULFONE

By

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Bachelor of Science in Plant and Soil Science

Oklahoma State University

Stillwater, Oklahoma

2017

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 2021

WINTER WHEAT VARIETAL TOLERANCE TO METRIBUZIN TANK-MIXED WITH PYROXASULFONE

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ACKNOWLEDGEMENTS

While words do no justice, I want to thank my advisor Dr. Misha Manuchehri for her ever positive attitude and ceaseless support. I am so fortunate to have had such a patient, selfless, hardworking, and devoted professor that always encouraged me during this study. Thank you for your exemplary leadership, dedication to your students, and friendship.

Next, I would like to thank my committee members Dr. Brett Carver and Dr. Amanda de Oliveira Silva for all of their contributions. I truly appreciate your time, wisdom, and advice that made this project possible. I have been so blessed to be surrounded by such professional and outstanding people.

To my wife Mariah, thank you for all of the love and support you have given me during this process. Thank you for your understanding when I got home late from harvesting trials or had to go in early to spray fields. Your passion and dedication to your own profession has given me an example to reach for in mine.

I also want to thank everyone at the Weed Science Lab. While there have been many who have helped in so many ways, I want to thank my fellow graduate students Hannah Lindell, Tanner Childers, and Caitlyn Carnahan for always helping out when needed and allowing me to learn from them and their research. We have had some really great times and I truly appreciate all of you. Thank you to the student workers that have helped me way past operating hours to fill pots for greenhouse experiments, assist in planting trials in extremely cold conditions, and enter seemingly never-ending data. Blain

Ball, Ethan and Eric Moreau, Jarrett Selman, and Deacon Burleson are just a few that have helped in the completion of my project.

This project would not have been possible without the support of Oklahoma producers Jay and Cale Leeper who allowed us to use their field for a trial. Thank you to Oklahoma State University, the Oklahoma Agricultural Experiment Station, the Oklahoma Wheat Commission, and Oklahoma Genetics Inc. Bobby Weidenmaier, Cameron Murley, and Josh Massey were essential in this project and I cannot thank them enough for keeping an eye on my trials and all of their maintenance work.

Lastly, thank you to my parents Curtis and Jennifer Newlin whose encouragement made this achievement possible. I am so fortunate to have been raised by such supportive people that have always been there for me.

Name: LANE NEWLIN

Date of Degree: DECEMBER, 2021

Title of Study: WINTER WHEAT VARIETAL TOLERANCE TO METRIBUZIN TANK-MIXED WITH PYROXASULFONE

Major Field: PLANT AND SOIL SCIENCES

Abstract: Metribuzin is a herbicide that is widely used in cropping systems. However, its use in winter wheat in Oklahoma has declined due to varietal sensitivity or lack of information regarding the topic. To evaluate modern wheat varieties, a trial was conducted at Dacoma, Fort Cobb, Goodwell, and Perkins, Oklahoma during the 2019-2020 growing season and Fort Cobb, Goodwell, and Perkins during the 2020-2021 growing season. Varieties LCS Fusion AX, Showdown, Strad CL Plus, and Uncharted were evaluated. Treatments consisted of two herbicide tank mixtures (pyroxasulfone at 119 g ai ha^{-1} plus 105 (1X) or 210 (2X) g ai ha^{-1} of metribuzin) and a nontreated control. Mixtures were applied preemergence (PRE) or delayed preemergence (DPRE). Peak visual crop injury and crop yield were recorded. For peak visual injury, there was an application timing by metribuzin rate interaction at Fort Cobb and Perkins in 2020 and Fort Cobb and Goodwell in 2021 where the 1X rate of metribuzin applied DPRE resulted in similar or less damage than the same rate applied PRE. Meanwhile, the 2X rate always resulted in the greatest injury compared to the 1X rate and nontreated. In 2020, applying the 2X rate PRE resulted in the most crop injury at Perkins while Fort Cobb injury was similar for PRE and DPRE applications at the 2X rate. At Fort Cobb and Goodwell in 2021, the highest crop response was recorded following the 2X rate applied DPRE. For grain yield, a variety by rate interaction at in 2020 revealed that Showdown was the only variety with no yield reduction at 1X and 2X rates compared to the nontreated. For the same interaction at Fort Cobb, yield decreased for all varieties each time herbicide rate increased. A variety by application timing interaction was recorded at Dacoma in 2020 and at Fort Cobb in 2021. At Dacoma, yield was reduced for LCS Fusion AX at the DPRE timing compared to the PRE. At Fort Cobb, the same trend was observed for all four varieties. Results suggest that variety, soil type, application timing, metribuzin rate, and environment play an important role in crop response.

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CHAPTER I

LITERATURE REVIEW

Winter wheat (*Triticum aestivum* L.) is the most widely produced and consumed cereal grain in the world (Lukow and Mcvetty 2004). Winter wheat has been grown for hundreds of years in the United States and continues to be a crucial piece of our economy. Almost 75% of all U.S. grain products come from wheat flour (NAWG 2021). In Oklahoma, winter wheat is the top ranked crop grown with 1.72 million hectares planted and 2.8 million metric tons produced in 2020 (USDA NASS 2020). Much of the acreage planted is grazed during its vegetative stage and if it is grazed and harvested for grain, it is known as dual-purpose wheat, giving producers in the southern Great Plains two sources of income (Epplin et al. 2001). Because wheat has a relatively low input cost, it ties up less equity during the growing season than other crops and because it also can be used for dual-purpose, it often is grown continuously.

With any monoculture cropping system, pest management is a major challenge. In monoculture wheat, weeds adapt to the repetitive system and controlling them is economically vital as infestations can lead to yield reductions up to 50% (Kleeman and Gill 2008) or more. *Bromus* species (*spp.)*, feral rye (*Secale cereale*), Italian ryegrass [*Lolium perenne* L. *ssp. multiflorum (Lam) Husnot*], jointed goatgrass (*Aegilops cylindrica* Host.), and wild oat (*Avena fatua* L.) are among the 10 most common and troublesome weeds for wheat producers to manage in the southern Great Plains (Fast et al. 2009). In 1998, a survey was conducted in Oklahoma over three major wheat-producing counties including Alfalfa, Kingfisher, and Garfield. The survey concluded that between 70% and 89% of fields within these counties had *Bromus spp.* infestations to some degree (Barnes et al. 1999). Runyan et al. (1982) also found that *Bromus spp.* are present in approximately 1.4 million hectares of wheat in Oklahoma.

In response to an ever-growing human population and pests edging at yields and quality annually, wheat breeding programs are constantly developing varieties that will best fit our systems. In Oklahoma, public varieties dominate the acreage. For example, during this past 2020-21 season, the top four planted wheat varieties were developed by Oklahoma State University's Wheat Improvement Team (USDA 2021). New wheat varieties are not only bred for increased yield and disease resistance. Other factors might include end-use quality, insect resistance, drought hardiness, and tolerance to low soil pH. However, one response that is sometimes overlooked is variety response to conventional herbicides. Therefore, some varieties exhibit increased injury compared to others when exposed to certain herbicides (Villarroya et al. 2000). Although variety tolerance information is sometimes revealed on a herbicide label, this information is rarely updated, especially when a product is off-patent. This can cause confusion among applicators and may make them less likely to spray a particular product if they are unsure of how the variety will respond.

In 2017, a survey revealed that 36% of Oklahoma farmland acres were in a no-tillage (no-till) system (LaRose and Myers 2019). With the absence of physical/mechanical tools, no-till producers must rely on cultural and chemical control options to combat weed issues. While there are herbicide options available for controlling grass weed species in winter wheat, limitations exist. Pinoxaden, for example, is a POST herbicide option for controlling common troublesome weed species such as wild oat and Italian ryegrass but is only labeled to suppress other common weeds like *Bromus spp.* (Anonymous 2014). Some labeled herbicide options that do provide control of *Bromus spp.* include pyroxsulam, sulfosulfuron, and propoxycarbazone. These active ingredients all belong to the acetolactate synthase (ALS) group of herbicides (WSSA group number 2) and have been continuously used in herbicide rotations causing weed biotypes to become resistant and their usage less effective over time (Tranel and Wright 2017).

To confront troublesome weed issues in crop, herbicide tolerant winter wheat varieties have been developed through selective breeding that allow for the use of herbicides in-season that would normally severely damage the wheat crop. The two herbicide tolerant systems include Clearfield® and CoAXium® and have helped with weed pressure, but they can be expensive and have their limitations. The Clearfield® production system utilizes the active ingredient imazamox, another WSSA group 2 ALS inhibitor herbicide, for PRE and POST control/suppression of several broadleaf and grass weed species (Anonymous 2017a). The CoAXium® system uses the active ingredient quizalofop-P-ethyl (quizalofop), an acetyl Coenzyme A carboxylase (ACCase) inhibiting herbicide (WSSA group number 1), for POST control of many, susceptible grass weed species. While the systems can be valuable tools, stewardship must be demonstrated by the applicator to ensure that resistant weed biotypes are not selected for. Unfortunately, in the case of these two technologies, resistant biotypes of target weed species already exist (Heap 2021a, 2021b).

The ALS group of herbicides has more cases of resistance than any other herbicide group (Tranel and Wright 2017). Documented cases of imazamox resistance have been reported in the U.S. and even more alarming are the cases already in Oklahoma and bordering states. Resistance has been confirmed in true cheat (*Bromus secalinus* L.*)* (Kansas and Oklahoma), downy brome (*Bromus tectorum* L.), Japanese brome (*Bromus japonicas* L.) (Kansas), and other annual grass weed species such as Italian ryegrass in Arkansas and Oklahoma, and feral rye found in Colorado in 2018 (Heap 2020a, 2021c). Weeds resistant to ACCase herbicides in the U.S. consists of wild oat (clodinafop-propargyl, diclofop-methyl, fenoxaprop-ethyl, quizalofop, sethoxydim, and pinoxaden), downy brome (clethodim, fluaxifop-butyl, quizalofop, and sethoxydim), and Italian ryegrass (cyhalofop-butyl, clodinafop-propargyl, diclofop-methyl, fenozaprop-ethyl, fluaxifop-butyl, quizalofop, pinoxaden, and sethoxydim) along with other monocot species that are problematic in other cropping systems (Heap 2021b). In some instances, downy brome and Italian ryegrass biotypes are cross resistant to other sites of action such as ALS herbicides in addition to ACCase herbicide chemistries (Heap 2021b).

Grass weed species such as those listed above will continue to persist in Oklahoma monoculture winter wheat systems as the remaining effective herbicides are continuously used. Repeated use of one herbicide active ingredient or herbicide site of action increases the likelihood of selection for herbicide resistant weed biotypes (Vencill et al. 2017). The weeds that can survive applications are singled out, available to pass their genetic information on more readily through reproduction. While it is no small task, weed managers must strive to integrate management strategies in order to decrease the application of similar herbicides, selecting for resistance. Tank-mixing multiple herbicide sites of action that are effective on a target weed species is one strategy to delay resistance but should still be used with other practices. A common waterhemp (*Amaranthus tuberculatus*) glyphosate resistance study in 2004-2005 explained that tank-mixing glyphosate with a herbicide mean complexity of 2.5 modes of action per application resulted in a field being 83 times less likely to produce glyphosate resistant common waterhemp seeds 4-6 years later as opposed to a field with only 1.5 modes of action (Evans et al. 2015). Diggle et al. (2003) mentioned that herbicides essentially enhance selectivity in weed populations and where herbicide genetic variability exists, resistance can consequently result rapidly.

Combining cultural practices such as crop rotation, planting date, decreased row spacing, and varietal competitiveness with mechanical and/or chemical practices is the best strategy to manage weeds in the long-term. However, limited, effective chemical options exist due to the development of herbicide resistance. Until now, it had been nearly four decades since a new herbicide site of action was released. Therefore, looking back to past herbicide chemistries and how they might fit into current systems is one strategy to prolong the future of Oklahoma wheat systems.

From a study on net returns from true cheat control in wheat in Oklahoma, one location exhibited an increase in net returns was not simply acquired by solely decreasing row spacing unless chemical options like chlorsulfuron plus metsulfuron or metribuzin were added into the practice (Justice et al. 1993). Others also documented that metribuzin was an effective herbicide for *Bromus spp.* management, providing between 80 to 100% control; however, severe crop injury is a concern (Appleby and Morrow 1990; Peeper and

Morrow 1990). Shaw and Wesley (1991) found wheat response to metribuzin higher when applied PRE as opposed to a later wheat growth stage with injury as high 90% at 413 g ai ha^{-1}, resulting in yield reduction, but providing more than 80% control of Italian ryegrass. Griffin (1985) also recorded excellent control of Italian ryegrass, up to 95% when applying early POST; however, when delaying application to fully tillered wheat resulted in decreased, inadequate Italian ryegrass efficacy .

Metribuzin made its debut in Germany by Bayer in 1970 for control of certain broadleaf weeds and grasses in potatoes. Only three years after its debut, metribuzin was labeled in the United States. It soon found its place in other crops such as soybean, wheat, corn, and a variety of vegetable crops. Since then, it has been used to manage certain grasses and broadleaf weeds in cereals, soybean, potatoes, forages, field corn, pulse crops, and some vegetables. Metribuzin is a selective triazinone herbicide (WSSA group number 5) that works by interfering with the photosystem II electron transport chain complex in the chloroplast (Heri et al. 2008). Metribuzin is primarily absorbed through the roots of susceptible plants but also can have some control coming from foliage contact (Buman et al. 1992). After a brief initial period of rapid adsorption from saturation of root zone, metribuzin movement through the plant has been found to be directly proportional to a plant's transpiration rate (Buman et al. 1992).

In winter wheat, metribuzin can be applied POST, beginning at the two-leaf stage, to manage many broadleaf and grass weed species (Blackshaw 1990; Grey and Bridges 2003; Shaw and Wesley 1991). Metribuzin used at the rates labelled in wheat also suppress little barley, annual bluegrass, several *Bromus spp.*, wild oat, and rescuegrass (Anonymous 2004). Metribuzin also can be tank-mixed with pyroxasulfone [and once was recommended on the Zidua DF label (Anonymous 2017b) at the early POST timing. Because certain winter wheat varieties are more tolerant to metribuzin than others, using this herbicide on a variety that is less tolerant can result in severe crop injury (Blackshaw 1993; Retzinger and Richard 1983; Shaw and Wesley 1991). Unfortunately, most of the information available on susceptibility and tolerance is for varieties that we no longer use (Blackshaw 1993; Runyan et al. 1982; Wicks et al. 1987).

While metribuzin has been used for close to fifty years, there is still much to learn about this triazinone herbicide. From the research that has been conducted, it appears that metribuzin tolerance comes from a range of factors depending on the specific crop being examined. Varietal sensitivity has appeared in dicot crops such as soybean (*Glycine max* L.), potato (*Solanum tuberosum* L.), and tomatoes (*Lycopersicon esculentum* L). A study was performed to evaluate metribuzin tolerance on wild soybean (*Glycine soja* Siebold & Zucc.) and commercially planted soybean. Soybean varieties were crossed and tolerance to metribuzin was determined to come from a single dominate gene that is probably the same for both species (Kilen and He 1992). Dejong (1983) found that sensitivity to metribuzin in cultivated diploid potatoes came from a single recessive gene. Metribuzin tolerance in cereal crops such as barley and winter wheat is more complicated than in the previously mentioned field crops. Sensitivity in winter wheat has been linked to cytoplasmic and nuclear genes (Ratliff et al. 1991) as well as differential metabolism entailing conjugate formation (Runyan et al. 1982).

In contrast to dicot field crops mentioned above where genes predominantly control plant sensitivity, resistance in many weed species is closer associated with chloroplast alterations rendering the binding site less effective for triazine herbicides

(Darr et al. 1981). For example, in a study by Darr et al. (1981), weed species *Brassica campestris* L. resistance is accredited to chloroplast thylakoid alterations causing a decrease in herbicide activity at the triazine-binding site in the photosystem II complex. Varietal tolerance in cereal crops such as barley (*hordeum vulgare* L.), durum wheat (*T. turgidum* L.), and winter wheat also has been examined. A study on metribuzin varietal tolerance in barley concluded that a higher rate of metabolism to metribuzin is thought to be a primary factor behind tolerant varieties (Gawronski et al. 1986) while durum wheat tolerance was dependent on many genes or quantitative traits (Villarroya et al. 2000). While there is still much work to be performed on crop sensitivity to metribuzin, we know that certain winter wheat varieties are available that possess a higher tolerance to metribuzin and they should be determined and utilized.

Metribuzin has been a prominently used herbicide for many years and continues to be used because of its proven track record; however, there are a number of factors other than varietal tolerance that should be considered when using metribuzin that can make it less effective. Control of weeds can be inconsistent stemming from soil characteristics like soil pH, texture, moisture, and organic matter (Ladlie et al. 1976). The half-life of metribuzin is correlated to multiple factors such as organic matter, soil type and temperature, and soil pH (Peter and Weber 1985). Increases in soil pH and temperature has been linked to a decrease in metribuzin half-life. Soils containing a higher percentage of organic matter delay the half-life decay as opposed to soils with less organic matter (Peter and Weber 1985). Metribuzin has a high affinity for soil organic matter but is not as tightly adsorbed to clay particles (Shaner 2014). As soil pH increases, adsorption appears to decrease while mobility increases within the soil (Shaner 2014).

Apart from its weed control efficacy, tolerance of the wheat crop under the influence of this herbicide is equally important for maximum crop production (Kleeman and Gill 2008). Better understanding of metribuzin's tolerance in wheat would be advantageous in the context of improving weed management. Through more research, the alleles that make tolerant varieties less susceptible to metribuzin could be flagged and introgressed into modern high yielding and desirable varieties, providing another option for weed control through metribuzin (Bhoite et al. 2018). Additionally, because metribuzin is primarily adsorbed through plant roots, it requires incorporation soon after application through movement into the soil profile. On the other hand, too much rain can saturate the soil and wash the herbicide out of the desired root zone or if the soil is already saturated, not allow the herbicide to move into the targeted root zone (Ratliff and Peeper 1987**).** Finally, cold weather can increase phytotoxicity as metabolism is slowed (Retzinger and Richard 1983).

While we still have options to aid in controlling grass weed infestations in Oklahoma wheat production systems, our herbicide choices are limited and will only continue to decline without implementing better crop stewardship practices like long-term rotation of crops and herbicides. Producers must look to cultural, mechanical, and vintage herbicide chemistries to maintain control of their fields. Through evaluating metribuzin tolerance of newly released, popular varieties in the Oklahoma area, wheat producers may regain a viable option for controlling grass weed species. The information gained from these varieties will impact how producers utilize them, how long they remain commonly planted, as well as steer future varietal releases if high tolerance is indicated.

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CHAPTER II

WINTER WHEAT VARIETAL TOLERANCE TO METRIBUZIN TANK-MIXED WITH PYROXASULFONE

Introduction

The most popularly grown agricultural commodity in Oklahoma is winter wheat with approximately 1,720,000 hectares planted in 2020. To further elaborate, the combined planted acreage of cotton, corn, soybean and grain sorghum in Oklahoma for the same year totaled less than half of wheat at 708,000 hectares (NASS USDA 2020a). Winter wheat is favorable to producers in Oklahoma because it is well-adapted, generally has less input costs than other crops, and is capable of multiple functionalities like grazing, haying, and grain harvest that can be capitalized on depending on other commodity prices and producer specific needs annually.

Because winter wheat is produced on such a large portion of Oklahoma land year after year, grassy weed species have become prevalent in many fields and control has become difficult. In 1982, Runyan et al. did a survey on weed species contained in Oklahoma wheat production systems and found a staggering 1.4 million hectares contained *Bromus species (spp.)*. Lack of cultural control methods like crop rotation combined with limited herbicide options being heavily relied upon has led to the development of resistant weed species such as true cheat (*Bromus secalinus* L.*)* and Italian ryegrass [*Lolium perenne* L. *ssp. multiflorum (Lam) Husnot*] (Heap 2020a). While this is concerning, habitual winter wheat production continues for a vast majority of Oklahoma with no change in sight as herbicide tolerant wheat productions systems continue to be adopted. Clearfield® and CoAXium® wheat production systems have continued to increase in popularity as they allow producers to stay in wheat production and control or suppress grassy weed species by spraying in season with minimal crop injury and adequate weed efficacy. Between the 2020 and 2021 wheat seasons, a Clearfield® production wheat variety, Doublestop CL Plus, ranked in the top three for percentage of seeded hectares for Oklahoma (NASS USDA 2020c). In 2019, the active ingredient used in Clearfield® wheat production systems, imazamox was applied on a majority of Clearfield® wheat production in Oklahoma (NASS USDA 2020a). CoAxium® wheat production in Oklahoma is also on the rise. In 2018, 3,300 hectares were in production increasing the following two years to 30,800 and 70,800, respectively (C Shelton, personal communication).

While producers are utilizing a weed control option at their disposal, they can also expect a decrease in efficacy in future years as resistant weed biotypes escalate due to selection pressure and expansion into other cropping systems. For example, herbicide tolerant sorghum systems igrowth® and Double Team™, are currently being developed that also utilize imazamox and quizalofop, respectively. Herbicide resistant weed species already exist in the region and some have for more than 10 years. In 2009, true cheat was documented to be cross resistant to (acetolactate synthase) ALS herbicides in Oklahoma (Heap 2020a, 2021b) and although not formally recorded, most Italian ryegrass species are cross resistant to ACCase herbicides (WSSA group number 1). With this information at hand, other options should be considered if producers will not gravitate towards cultural control methods.

As new herbicide sites of action have been sparse in the past 40 years, looking even further back may present a reasonable pursuit to evaluate a herbicide that has declined in use since its release. Metribuzin, developed by Bayer Crop Science in the early 70's, was once commonly used in wheat soon after its launch and around 1980, it was the herbicide of choice in North America to control downy brome in wheat production systems (Gigax 1979; Peeper 1984). The original herbicide label contained a list of tolerant and susceptible wheat varieties to metribuzin (Anonymous 2004a). Over time, as new varieties were released and the label varieties fell to the way side, metribuzin use in wheat dwindled as the label was not updated and producers feared spraying the wrong variety and risking crop injury. While its use in winter wheat has receded, it can still be found as an active ingredient combined with flufenacet (WSSA group number 15) in the winter wheat herbicide product Axiom® (Anonymous 2014b). However, due to tolerance issues sometimes observed, most producers in the region apply pyroxasulfone, another WSSA group number 15 herbicide, instead of flufenacet + metribuzin because the risk for crop injury is less. Kumar et al. (2017) observed no wheat injury from applying pyroxasulfone PRE at 89 to 178 g ai ha^{-1} (2017). If current tolerant varieties were identified, metribuzin and flufenacet + metribuzin could again be a management option for wheat producers that do not want to immediately rotate crops and its use could prolong other heavily relied upon wheat herbicides and systems.

The objectives of this research were to evaluate the response of four commercially available winter wheat varieties released between 2018 and 2020 to two rates of metribuzin (105 g ai ha^{-1} and 210 g ai ha^{-1}) at two separate application timings (PRE and DPRE). Trials were conducted at Dacoma, Fort Cobb, Goodwell and Perkins, Oklahoma to examine environmental factors such as temperature, rainfall, soil texture, pH, and other conditions that might impact metribuzin activity, including wheat response. By identifying a tolerant variety or varieties, future wheat breeding lines could focus on metribuzin tolerance and provide producers with the option to spray metribuzin to control grassy weed species in winter wheat.

Materials and Methods

Field experiments were conducted in Dacoma (36.70ºN, -098.56ºW, elevation of 423 m), Fort Cobb (35.14ºN, -098.46ºW, elevation of 421 m), Goodwell (36.59ºN, -101.61ºW, elevation of 996 m), and Perkins (35.99ºN, -097.04ºW, elevation of 279 m), Oklahoma during the 2020 season and again at Fort Cobb, Goodwell, and Perkins for the 2021 season. Each field site was monitored from planting (October or November) to harvest (May or June). All agronomic practices and data collection dates are described in Table 2.1. Field seasons will be referred to as the year harvest took place in.

The Dacoma site was on a 0 to 1 percent slope and made up of a Grant silt loam (Fine-silty, mixed, superactive, thermic Udic Argiustolls) with a 1 to 3 percent slope. Goodwell was on a Gruver clay loam (Fine, mixed, superactive, mesic Aridic Paleustolls) with a 0 to 1 percent slope. Fort Cobb was on a Binger fine sandy loam (Fine-loamy, mixed, active, thermic Udic Rhodustalfs) with a 1 to 3 percent slope, and Perkins was on a Teller fine sandy loam (Fine-loamy, mixed, active, thermic Udic Argiustolls) with a 1 to 3 percent slope. A pH of 5.3 was obtained from Dacoma soil test results before planting for the 2020 growing season. Fort Cobb soil test results revealed a pH of 7.0 for the 2020 growing season and 7.5 for the 2021 growing season. For the 2020 growing season at Goodwell, a pH of 7.6 was recorded and 7.5 for 2021. Perkins had pH levels of 6.2 and 6.1 for the 2020 and 2021 growing seasons, respectively.

Irrigation capabilities were available at all trial sites except for Dacoma. For the 2020 growing season, rainfall at Alva, Oklahoma (closest mesonet station to Dacoma) totaled 31.85 cm. Fort Cobb received 40.64 cm with the addition of 4.43 cm of irrigation during the season (45.07 cm total). Goodwell rainfall amounted to 19.91 cm with the addition of 10.16 cm via irrigation totaling 30.07 cm and Perkins received 53.90 cm of rainfall.

Precipitation totals for the 2021 growing season entailed 31.78 cm of rainfall at Fort Cobb accompanied with 4.32 cm of irrigation (36.10 cm total). Goodwell received 27.91 cm of rainfall and 15.24 cm of irrigation totaling 43.15 cm. Perkins amounted to 61.82 cm of precipitation with 60.55 cm coming from rainfall and 1.27 cm came from irrigation.

All sites were conventionally tilled with a disk plow periodically through the fallow season and field cultivated prior to planting except for Dacoma, which was in a no-till system. Some sites received a burndown application of glyphosate after the previous harvest in efforts to keep weed populations under control. Each site was left fallow the summer before planting with the exception of Fort Cobb, which was planted to peanuts during the summer of 2019 and 2020. The peanut crop was harvested and the soil worked with a disk plow and field cultivator before the trial was established. For the 2021 field season, Fort Cobb, Goodwell, and Perkins were planted December 2, October 8, and October 14 respectively. The planting date at Fort Cobb was delayed due to a late peanut harvest and undesirable planting conditions. Field experiments were planted with a Great Plains Drill model number 3P605NT (Great Plains Ag, 1525 E. North Street, Salina, KS 67401) with 19 cm row spacing equipped with a seven row Kincaid cone-planter. Seeding rate per trial plot was 67 kg ha^{-1}.

Each trial was arranged in a randomized complete block design with four replications. Between the 2020 and 2021 seasons, plot lengths varied between 9.14 m, 10.67 m, and 12.19 m.

Plot width was constant during both years at 1.33 m. Treatments were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} with water as the sole carrier. Treatments were applied at one of two timings, PRE or delayed PRE. Preemergence treatments were applied within 24 hours after planting. Delayed PRE treatments were typically applied within 10 to 14 days after planting once 80% of germinated wheat seeds had shoots at least 12.7 mm long until wheat spiking. In some instances, delayed PRE treatments were prolonged due to soil moisture, rain forecast, or cold temperatures hindering wheat growth. Four wheat varieties were tested in the trial for their tolerance to metribuzin tank-mixed with pyroxasulfone at different application timings and rates. Varieties included: LCS Fusion AX, Showdown, Strad CL Plus, and Uncharted. Herbicide treatments consisted of metribuzin (Metribuzin 75®DF, Loveland Products INC, P.O. Box 1286, Greeley, Colorado 80634-1286) at 105 or 210 g ai ha^{-1} tank-mixed with pyroxasulfone (Zidua® SC, BASF Corporation, 26 Davis Drive, Research Triangle Park, North Carolina 27709) at 119 g ai ha^{-1}. Treatments were incorporated into the soil profile by rainfall or irrigation. A soil sample was collected prior to planting and fertility requirements were applied preplant and in-season following local, OSU recommendations (de Oliveira Silva et al. 2020). A fungicide was applied in the spring at each location with application date varying based on disease pressure (Hunger 2019).

Wheat visual injury was recorded approximately every two weeks once injury symptoms started to occur until the trials were harvested. Visual injury was assessed on a scale of 0 to 100 percent for all treatments, with 0 being no visual injury in comparison to the nontreated and 100 percent being a completely dead plot containing no actively growing wheat. Biomass from one meter of row was collected at Perkins and Fort Cobb during the 2020 and 2021 growing seasons.

Biomass samples were collected at three separate timings including peak injury, spring green-up to jointing (Feekes 4 to Feekes 6), and at physiological maturity (Feekes 11.4). All samples apart from harvest biomass samples were dried in an oven at 49°C for 7 days and dry weight was recorded. After dry weights were recorded for harvest biomass samples, number of heads per sample were recorded and samples were threshed with an Almaco plant and head thresher, model number SVSE-2 (Allan Machine Inc., 99 M Avenue Nevada, IA 50201) to determine seed weight per sample. Harvest index per plot was determined from dividing sample seed weight by sample biomass weight. Finally, wheat was harvested with a Wintersteiger, model Classic, small plot combine (Wintersteiger Inc, 4709 Amelia Earhart Dr, Salt Lake City, UT 84116). Grain collected from trials were ran through a Ross-Ferrell seed cleaner, model Clipper M-2B (Ferrell-Ross Roll Manufacturing, Inc, 3690 FM 2856, Herford, TX 79045) if needed. A moisture and test weight sample was recorded for each plot using a DICKEY-john moisture tester model mini GAC® plus (DICKEY-john, 5200 Dickey John Road, Auburn, IL 62615).

All data collected was analyzed in SAS 9.4 (Version 9.4, SAS Institute Inc., SAS Campus Drive, NC) using PROC MIXED. Means were separated at an α level of 0.05. Due to location by treatment interactions at multiple sites, locations were analyzed separately and never combined in aim to provide a clear and concise illustration of metribuzin effects on winter wheat varieties at locations with specific environmental and soil characteristics.

Results and Discussion

Peak Visual Crop Injury

Peak visual crop injury during the 2020 season occurred between eight and nine weeks after applying the delayed PRE at each site. The 2021 growing season featured a delay in peak visual injury, primarily at Fort Cobb and Perkins, where peak injury occurred between 14 and 15 weeks after the delayed PRE application likely due to cold temperatures and quantity and timeliness of rainfall, which decreased plant metabolism (Table 2.3). Goodwell reached peak injury at six weeks after application. A variety by metribuzin rate interaction took place at Perkins during the 2020 season and at Fort Cobb during the 2021 growing season (Table 2.4). The interaction at Perkins indicated that there was no difference in variety response at the low rate of 105 g ai ha^{-1}, but varietal sensitivity was displayed at the high rate of 210 g ai ha^{-1} where varieties LCS Fusion AX and Uncharted exhibited 68 and 61% visual injury, respectively. Varieties Showdown and Strad CL Plus exhibited similar but approximately 28% less injury than LCS Fusion AX and Uncharted. Finally, similar injury was documented for Showdown regardless of metribuzin rate while LCS Fusion AX, Strad CL Plus, and Uncharted experienced increased injury at the 2X rate of metribuzin compared to the 1X rate. Conversely, at Fort Cobb in 2021, injury increased by at least two times for all four varieties from the 1X to 2X rate of metribuzin.

A variety by application timing interaction occurred at Goodwell during the 2021 growing season. At the PRE timing, all varieties displayed 5% or less visual injury. Both LCS Fusion AX and Uncharted exhibited increased visual injury levels as application timing changed from PRE to DPRE while Showdown and Strad CL Plus indicated no difference in visual injury between either application timing. A variety effect was observed for peak visual injury at Fort Cobb and Dacoma during the 2020 growing season and Goodwell during the 2021 growing season (Table 2.4). At each site year, LCS Fusion AX exhibited the highest level of crop damage, but injury was not different than Uncharted at Fort Cobb 2020 or Showdown at Goodwell 2021. At Fort Cobb, similar peak visual injury was observed for LCS Fusion AX and

Uncharted (~40%) while injury was less but similar for varieties Showdown and Strad CL Plus (~32%). At Dacoma 2020 and Goodwell 2021, injury never exceeded 16%.

A rate by application timing interaction was present for Fort Cobb and Perkins during the 2020 growing season and for Fort Cobb and Goodwell during the 2021 growing season (Table 2.5). At Fort Cobb, visual injury was similar (~28%) at the low rate regardless of application timing while injury decreased from 56% to 31% for PRE and DPRE applications at the high rate, respectively. At Perkins, similar wheat injury (~56%) was observed at the high rate, regardless of application timing. However, application timing was crucial at the low rate where 12% less injury occurred following the DPRE timing compared to the PRE timing. For the 2021 growing season, the highest level of damage (88%) was recorded at Fort Cobb following the 2X rate of metribuzin at the DPRE timing. At the same location and rate, injury was reduced to 42% following the PRE timing. At the low rate, injury at Goodwell followed a similar trend to Fort Cobb 2020 where injury was similar following the low rate of metribuzin regardless of application timing. Conversely, at the high rate, injury increased over three times from the PRE to DPRE timing. Finally, a rate effect was noted at Dacoma for the 2020 growing season and at Perkins for the 2021 growing season where injury doubled at Perkins from the low to high rate. At Dacoma, injury also was greatest at the high rate (15%) but was similar and only 2% less following the low rate.

Between both the 2020 and 2021 growing seasons, Perkins and Fort Cobb experienced more crop injury than Goodwell and Dacoma. A more coarse soil texture at Perkins and Fort Cobb compared to Goodwell and Dacoma is likely the reason for this pattern, hence the reason why the recommended rate of metribuzin shifts with soil texture and organic matter (Anonymous 2004). Perkins and Fort Cobb were planted on fine sandy loam soil types while Goodwell and

Dacoma soil types were a clay loam and a silt loam, respectively. Blackshaw's (1993) findings support this claim as they observed increased injury when metribuzin was applied on a sandy clay loam as opposed to a clay loam soil texture. A higher cation exchange capacity in loam soil types at Goodwell and Dacoma likely resulted in more herbicide adsorption to soil colloids leaving less availability for plant uptake than the sandy soil texture at Perkins and Fort Cobb (Ladlie et al. 1976). When evaluating response differences at sites, pH should also be considered in combination with soil texture as metribuzin persists longer in acidic conditions and plant adsorption of metribuzin increases as soil pH decreases (Ladlie et al. 1976; Shaner 2014). Fort Cobb and Perkins had lower pH values (pH of 7.0-7.5 and 6.1-6.2, respectively) than Goodwell (pH of 7.5-7.6) while Dacoma had a pH of 5.3.

Dacoma was the only location that did not have irrigation capabilities, leaving incorporation up to timely rainfall where 14 mm of rain did fall three days after the PRE application, and 10 mm in the days after the DPRE application (Table 2.2). Per both herbicide labels, 12.7 mm of moisture is needed to properly incorporate the herbicides into the soil profile (Anonymous 2004, Anonymous 2017). Moisture received the following days after applications also likely played a role in crop response. When examining the rate by application timing interaction for Fort Cobb and Perkins during the 2020 season and for Fort Cobb and Goodwell during the 2021 season, dissecting locations by growing season may help to explain the data. For the 2020 season, there was no difference or a decrease in crop response following the DPRE application compared to the same rate applied PRE, but never an increase. Contrarily, for the 2021 growing season, crop response following the PRE application timing was not different or less when compared to the DPRE application. In season conditions around date of application like timely rainfall or irrigation, amount of rainfall, and temperature are most likely linked to the outcome of the interaction. For the 2020 growing season, Fort Cobb received only 8.6 mm of rainfall three days after the PRE application and another 7.1 mm 16 days after the PRE. The DPRE application received 21 mm in the following eight days after application. Perkins received 77.4 mm of rainfall in the 9 days between the PRE and DPRE application and received 61.1 mm of rainfall in the 10 days following the DPRE application. Less wheat response from the DPRE application for both locations may have been a result of a more mature wheat crop at application as younger plants are more sensitive to metribuzin and should be applied to at a lower concentration (Anonymous 2004b). However, it is interesting that wheat response was similar following the PRE application timing at Perkins as 138.5 mm of rain fell in the following 19 days after application and this could have potentially washed the herbicide out of the soil profile and reduced soil concentrations. VanGessel et al. (2017) looked at metribuzin application timing with the same rates of metribuzin in this study at 2-leaf, early spring, and late spring applications and noted reduced injury at the 2-leaf stage compared to the early spring where large rainfall events soon after application washed metribuzin into the lower soil profile

For the 2021 growing season, Fort Cobb and Perkins received ample rainfall or irrigation to incorporate the herbicides into the soil profile in a timely manner after applications were made (Table 2.3). Fort Cobb however was planted very late this season (December 2) and conditions were less than desirable after planting with air and soil temperature (five cm under bare soil) averaging 3.9 and 5°C, respectively, the seven days following (Table 2.1). This likely delayed emergence and slowed growth abating the ability of the wheat to metabolize the metribuzin effectively, causing an increase in crop response. Temperatures for this season were more extreme than most in Oklahoma and the DPRE timing was sprayed just seven weeks before a major winter ice storm brought average temperatures of -17°C for several days. This event likely occurred before wheat treated at the DPRE timing was able to fully metabolize the metribuzin, resulting in increased response. The injury likely did not result from pyroxasulfone as Grey and Newsom (2017) found no response to rate or yield compared to the nontreated control when applied at 120 g ai ha^{-1} and Kumar et al. (2017) also observed no wheat injury following a PRE application at 89 to 178 g ai ha^{-1} of pyroxasulfone. The interaction at Goodwell indicated an increase in crop response when delaying application timing at the 2X rate, but only resulted in a 12% increase and this was most likely due to lower temperatures in days following application as the average temperature in the 10 days following the DPRE application was 4.4°C compared to 15.8°C that followed the PRE.

Harvest Biomass

Final biomass was collected within 24 hours prior to harvest at Fort Cobb and Perkins during both seasons. A metribuzin rate effect was present for both locations during the 2020 season and Perkins during the 2021 season. A rate by application timing interaction was also indicated at Fort Cobb 2021 and an application timing effect for Perkins 2021 (Table 2.6). The rate effect for Fort Cobb and Perkins 2020 was similar where the low rate of metribuzin produced comparable amounts of biomass to the nontreated as well as the high rate, while the high rate did result in a decrease of biomass production when compared to the nontreated. A slightly different story took place at Perkins 2021 where with the 1X and 2X rates produced similar amounts of biomass (267 and 235 g, respectively), but less than the nontreated control (283 g). A rate by application timing interaction at Fort Cobb during the 2021 growing season demonstrated that as rate increased within a specific application timing, biomass production decreased. Applying metribuzin at the low rate DPRE was comparable to the low and high rate applied PRE. However, at 205 g ai ha^{-1} of metribuzin applied DPRE, the least amount of biomass was produced with greater than a fourfold decrease compared to the nontreated control. Lastly, an application timing effect for Perkins 2021 resulted in a greater reduction in biomass when applying DPRE instead of PRE.

While no variety by treatment interactions were significant when investigating harvest biomass, metribuzin rate, application timing, and a combination of the two were important. At Fort Cobb in 2021, there was a decrease in biomass production at the PRE timing compared to DPRE, this is not consistent with Shaw and Wesley's (1991) findings where wheat response to metribuzin was higher when applied PRE as opposed to a later wheat growth stage. However, it should be noted that Shaw and Wesley had a larger gap in application timings (PRE to fully tillered) than this experiment [PRE and DPRE (26 days)]. Another factor that could have influenced biomass production for application timing is rainfall amount and timeliness. In the 10 days following the PRE application, only 1.9 mm of rainfall was recorded with 10.7 mm coming on the eleventh day after application (Table 2.3). For DPRE, 49.6 mm of rainfall fell in the following 10 days with 49.3 mm coming in the five days following application. Concentration of rainfall events and proximity to application date likely affected herbicide availability in the upper soil profile and for plant uptake. Crop response may have increased if rainfall happened to wash metribuzin concentrations very near wheat seedlings. Shaw and Wesley (1991) also looked at metribuzin on course textured soils and experienced increased injury with 55 mm of rainfall coming within two weeks after application leading them to hypothesize an increase in seedling absorption of metribuzin leading to greater injury.

Grain Yield

Perkins 2020 and Fort Cobb 2021 growing seasons produced a variety by metribuzin rate interaction for wheat grain yield (Table 2.7). For Perkins, Strad CL Plus was the only variety where a yield decrease occurred when rate increased from nontreated to 1X, and again from 1X to 2X rate. Yield for LCS Fusion AX and Uncharted varieties decreased when the high rate of metribuzin was applied compared to the nontreated controls. Showdown was the only variety that maintained yield from the nontreated control to high rate of metribuzin. Findings from a field trial of 10 varieties including TAM 101, deemed tolerant, observed nine of the 10 varieties indicated a yield reduction to 600 g ha^{-1} of metribuzin with TAM 101 exhibiting no yield reduction at that rate and only a reduction at 1,100 g ha^{-1} rate (Runyan et al. 1982). While rates of metribuzin used in the Runyan et al. experiment were applied in the spring and thus higher, response from varieties is still relatable in this study. The variety by rate interaction at Fort Cobb followed a different trend. All varieties exhibited a reduction in yield as metribuzin rate increased. The 2X rate yielded less than the nontreated and 1X rate for each respective variety. Yield for all varieties was similar at the low rate of metribuzin with the exception of LCS Fusion AX, which yielded lower than the other varieties. At the high rate of metribuzin, varieties again yielded similar excluding Strad CL Plus, which yielded significantly higher.

A variety by application timing interaction occurred at Fort Cobb 2021 and Dacoma 2020. For all varieties, metribuzin PRE resulted in higher yields than applying DPRE. Investigation of this interaction also indicates that while each variety experienced a yield decrease as application date was delayed, LCS Fusion AX was the only variety that consistently produced the lowest yields at both application timings. This may have been due to rainfall timeliness and temperatures following applications as 1.9 mm of rainfall was recorded the 10 days following the PRE application, with 10.7 mm coming on the eleventh day after application (Table 2.3). For the DPRE timing, 49.6 mm of rain fell in the following 10 days with 49.3 mm coming in the five days following application. Colder temperatures were also recorded for a 10 day average following the DPRE application (4.4°C) compared to PRE (15.8°C). Contrary to Fort Cobb, at Dacoma 2020, the variety by application timing interaction resulted in no yield differences in application timing for all varieties except for LCS Fusion AX where applying PRE decreased yield compared to the DPRE timing.

A metribuzin rate by application timing interaction was also noted at Fort Cobb during the 2020 growing season and Fort Cobb, Perkins, and Goodwell during the 2021 growing season (Table 2.8). For Fort Cobb 2020, the low rate of metribuzin at either application window and the high rate of metribuzin at the DPRE timing were not different than yield following the nontreated controls. Applying metribuzin at the PRE timing decreased yield from the nontreated to low rate and low rate to high rate while yield was similar at the DPRE timing regardless of herbicide rate. The same interaction was present at Fort Cobb 2021 where for each timing, yield decreased with the presence of metribuzin and from the low to high rate. Yield at the DPRE timing for each rate also produced less grain than at the PRE timing. There was a similar trend for the Perkin's 2021 growing season following the DPRE timing where yield decreased as rate increased. The same trend occurred at Perkins; however, at the PRE timing, the low rate of metribuzin (105 g ai ha^{-1}) yielded similar to the nontreated control, while the high rate of 210 g ai ha^{-1} yielded less than the control. Goodwell 2021's growing season followed the same pattern as Fort Cobb and Perkins during the 2021 growing season where an increase in rate always resulted in lower yields. Preemergence applications mirrored different aspects of both Fort Cobb and Perkins during the same year in the way of yield decrease as rate increased (trend also found at Perkins) and the high rate applied PRE was comparable in yield to the low rate applied DPRE (trend also observed at Perkins). When analyzing the overall picture of these rate by application timing interactions from all four site years, the low rate of metribuzin applied PRE yielded higher than when applied DPRE at Fort Cobb and Goodwell in 2021. There was no significant differences in yield at Perkins during the 2020 or 2021 growing season. When evaluating the high rate of metribuzin from an application timing perspective, applying at the PRE timing did result in higher yields at all locations except for the Perkins 2020 growing season where applying DPRE produced a higher yield than the PRE timing. While yield can be a highly variable factor, applying 105 g ai ha^{-1} at the PRE timing did result in the most consistent results where yield was either similar to the nontreated control or resulted in a slight reduction in yield compared to other rate and application timing combinations.

The only metribuzin main rate effect was evident at Dacoma for the 2020 growing season. The low rate and high rate of metribuzin did not result in a significant difference in yield, but both rates yielded lower than the nontreated control. The Fort Cobb 2020 growing season accompanied with Perkins and Goodwell during the 2021 growing season exhibited a variety effect for yield. While varietal yield varied between site years, the only constant yield trend observed was Showdown's dominance as the top grain producing variety. Strad CL Plus also yielded similar to Showdown at Perkins.

Test Weight

Test weight was sampled from grain harvest at each site and indicated a variety by application timing by rate interaction for Fort Cobb 2021 (Table 2.9). Compared to the nontreated control plots, LCS Fusion AX declined in test weight at the low rate of metribuzin applied PRE and both application timings at the high rate. Test weight for both application timings were similar at 105 g ai ha^{-1} (~75.9 kg hL) of metribuzin and at 210 g ai ha^{-1} (~71.9 kg hL) with the high rate reducing test weight by four kg hL compared to the low rate of metribuzin. A reduction in test weight for Showdown was not present at either application timings for the low rate of metribuzin compared to the nontreated control plots. However, application of the high rate of metribuzin resulted in a decrease of test weight at both timings compared to the nontreated control and low rate with the DPRE timing having the lowest test weight. Strad CL Plus and Uncharted followed a similar trend where there was a reduction in test weight following the high rate of metribuzin applied DPRE compared to the nontreated control.

Table 2.10 features a metribuzin rate by variety interaction for Fort Cobb and Perkins during the 2020 season and a rate effect for Perkins during the 2021 season. At Fort Cobb, LCS Fusion AX nontreated was similar to the 1X and 2X rates, but test weight was reduced at the 2X rate when compared to the 1X rate of metribuzin. Test weight for nontreated Showdown was not significantly different than the low or high rate. Strad CL Plus did not waiver in test weight at any rate of metribuzin and Uncharted test weight was similar at both the low and high rate compared to the nontreated control, but the high rate of metribuzin exhibited a decline in test weight when compared to the low rate. For the rate by variety interaction at Perkins 2020, test weight decreased each time rate increased from the nontreated for LCS Fusion (Table 2.10). Between the nontreated to the 1X rate, and 1X to 2X rates, a test weight reduction of 1.4 and 2.6 kg hL was experienced, respectively. Conversely, varieties Showdown and Uncharted exhibited no decrease in test weight across application rates. Test weight for Strad CL Plus following the 105 g ai ha^{-1} rate was not different from the nontreated control or the 210 g ai ha^{-1} rate, while the high rate did cause a reduction in test weight compared to the nontreated check. Lastly, a rate effect occurred at Perkins for the 2021 season where test weight was similar for both rates of metribuzin but less than the nontreated control.

A reduction in test weight can be expected as rate of metribuzin is increased. Some varieties will experience larger drops in test weight such as LCS Fusion AX and this factor should be considered when picking a wheat variety to incorporate into a wheat system that utilizes metribuzin in its herbicide rotation. Metribuzin applied on varieties Showdown, Strad CL Plus, and Uncharted appear to have less of an effect on test weight than on LCS Fusion AX, but still result in reductions at certain rates depending on environmental conditions. At Fort Cobb 2020, the high rate of metribuzin applied on variety Showdown resulted in a higher test weight than at the low rate of metribuzin. This could be due to more desirable weather conditions during wheat anthesis as heading date was often slightly delayed between rate increases at sites that experienced increased crop injury (sometimes as long as seven days between treatments). Research by Blackshaw (1993) also observed a delay in wheat maturity, often five to eight days, indicating the prolonged effects of crop injury.

From data collection and examination, some conclusions can be determined from the results. First, peak visual injury demonstrated that in many cases the 2X rate of metribuzin used in this study, 210 g ai ha^{-1}, crosses the threshold of crop safety. Also, application timing response can be heavily influenced by environmental conditions and was best described in the 2X rate response differences between trial years. Next, through examination of harvest biomass production, it can be observed that conditions such as rainfall, temperature, and weather patterns can dictate plant response by intensifying the effects of application timing and rate. While environmental factors are beyond control in most cases, selecting for varietal tolerance, proper rate, and application timing mayhelp to minimize crop damage. For example, in this study, applying the low rate of metribuzin PRE resulted in the least impact on biomass production. However, as mentioned in *Peak Visual Crop Injury*, environmental conditions around and after planting should be considered when interpreting results as adverse conditions such as extreme cold temperatures followed DPRE applications during the 2021 season, resulted in increased crop response?. Yield results indicated that wheat following the low rate of metribuzin yielded more than wheat following high rate of metribuzin regardless of application timing; however, applying at the PRE timing always resulted in a higher yield at both the low and high rate.

Results from the above mentioned interactions and effects suggest that metribuzin rate, application timing, winter wheat variety, and soil characteristics are all important to consider when incorporating metribuzin into a winter wheat herbicide rotation; however, assuming the proper rate is applied, environmental factors seem to play the most critical role in crop response.

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Table 2.1. Agronomic practices and data collection dates for Dacoma, Fort Cobb, Goodwell, and Perkins, OK during the 2020 and 2021 seasons.

Year	Location	Planting date	PRE[a] herbicide application date[a]	DPRE herbicide application date	Biomass I collection date[b]	Biomass II collection date	Biomass III collection date	Total in season irrigation (cm)	Total in season rainfall (cm)	Total in season rainfall and irrigation total (cm)	Harvest date
2020	Dacoma	Oct. 23	Oct. 23	Nov. 20	-	-	-	-	31.85	31.85	June 18
2020	Fort Cobb	Nov. 4	Nov. 4	Nov. 22	Dec. 19	Apr. 7	June 11	4.43	40.64	45.07	June 11
2020	Goodwell	Oct. 11	Oct. 11	Oct. 24	-	-	-	10.16	19.91	30.07	July 1
2020	Perkins	Oct. 18	Oct. 18	Oct. 29	Dec. 9	Apr. 2	June 15	-	53.9	53.9	June 15
2021	Fort Cobb	Dec. 2	Dec. 2	Dec. 28	Mar. 1	Apr. 2	June 24	4.32	31.78	36.10	June 24
2021	Goodwell	Oct. 8	Oct. 8	Oct. 22	-	-	-	15.24	27.91	43.15	June 29
2021	Perkins	Oct. 14	Oct. 14	Oct. 23	Dec. 8	Mar. 26	June 18	1.27	60.55	61.82	June 18

[a] Preemergence applications were applied within 24 hours of planting and DPRE applications were sprayed at wheat spike.

[b] Biomass was not collected from Dacoma or Goodwell at any of the three collection timings.

Table 2.2 Rainfall and irrigation totals by day for the first 35 days after planting at Dacoma, Fort Cobb, Goodwell, and Perkins, OK during the 2020 season.

	Dacoma		Fort Cobb		Goodwell		Perkins	
	Rainfall	Irrigation	Rainfall	Irrigation	Rainfall	Irrigation	Rainfall	Irrigation
DAP[a]	mm							
0[b]	0	0	0	0	0	0	0.5	0
1	11.9	0	0	0	0	0	0.5	0
2	1.8	0	0	0	0	0	20.3	0
3	0.3	0	8.6	0	0	0	0	0
4	0	0	0	0	0	19	0	0
5	0	0	0	0	0	0	3.3	0
6	0	0	0	0	0	0	27.4	0
7	0	0	0	0	0	0	25.1	0
8	0	0	0	0	0	0	0.3	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0*	0*
11	0	0	0	0	0	0	29.7	0
12	0	0	0	0	0*	0*	1.5	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	4.8	0	0	0	0	0	0	0
16	0	0	7.1	0	0	0	0	0
17	0	0	1.8*	0*	0	0	0	0
18	0	0	6.4	0	0	0	0	0
19	0	0	0	0	0	0	20.8	0
20	0	0	0	0	0	0	9.1	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0.3	0	0	19	0.3	0
24	0	0	10.2	0	0	0	0.5	0

25	0	0	2	0	0	0	0	0
26	0	0	0.3	0	0	0	0	0
27	0*	0*	0	0	0.5	0	0	0
28	7.6	0	0	0	0	0	0	0
29	0.8	0	0	0	0	0	0	0
30	1.5	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	3.8	0
34	0	0	0	0	0	0	3	0
35	0	0	0	0	0	0	6.6	0
Total	28.7		36.7		38.5		152.9	

[a] Abbrevations: DAP, days after planting.

[b] PRE applications were made the same day as planting.

*Indicates when DPRE was applied for each location. Dacoma DPRE applied 28 DAP, Fort Cobb DPRE applied 18 DAP, Goodwell DPRE applied 13 DAP, and Perkins DPRE applied 11 DAP.

Table 2.3 Rainfall and irrigation totals by day for the first 35 days after planting at Fort Cobb, Goodwell, and Perkins, OK during the 2021 season.

	Fort Cobb		Goodwell		Perkins	
	Rainfall	Irrigation	Rainfall	Irrigation	Rainfall	Irrigation
DAP[a]	——— mm ———					
0[b]	1.3	0	0	0	0	0
1	0	0	0	25.4	0	12.7
2	0.3	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0.5*	0*
9	0.3	0	0	0	0	0
10	0	0	0	0	0	0
11	10.7	0	0	0	0.3	0
12	3	0	0	0	30.2	0
13	0	0	0.5*	0*	34.5	0
14	3.6	0	0	0	46.2	0
15	1.3	0	0	0	10.2	0
16	0	0	0	0	0	0
17	0	0	1.3	0	0	0
18	0	0	0	0	0	0
19	0	0	0.8	0	0	0
20	0	0	16.8	0	0	0
21	0	0	18.5	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0

25	0*	0*	0	0	0	0
26	0	0	0	0	0	0
27	16.3	0	0	0	2.3	0
28	11.7	0	0	0	0	0
29	13.2	0	0	0	0	0
30	8.1	0	0	0	0	0
31	0	0	0	0	0.8	0
32	0.3	0	0	0	0	0
33	0	0	0	0	0	0
34	0	0	0	0	0	0
35	0	0	0	0	0	0
Total	70.1		63.3		137.7	

[a] Abbreviations: DAP, days after planting.

[b] Preemergence applications were made the same day as planting.

*Indicates when DPRE was applied for each location. Fort Cobb DPRE applied 26 DAP, Goodwell DPRE

Table 2.4. Peak visual crop injury (percent of nontreated control) at Fort Cobb, Dacoma, and Perkins, OK during the 2020 season and Fort Cobb and Goodwell, OK during the 2021 winter wheat growing season.

	Fort Cobb 20	Dacoma 20	Perkins 20		Fort Cobb 21		Goodwell 21	
	% Visual crop injury[a]							
Variety*rate			105 g ai ha^{-1}[b]	210 g ai ha^{-1}	105 g ai ha^{-1}	210 g ai ha^{-1}		
LCS Fusion AX			39 cd[c]	68 a	29 de	72 a		
Showdown			40 bcd	48 b	23 e	66 ab		
Strad CL Plus			33 d	46 bc	27 de	58 c		
Uncharted			40 bcd	61 a	31 d	64 bc		
Variety*application timing							PRE	DPRE[d]
LCS Fusion AX							4 c	15 a
Showdown							4 bc	8 b
Strad CL Plus							3 c	7 bc
Uncharted							5 bc	13 a
Variety								
LCS Fusion AX	40 a	16 a					9 a	
Showdown	33 b	14 b					9 a	
Strad CL Plus	31 b	13 c					6 b	
Uncharted	39 a	12 c					4 b	

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[a] Peak visual crop injury for Fort Cobb 20, Dacoma 20, Perkins 20, Fort Cobb 21, and Goodwell 21 occurred at eight, nine, eight, fifteen, and six weeks after delayed preemergence applications, respectively.

[b] The 105 g ai ha^{-1} and 210 g ai ha^{-1} of metribuzin rates were tank-mixed with 119 g ai ha^{-1} of pyroxasulfone. Preemergence applications were applied within 24 hours after planting and delayed preemergence applications were sprayed at wheat spike.

[c] Means for each main effect or interaction for each site year followed by a common letter were similar in accordance with Fisher's protected LSD at $P < 0.05$.

[d] Abbreviations: DPRE, delayed preemergence.

Table 2.5 Peak visual crop injury (percent of nontreated control) at Fort Cobb, Perkins, and Dacoma, OK during the 2020 season and Fort Cobb, Perkins, and Goodwell, OK during the 2021 winter wheat growing season.

	Fort Cobb 20		Perkins 20		Dacoma 20		Fort Cobb 21		Perkins 21		Goodwell 21	
	% Visual crop injury[a]											
Rate*application timing	PRE	DPRE[b]	PRE	DPRE	PRE	DPRE	PRE	DPRE	PRE	DPRE	PRE	DPRE
105 g ai ha^{-1}[c]	30 bc[d]	26 c	44 b	32 c			23 d	32 c			2 c	4 bc
210 g ai ha^{-1}	56 a	31 b	57 a	55 a			42 b	88 a			5 b	17 a
Rate												
105 g ai ha^{-1}					15 a				16 a			
210 g ai ha^{-1}					13 b				32 b			

[a] Peak visual crop injury for Fort Cobb 20, Perkins 20, Dacoma 20, Fort Cobb 21, Perkins 21, and Goodwell 21 occurred at eight, eight, nine, fifteen, fourteen and six weeks after delayed preemergence application, respectively.

[b] Abbreviations: DPRE, delayed PRE.

[c] The 105 g ai ha^{-1} and 210 g ai ha^{-1} of metribuzin rates were tank-mixed with 119 g ai ha^{-1} of pyroxasulfone. Preemergence applications were applied within 24 hours after planting and delayed preemergence applications were sprayed at wheat spike.

[d] Means for each main effect or interaction for each site year followed by a common letter were similar in accordance with Fisher’s protected LSD at $P < 0.05$.

Table 2.6. Harvest biomass at Fort Cobb and Perkins, OK during the 2020 and 2021 growing seasons.

	Fort Cobb 20[a]	Perkins 20	Fort Cobb 21		Perkins 21
	---------- Biomass (g 1 m row^{-1}) ----------				
Rate*application timing			PRE	DPRE[b]	
Nontreated			230 a[c]	227 a	
105 g ai ha^{-1}[d]			181 b	171 bc	
205 g ai ha^{-1}			147 c	54 d	
Rate					
Nontreated	233 a	278 a			283 a
105 g ai ha^{-1}	207 ab	252 ab			267 b
205 g ai ha^{-1}	186 b	231 b			235 b
Application timing					
PRE					272 a
DPRE					250 b

[a] Harvest biomass was collected within 24 hours prior to grain harvest of trial for each location.

[b] Abbrevations: DPRE, delayed preemergence.

[c] The 105 g ai ha^{-1} and 210 g ai ha^{-1} of metribuzin rates were tank-mixed with 119 g ai ha^{-1} of pyroxasulfone.

[d] Means for each main effect or interaction for each site year followed by a common letter were similar in accordance with Fisher's protected LSD at $P < 0.05$.

Table 2.7. Plot grain yield (kg ha^{-1}) collected at Perkins, OK during the 2020 growing season and for Fort Cobb and Dacoma, OK during the 2021 growing season.

	Perkins 20			Fort Cobb 21			Dacoma 20	
	---------------------- Yield (kg ha^{-1}) ----------------------							
Variety*rate	Nontreated	105 g ai ha^{-1}	210 g ai ha^{-1}	Nontreated	105 g ai ha^{-1}	210 g ai ha^{-1}		
LCS Fusion AX	5952 bc[b]	5529 cd	4040 e	6018 b	3715 d	1266 f		
Showdown	6223 ab	5859 bc	5672 bcd	7164 a	4911 c	1631 f		
Strad CL Plus	6640 a	6023 bc	5233 d	6838 a	4861 c	2893 e		
Uncharted	5477 cd	5237 d	4264 e	7352 a	4877 c	1875 f		
Variety*application timing					PRE	DPRE	PRE	DPRE
LCS Fusion AX					3994 c	3338 d	4881 d	5254 c
Showdown					5081 b	4056 c	5661 b	5509 bc
Strad CL Plus					5640 a	4088 c	6037 a	5726 ab
Uncharted					5490 ab	3911 cd	5302 c	5329 c

[a] Abbreviations: DPRE, delayed preemergence.

The 105 g ai ha^{-1} and 210 g ai ha^{-1} of metribuzin rates were tank-mixed with 119 g ai ha^{-1} of pyroxasulfone. Preemergence applications were applied within 24 hours after planting and DPRE applications were sprayed at wheat spike.

[b] Means for each main effect or interaction for each site year followed by a common letter were similar in accordance to Fisher's protected LSD at $P < 0.05$.

Table 2.8. Plot grain yield (kg ha^{-1}) collected at Fort Cobb, Perkins, and Dacoma, OK during the 2020 and Fort Cobb, Perkins, and Goodwell, OK during the 2021 growing season.

	Fort Cobb 20		Dacoma 20	Fort Cobb 21		Perkins 21		Goodwell 21	
	Yield (kg ha^{-1})								
Rate*time	PRE	DPRE[a]		PRE	DPRE	PRE	DPRE	PRE	DPRE
Nontreated[b]	6124 a[c]	5776 ab		6905 a	6781 a	5445 ab	5548 a	7440 a	7359 ab
105 g ai ha^{-1}	5488 b	5732 b		5043 b	4139 c	4940 bc	4724 c	7286 b	7092 c
205 g ai ha^{-1}	3960 c	5479 b		3206 d	625 e	4424 c	3449 d	7044 c	6551 d
Rate									
Nontreated			5663 a						
105 g ai ha^{-1}			5427 b						
205 g ai ha^{-1}			5326 b						
Variety									
LCS Fusion AX	5379 b					4267 b		6585 d	
Showdown	5855 a					5062 a		7802 a	
Strad CL Plus	5493 b					5163 a		7389 b	
Uncharted	4979 c					4527 b		6739 c	

[a] Abbreviations: DPRE, delayed preemergence.

[b] The 105 g ai ha^{-1} and 210 g ai ha^{-1} of metribuzin rates were tank-mixed with 119 g ai ha^{-1} of pyroxasulfone. Preemergence applications were applied within 24 hours after planting and delayed preemergence (DPRE) applications were sprayed at wheat spike.

[c] Means for each main effect or interaction for each site year followed by a common letter were similar in accordance to Fisher's protected LSD at $P < 0.05$.

Table 2.9. Test weight from plot grain yield samples at Fort Cobb, OK during the 2021 growing season.

	Fort Cobb 21					
	——— kg hL ———					
	PRE			DPRE[a]		
Variety*application timing*rate interaction	Nontreated	105 g ai ha^{-1b}	205 g ai ha^{-1}	Nontreated	105 g ai ha^{-1}	205 g ai ha^{-1}
LCS Fusion AX	77.4 ef[b]	76.3 fgh	71.6 j	78.4 de	75.4 gh	72.1 ij
Showdown	79.4 cd	77.4 ef	74.9 hi	78.8 cde	77.1 efg	66.9 k
Strad CL Plus	81.9 a	80.5 abc	79.8 bcd	81.5 ab	79.7 bcd	75.2 gh
Uncharted	80.2 abcd	79.3 cd	78.9 cde	80 bcd	80.6 abc	73.5 hij

[a] Abbreviations: DPRE, delayed preemergence.

[b] The 105 g ai ha^{-1} and 210 g ai ha^{-1} of metribuzin rates were tank-mixed with 119 g ai ha^{-1} of pyroxasulfone. Preemergence applications were applied within 24 hours after planting and DPRE applications were sprayed at wheat spike.

[b] Means for each main effect or interaction for each site year followed by a common letter were similar in accordance to Fisher’s protected LSD at $P < 0.05$.

Table 2.10. Test weight from plot grain yield samples at Fort Cobb and Perkins, OK during the 2020 season and Perkins, OK during the 2021 growing season.

	Fort Cobb 20				Perkins 20				Perkins 21
	kg hL^{-3}								
Rate*variety interaction	LCS Fusion AX	Showdown	Strad CL Plus	Uncharted	LCS Fusion AX	Showdown	Strad CL Plus	Uncharted	
Nontreated[a]	80.8 cde[b]	80.5 cde	81.7 ab	80.7 cde	81.3 bc	81.6 abc	82.2 ab	81.6 abc	
105 g ai ha^{-1}	81 bcd	80.4 de	82 a	81 bcd	79.9 d	81.4 abc	81.4 abc	82.4 a	
205 g ai ha^{-1}	80.1 e	81.3 abc	81.3 abc	80.1 e	77.3 e	80.9 cd	80.9 cd	81.5 abc	
Rate									
Nontreated									79.2 a
105 g ai ha^{-1}									78.1 b
205 g ai ha^{-1}									77.3 b

[a] The 105 g ai ha^{-1} and 210 g ai ha^{-1} of metribuzin rates were tank-mixed with 119 g ai ha^{-1} of pyroxasulfone.

[b] Means for each main effect or interaction for each site year followed by a common letter were similar in accordance to Fisher's protected LSD at $P < 0.05$.

CHAPTER III

TOLERANCE OF 31 HARD RED WINTER WHEAT VARIETIES TO METRIBUZIN: A GREENHOUSE STUDY

Introduction

Oklahoma wheat producers have struggled for years to find a herbicide system in wheat that possesses the proper combination of weed efficacy and crop safety. Metribuzin is a herbicide that brings a high level of efficacy to target weeds in a wheat production system, but use has fallen off due to crop safety concerns (VanGessel et al. 2017). Winter annual grass weeds like true cheat (*Bromus secalinus* L.) and rescuegrass (*Bromus catharticuz* L.) have adapted to production fields as wheat has been planted continuously on a large majority of Oklahoma production hectares (USDA NASS 2020a). In monoculture small grain systems, winter annual grass weeds adapt to the repetitive system and controlling them is economically vital as infestations can lead to yield reductions up to 50% (Kleeman and Gill 2008) or more.

In 1998, a survey was conducted in Oklahoma over three major wheat-producing counties including Alfalfa, Kingfisher, and Garfield. The survey concluded that between 70% and 89% of fields within these counties had *Bromus species* (*spp.*) infestations to some degree (Barnes et al. 1999). Runyan et al. (1982) also found that *Bromus spp.* were present in approximately 1.4 million hectares of wheat in Oklahoma. Attaining control and suppression of the above mentioned species has become more difficult annually as resistant biotypes have developed and lack of cultural control practices remain unchanged. From one study on net returns from true cheat control in wheat in Oklahoma, one location revealed that an increase in net returns was not simply acquired by solely decreasing row spacing unless chemical options like chlorsulfuron plus metsulfuron or metribuzin were added into the practice (Justice et al. 1993). Others also documented that metribuzin was an effective herbicide for *Bromus spp.* management, providing between 80 to 100% control; however, severe crop injury was a concern (Appleby and Morrow 1990; Peeper and Morrow 1990). Shaw and Wesley (1991) found wheat response to metribuzin was greatest when applied PRE as opposed to a later wheat stage with injury rates as high as 90% when applying 430 g ai ha^{-1}. Injury translated into yield reduction, but provided more than 80% control of Italian ryegrass at rates of 280 g ai ha^{-1} and 430 g ai ha^{-1}. Although metribuzin has provided adequate efficacy of target weed species in Oklahoma, crop safety concerns limit adoption. Varieties exist that inheritably have a higher tolerance to metribuzin than others, but identification of current tolerant varieties is limited (VanGessel et al. 2017; Runyan et al. 1982). The wheat variety industry is fast paced and not enough research has been conducted to keep up withon currently used varieties in Oklahoma and their tolerance to metribuzin (Runyan et al. 1982).

There are many wheat varieties that are valuable for Oklahoma producers depending on their location, agronomic needs, and other factors like soil characteristics. Gallagher, Smith’s Gold, Doublestop CL Plus, Iba, Green Hammer, Bentley, Endurance, LCS Chrome, LCS Fusion AX, and OK Corral are just a few of the top 20 wheat varieties planted in Oklahoma for the 2021 season, accounting for over 41% of seeded hectares (USDA NASS 2021b). Gallagher was the most common variety planted for the last growing season with 10.9% of production (USDA NASS 2021b). Because there is a large number of commonly planted wheat varieties in Oklahoma, a greenhouse study was performed to evaluate metribuzin tolerance to current, highly used varieties in Oklahoma. Thirty-one varieties were tested to different rates of metribuzin tank-mixed with pyroxasulfone sprayed at the wheat spike growth stage to identify varieties that are most tolerant to a herbicide that may offer increased management of economically important weeds.

Materials and Methods

A greenhouse study was performed to evaluate tolerance levels of 31 winter wheat varieties to multiple rates of metribuzin tank-mixed with pyroxasulfone. The study was a factorial arranged as a randomized complete block design including three replications with one pot being a replicate. Four rates of metribuzin were assessed including 52.5 g ai ha^{-1}, 105 g ai ha^{-1}, 210 g ai ha^{-1}, 420 g ai ha^{-1}, and a nontreated control. All rates of metribuzin were tank-mixed with 119 g ai ha^{-1} of pyroxasulfone with the exception of the nontreated control. Field soil was used to simulate a more accurate depiction of metribuzin movement in the soil profile, plant uptake, and to ensure metribuzin was not tied up from increased organic matter contained in potting soil. All treatments were sprayed when wheat reached the spike stage of development. Varieties included were, AG Icon, Baker’s Ann, Bentley, Canvas, Crescent AX, Doublestop CL Plus, Endurance, Green Hammer, Iba, KS Dallas, KS Silverado, KS Western Star, Langin, LCS Chrome, LCS Fusion AX, LCS T158, Lonerider, NF 101, OK Corral, Ruby

Lee, Showdown, Skydance, Smith's Gold, Spirit Rider, Strad CL Plus, TAM 101, TAM 114, Uncharted, Vona, WB 4699, and Zenda. These varieties were selected because they are popularly grown in Oklahoma, are expected to increase in planting proportion in the future, or because of known tolerance or susceptibility as with the case of TAM 101 and Vona.

The study was performed twice during the 2021 year. Run I was performed in April of 2021 and Run II was performed in September of 2021. Two seeds of each variety were planted in 24 cone pots measuring 6.4 cm wide by 30.5 cm tall. After emergence, pots were thinned to one plant per pot. Pots were filled with soil collected from the Oklahoma State University Cimarron Valley Research Station at Perkins, OK (35.99ºN, -097.04ºW, elevation of 279 m). The soil type was a Teller fine sandy (Fine-loamy, mixed, active, thermic Udic Argiustolls) with a pH of 6.2.

Once the spike stage was reached, pots were sprayed with their respective herbicide treatment in a DeVries Generation III Research Sprayer (DeVries Manufacturing, Hollandale, MN). Spraying was conducted at a carrier volume of 140 L ha^{-1} and a Turbo Teejet® 8001 EVS nozzle was used. After spraying, pots were allowed 12 hours of drying time before 40 mL of water was applied to incorporate the herbicide into the soil profile. This initial watering was administered via pouring the water into a pvc cap with holes drilled into the bottom placed over the top of the cone pots to simulate a rainfall event. Pots were then transported to a temperature controlled greenhouse of 15.5 to 26.6°C with 24 hour light and hooked up to an irrigation system outfitted with a spray stake stationed in each plot to deliver the same amount of water. Water was ran through 1.9 cm diameter pvc pipping to a Globe 24 volt solenoid attached to a Senninger

241 kPa pressure regulator to ensure all spray stakes received the same kPa of water during irrigation events. Polyethylene tubing measuring 1.9 cm in diameter was laid around replications with spray stake hoses linking them from the polyethylene tubing to the spray stakes. A Stakes sprayed water in a 160° pattern and were situated in the soil only rising above the soil profile, but below the rim of the pot to ensure water delivered acted as a rainfall event to incorporate the herbicides into the soil profile. Irrigation included 40 mL three days after initial irrigation and 40 mL seven days after initial irrigation totaling 120 mL for all pots in both trials.

Percent visual injury was observed 10 and 14 days after application for each treatment compared to the nontreated control. Biomass was cut at the soil surface for each plant 14 days after application and placed in a dryer set at 50°C for 48 hours. Finally, dry plant biomass was weighed and recorded.

All data collected was analyzed in SAS 9.4 (Version 9.4, SAS Institue Inc., SAS Campus Drive, NC) using PROC MIXED. Means were separated at an α level of 0.05. Due to an experimental run by treatment interactions, experimental runs were analyzed separately and never combined in aim to provide a clear and concise illustration of metribuzin effects on winter wheat varieties.

Results and Discussion

Percent visual injury compared to the nontreated control in each respected replication was recorded 10 days after spraying in both runs. A metribuzin rate effect and a variety effect was observed in both Run I and Run II (Table 3.1). The rate effect in Run I indicated that as rate increased, plant visual injury increased. Run II followed a similar trend with the exception of injury following the 2X (210 g ai ha^{-1}) and 4X (420 g ai ha^{-1})

rates being similar (98 and 93% injury, respectively). While seeing varying results between years of the experiment, VanGessel (2017) also witnessed a similar trend in crop response with 105 g ai ha^{-1} and 205^{-1} g ai ha^{-1} applied at 2-leaf wheat resulting in 43 and 77% injury, respectively.

A variety effect was also indicated in both runs of this experiment (Table 3.1). Depending on experimental run, there was frequent variability in crop response of a particular variety. However, some varieties consistently displayed tolerant or susceptible qualities. For example, averaged across metribuzin rate, 44 and 62% visual injury was recorded for WB 4699 for Run I and II, respectively. Crescent AX (43 and 64%) and Iba (64 and 65%) were two other varieties that appeared to exhibit less injury relative to their respective nontreated control compared to other varieties screened. When examining crop response at the label recommended rate for the soil type used (sandy loam), WB 4699 (12 and 8%), Crescent AX (21 and 63%), and Iba (37 and 50%) again indicated a higher level of tolerance per Run I and Run II, respectively. Other varieties that notably displayed some degree of tolerance were Showdown, TAM 101, and Uncharted. TAM 101 is listed on the metribuzin label as a tolerant variety (Anonymous 2004) and greenhouse findings from Runyan et al. (1982) also further demonstrate its high level of tolerance.

For biomass, a metribuzin rate effect and a variety effect were evident in Run I and Run II (Table 3.2). The rate effect for both Run I and Run II were similar with a general decrease in biomass percentage of the nontreated control as rate increased. Averaged across varieties, the 0.5X rate indicated the lowest reduction in biomass compared to the nontreated, 36 and 46% for Run I and Run II, respectively). The 1X rate averaged 27% in Run I and 29% in Run II. At the 2X rate, biomass percentage of the nontreated was not different than the 1X or 4X rate (22, 27, and 19%, respectively). Lastly, the 4X rate of metribuzin reduced biomass as a percentage of the nontreated to 19% for Run I and 25% for Run II.

Biomass also produced a variety response for both runs of the experiment (Table 3.2). While varieties produced different results between the two runs, some similarities can be attained. For both Run I and Run II, Varieties WB 4699 and Iba consistently ranked towards the top for the least reduction in biomass compared to their nontreated controls. Biomass of variety WB 4699 only indicated a reduction of 46 and 43% for Run I and Run II, respectively, for biomass reduction averaged across all rates compared to the nontreated control. Iba also exhibited more tolerance than many varieties with 41 and 38% reduction from the nontreated for Run I and Run II, respectively. These two varieties stood out in both runs also when looking directly at 1X rate, which is the labeled rate to apply in a field with soil texture and organic matter matching requirements (Anonymous 2004).

While not to the extent of WB 4699 and Iba, other varieties that exhibited consistent relative tolerance across both runs are varieties AG Icon, Bentley, Crescent AX, Doublestop CL Plus, LCS Chrome, and LCS T158. These varieties consistently produced low biomass reduction levels compared to their nontreated control and ranked within the top 10 varieties during both runs. They should be considered moderately tolerant to tolerant within this list. Also, TAM 101, previously deemed a tolerant variety in prior research (Runyan et al. 1982) ranked twelfth in Run I and tenth in Run II. While inconsistency was present at the 1X rate between Run I and Run II, TAM 101 was not significantly different in biomass percentage response than WB 4699 and Iba in Run I.

Previous research supported results indicated no fresh shoot biomass response for TAM 101 when applied with 0.14 kg ha^{-1} of metribuzin 30 days after planting, but a decrease for Vona of 50% compared to the nontreated control (Runyan et al. 1982).

In summary, when evaluating these varieties in accordance with response to all rates of metribuzin, the proper labeled 1X rate, and visual response ratings, a spectrum of tolerance and susceptibility can be determined. The varieties that exhibited the highest, consistent level of tolerance included WB 4699, Iba, and Crescent AX. Varieties that stood out for a lower level of tolerance included LCS Chrome, LCS T158, TAM 101, Showdown, and Uncharted. When deciphering susceptible varieties, Vona, Strad CL Plus, Smith's Gold, OK Corral, Baker's Ann, and LCS Fusion AX consistently indicated high visual injury response and low biomass production compared to the nontreated across all four rates, particularly at the 1X rate. All of these varieties experienced at least 75 and 65% visual injury between both runs for the 0.5X, 1X, 2X, and 4X rates combined and visual injury response at the 1X rate, respectively. For biomass percentage of the nontreated, 34 and 42% was recorded as the lowest reduction in biomass production for all four rates combined and at the 1X rate, respectively.

These figures differ with varieties that showed tolerant characteristic. WB 4699 ranged from 41-65% visual injury compared to the nontreated between Run I and Run II when evaluating all four rates of metribuzin together and 8-63% when only considering the 1X rate. Iba and Crescent AX (64-65 and 43-63%) also indicated less visual injury response than deemed susceptible varieties in this study at all four rates combined and the 1X rate, respectively. The tolerant varieties also ranged between 30-49% (all four rates combined) and 33-79%(1X) of biomass percentage of the nontreated, compared to susceptible varieties 14-34% and 8-41%, respectively. Findings are supported by a previous screening of varieties to metribuzin where TAM 101 displayed tolerant characteristics over Vona in all three observations of the study (Runyan et al. 1982). Through this evaluation, current varieties can be categorized on a spectrum as tolerant, somewhat tolerant, susceptible, and somewheat susceptible. However, wheat injury levels will fluctuate as crop response is determined also by soil characteristics and environmental factors. However, for producers who plan to use metribuzin in wheat, our results suggest that varieties WB 4699, Iba, and Crescent AX exhibit tolerant characteristics and may decrease crop response to metribuzin.

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Table 3.1. Visual injury expressed as a percentage of the nontreated control.

	——————————— % visual injury		———————————	
	% injury across all four		% injury at 105 g ai ha^{-1a}	
Variety	Run I[b]	Run II	Run I	Run II
AG Icon	73 c-i[c]	68 e-h	97 ab	40 cd
Baker's Ann	85 a-d	92 a-d	97 ab	100 a[d]
Bentley	80 a-g	77 e-h	100 a	77 a-c
Canvas	55 i-m	81 a-h	45 c-g	80 a-c
Crescent AX	43 m	64 gh	22 fg	63 a-c
Doublestop CL Plus	62 g-l	85 a-e	42 c-g	75 a-c
Endurance	78 b-h	85 a-e	62 a-f	100 a
Green Hammer	68 d-k	94 a-d	77 a-e	100 a
Iba	64 f-k	65 f-h	37 e-g	50 b-d
KS Dallas	63 g-k	81 a-h	60 a-f	77 a-c
KS Silverado	86 a-d	87 a-e	100 a	100 a
KS Western Star	79 a-h	82 a-g	83 a-d	83 a-c
Langin	66 e-k	78 c-h	67 a-e	80 a-c
LCS Chrome	64 f-k	80 b-h	55 b-g	83 a-c
LCS Fusion AX	87 a-d	75 d-h	100 a	65 a-c
LCS T158	53 j-m	94 a-d	40 d-g	82 a-c
Lonerider	82 a-f	84 a-f	97 ab	100 a
NF 101	71 c-j	99 ab	100 a	100 a
OK Corral	85 a-e	89 a-e	100 a	100 a
Ruby Lee	84 a-e	92 a-d	97 ab	68 a-c
Showdown	63 g-k	76 c-h	65 a-f	73 a-c
Skydance	84 a-e	94 a-d	65 a-f	100 a
Smith's Gold	89 a-c	94 a-d	92 ab	100 a
Spirit Rider	93 ab	90 a-d	90 ab	100 a
Strad CL Plus	87 a-c	100 a	97 ab	100 a

TAM 101	51 k-m	80 b-h	40 d-g	77 a-c
TAM 114	61 h-m	89 a-d	45 c-g	100 a
Uncharted	64 f-k	77 c-h	53 b-g	67 a-c
Vona	97 a	95 a-c	92 ab	78 a-c
WB 4699	44 lm	62 h	12 g	8 d
Zenda	74 c-h	85 a-e	80 a-e	95 ab
Metribuzin rate				
52.5 g ai ha^{-1}	35 d	62 c		
105 g ai ha^{-1}	71 c	81 b		
210 g ai ha^{-1}	88 b	93 a		
420 g ai ha^{-1}	96 a	99 a		

[a] 105 g ai ha^{-1} is the desired application amount for this soil texture and organic matter content per label requirements.

[b] Means for each main effect or interaction for each site year followed by a common letter were similar in accordance to Fisher's protected LSD at $P<0.05$.

[c] In 2021, Run I was performed in April and Run II was performed in September.

[d] 100 signifies all three pots of the treatment within the run were dead.

Table 3.2. Wheat biomass expressed as a percentage of the nontreated average.

	% of average nontreated biomass[a]			
	Biomass averaged across all four rates		Biomass from 105 g ai ha^{-1}[a]	
Variety	Run I	Run II	Run I	Run II
AG Icon	31 b-g[c]	44 a-c	17	57 ab
Baker's Ann	22 e-k	22 f-k	15	23 c-h
Bentley	29 c-i	38 a-e	22	26 c-h
Canvas	38 bc	21 g-k	36	18 e-h
Crescent AX	30 c-i	49 a	33	45 b-e
Doublestop CL Plus	36 b-d	29 d-h	26	28 c-h
Endurance	24 d-k	30 d-h	26	26 c-h
Green Hammer	43 ab	20 g-k	30	15 gh
Iba	38 bc	41 a-d	42	48 bc
KS Dallas	38 bc	25 f-k	44	25 c-h
KS Silverado	20 f-k	32 c-g	20	22 c-h
KS Western Star	17 h-k	24 f-k	21	17 gh
Langin	29 c-h	24 f-k	27	24 c-h
LCS Chrome	31 b-g	44 a-c	27	33 b-h
LCS Fusion AX	14 k	34 b-f	15	41 b-g
LCS T158	40 b-e	30 d-h	25	30 b-h
Lonerider	17 i-k	31 d-h	14	26 c-h
NF 101	54 a	15 i-k	27	10 h
OK Corral	34 b-e	24 f-k	25	17 f-h
Ruby Lee	26 c-k	28 d-h	28	31 b-h
Showdown	30 b-h	27 e-i	17	30 b-h
Skydance	20 f-k	18 h-k	26	12 h
Smith's Gold	17 i-k	15 jk	16	12 h
Spirit Rider	21 e-k	39 a-e	24	45 b-f
Strad CL Plus	19 g-k	13 k	22	8 h

TAM 101	32 b-f	28 e-h	43	24 c-h
TAM 114	37 b-d	27 e-j	43	20 d-h
Uncharted	28 c-g	30 d-h	25	47 bd
Vona	15 jk	30 d-h	17	42 b-g
WB 4699	43 ab	46 ab	50	79 a
Zenda	20 f-k	31 d-h	18	31 b-h
Metribuzin rate				
52.5 g ai ha^{-1}	46 a	36 a		
105 g ai ha^{-1}	27 b	29 b		
210 g ai ha^{-1}	22 bc	27 bc		
420 g ai ha^{-1}	19 c	25 c		

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[a] Biomass collected from the 105 g ai ha^{-1} is the desired application amount for this soil texture and organic matter content per label requirements.

[b] Nontreated plants were averaged within a variety and run when comparing rate response as a percentage of the nontreated.

[c] Means for each main effect or interaction for each run followed by a common letter were similar in accordance to Fisher's protected LSD at $P < 0.05$.

APPENDICES

Note: Please read the directions in the following paragraph very carefully before proceeding.

These pages are where you type in text, images, etc. of your appendices. To best preserve the proper formatting and margin alignment, you should do this one section at a time. You can type in the title of each appendix over the placeholder text if necessary. However, on this first page, you should **only** add enough content to fill this first page. If you typed or pasted in too much content so that it created another page, delete this content on the second page and backspace until you are back on the first page. If you do not do this, the margins may be incorrect on the following pages.

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Table A.1. Biomass at peak visual injury at Fort Cobb and Perkins, OK during the 2020 and 2021 growing season.

	Fort Cobb 20[a]		Perkins 20		Fort Cobb 21		Perkins 21
	Biomass (g m row^{-1})						
Rate*application timing	PRE[b]	DPRE	PRE	DPRE	PRE	DPRE	
Nontreated[b]	1.4 a[c]	1.3 a			0.5 b	0.7 a	
105 g ai ha^{-1}	0.8 b	0.9 b			0.4 c	0.4 c	
205 g ai ha^{-1}	0.4 c	0.9 b			0.3 c	0.1 d	
Variety by application timing							
LCS Fusion AX	0.9 b	0.7 b					
Showdown	0.9 b	0.9 b					
Strad CL Plus	0.9 b	1.3 a					
Uncharted	0.8 b	0.8 b					
Rate							
Nontreated			1.4 a				4.2 a
105 g ai ha^{-1}			0.8 b				2.6 b
205 g ai ha^{-1}			0.4 c				1.9 b

[a] Abbreviations: DPRE, delayed preemergence.

Biomass at peak visual injury was sampled at Fort Cobb 2020 six weeks after PRE application and four weeks after DPRE application. Perkins 20 was collected seven weeks after PRE and six after DPRE. For the 2021 season, Fort Cobb was sampled at 13 weeks after PRE and nine weeks after DPRE while Perkins was eight and seven weeks after application respectively.

[b] Abbreviations: DPRE, delayed preemergence.

[c] The 105 g ai ha^{-1} and 210 g ai ha^{-1} of metribuzin rates were tank-mixed with 119 g ai ha^{-1} of pyroxasulfone.

[d] Means for each main effect or interaction for each site year followed by a common letter were similar in accordance to Fisher's protected LSD at $P < 0.05$

Table A.2. Biomass at spring green-up to jointing at Fort Cobb and Perkins, OK during the 2020 and 2021 growing seasons.

	Fort Cobb 20[a]			Perkins 20	Fort Cobb 21			Perkins 21
	Biomass (g m row^{-1})							
Variety * rate					NT[b]	105 g ai ha^{-1}	205 g ai ha^{-1}	
LCS Fusion AX					26.1 b[c]	3.8 de	0.7 e	
Showdown					22.4 c	4.1 de	0.7 e	
Strad CL Plus					34.8 a	5.9 d	2.2 e	
Uncharted					24.1 bc	3.1 de	1.1 e	
Application timing * rate	NT	105 g ai ha^{-1}	205 g ai ha^{-1}					
PRE	90 a	61 c	32 d					
DPRE	84 a	79 ab	71 bc					
Rate								
Nontreated				92 a				47 a
105 g ai ha^{-1}				58 b				29 b
205 g ai ha^{-1}				43 c				21 c
Application timing								
PRE				60 b		11.7 a		
DPRE				69 a		9.8 b		

[a] Abbreviations: NT, nontreated; DPRE, delayed preemergence.

[a] Spring green-up to jointing biomass was sampled at Fort Cobb 2020, 22 weeks after PRE application and 20 weeks after DPRE application. Perkins 20 was collected 24 weeks after PRE and 22 after DPRE. For the 2021 season, Fort Cobb was sampled at 17 weeks after PRE and 14 weeks after DPRE while Perkins was 23 and 22 weeks after application, respectively.

[b] The 105 g ai ha^{-1} and 210 g ai ha^{-1} of metribuzin rates were tank-mixed with 119 g ai ha^{-1} of pyroxasulfone. Preemergence applications were applied within 24 hours after planting and DPRE applications were sprayed at wheat spike.

[c] Means for each main effect or interaction for each site year followed by a common letter were similar in accordance to Fisher's protected LSD at $P < 0.05$.

Table A.3. Head counts recorded from one meter of row biomass collected prior to grain harvest for Fort Cobb and Perkins, OK during the 2020 and 2021 growing seasons.

	Fort Cobb 20	Perkins 20	Fort Cobb 21		Perkins 21
	——— Number of heads m row^{-1} ———				
Rate*application timing			PRE[a]	DPRE	
Nontreated			95 a[b]	97 a	
105 g ai ha^{-1}[c]			78 b	71 b	
210 g ai ha^{-1}			66 b	25 c	
Rate					
Nontreated	95 a	107 a			114 a
105 g ai ha^{-1}	83 b	87 b			109 a
210 g ai ha^{-1}	71 c	73 c			97 b
Application timing					
PRE					112 a
DPRE					102 b
Variety					
LCS Fusion AX		103 a	73 ab		
Showdown		87 b	64 b		
Strad CL Plus		90 ab	80 a		
Uncharted		78 b	71 ab		

[a] Abbreviations: DPRE; delayed preemergence.

[b] Means for each main effect or interaction for each site year followed by a common letter were similar in accordance to Fisher's protected LSD at $P < 0.05$.

[c] The 105 g ai ha^{-1} and 210 g ai ha^{-1} of metribuzin rates were tank-mixed with 119 g ai ha^{-1} of pyroxasulfone. PRE applications were applied within 24 hours after planting and delayed DPRE applications were sprayed at wheat spike.

Table A.4. Peak visual injury, harvest biomass, number of heads, and test weight for TAM 101 at Fort Cobb, OK during the 2020 season and Fort Cobb and Perkins, OK during the 2021 season.

	Fort Cobb 20			Fort Cobb 21			Perkins 21		
Peak visual injury					% visual crop injury				
Rate*application timing	105 g ai ha^{-1}	205 g ai ha^{-1}		105 g ai ha^{-1}	205 g ai ha^{-1}		105 g ai ha^{-1}	205 g ai ha^{-1}	
PRE	23	27		17 b^{b}	25 b		8	15	
DPRE	21	27		23 b	82 a		10	15	
Harvest biomass					g m row^{-1}				
Application timing*rate	Nontreated	105 g ai	205 g ai	Nontreated	105 g ai	205 g ai	Nontreated	105 g ai	205 g ai
PRE	218	225	151	186	140	215	235	230	251
DPRE	229	201	206	242	153	65	268	251	289
Yield					kg ha^{-1}				
Application timing*rate	Nontreated	105 g ai	205 g ai	Nontreated	105 g ai	205 g ai	Nontreated	105 g ai	205 g ai
PRE	5418	5195	5165	6095 a	4221 b	3771 b	4570	4657	4145
DPRE	5329	5129	4992	6006 a	3944 b	327 c	4257	4715	4555
Number of heads					Number m row-1				
Application timing*rate	Nontreated	105 g ai	205 g ai	Nontreated	105 g ai	205 g ai	Nontreated	105 g ai	205 g ai
PRE	96	85	65	89	69	104	122	116	130
DPRE	100	88	93	110	68	26	141	122	126
Test weight					kg hL				
Application timing*rate	Nontreated	105 g ai	205 g ai	Nontreated	105 g ai	205 g ai	Nontreated	105 g ai	205 g ai
PRE	80.7	80.5	81.5	79.3	78.5	78.2	76.7	77.8	75.9
DPRE	80.7	80.8	80.4	79.6	76.7	.^{c}	77.0	79.8	78.7

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[a] The 105 g ai ha^{-1} and 210 g ai ha^{-1} of metribuzin rates were tank-mixed with 119 g ai ha^{-1} of pyroxasulfone. Preemergence applications were applied within 24 hours after planting and DPRE applications were sprayed at wheat spike.

[b] Means for each main effect or interaction for each site year followed by a common letter were similar in accordance to Fisher's protected LSD at $P < 0.05$.

[c] Grain collected from harvest was an insufficient amount to run test weight analysis.

VITA

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