HORSEWEED AND SMALLSEED FALSEFLAX MANAGEMENT IN OKLAHOMA WINTER WHEAT

By

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Abstract: Quelex® (halauxifen + florasulam), Sentrallas® (thifensulfuron + fluroxypyr), and Talinor® (bromoxynil + bicyclopyrone) are three new postemergence premix herbicides developed for control of broadleaf weeds in winter wheat. These herbicides along with older products were evaluated for their control of horseweed (*Conyza canadensis* L.) in Oklahoma in the spring of 2017 and 2018. Control of smallseed falseflax (*Camelina microcarpa* Andrz. Ex DC.) also was evaluated at Lahoma, Oklahoma at the same time. Visual weed control was estimated every two weeks throughout the growing season and wheat yield was collected from three of the six site years. Horseweed size ranged from 5 to 20 cm at time of application while smallseed falseflax was approximately 6 cm both years. For the horseweed study, at all site years, halauxifen + florasulam achieved greater than 90% control with the exception of two treatments at Altus in 2018 and one at Ponca City in 2018. Thifensulfuron + fluroxypyr + dicamba achieved greater than 90% control at all site years except at Ponca City in 2017. However, when dicamba was replaced with MCPA in tank mix, control at all site years was lowered. Halauxifen + florasulam and thifensulfuron + fluroxypyr were both effective at controlling a wide range of horseweed rosette sizes across all locations while control with other treatments varied depending on presence of ALS resistance, weed size, and tank mix partners. For the smallseed falseflax study, dicamba alone achieved 90% control of smallseed falseflax while control with all other treatments was greater than 95% with the exception of halauxifen + florasulam + pyroxsulam and bromoxynil + bicyclopyrone. All treatments containing an ALS herbicide achieved adequate control of smallseed falseflax therefore resistance is not suspected in the population. For both studies, wheat yield was greater in 2017 compared to 2018 and was not affected by herbicide treatment.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table Page

CHAPTER I

LITERATURE REVIEW

Horseweed Biology

Horseweed is considered either a winter annual or summer annual. Since there is no dormancy period, horseweed seed can germinate as soon as it contacts a substrate if conditions are suitable (Buhler and Owen 1997; Nandula et al. 2006). Thus, seeds that germinate in the fall can establish a rosette before going into dormancy. In the spring, plants begin actively growing again, flower, and set seed early enough in the growing season for this cycle to reoccur. However, sometimes seeds germinate in early spring and can complete their entire life cycle before cool fall temperatures induce dormancy thus classifying horseweed as a summer annual (Regehr and Bazzaz 1979; Weaver 2001).

Horseweed is an erect herb, growing up to 2.5 meters tall. It has sessile, alternate leaves that almost appear whorled along the stem. The leaf margins are mostly entire and usually covered in short hairs. It produces a large panicle-like inflorescence with small, inconspicuous flowers. The ray flowers are white and disk flowers yellow and together make up a capitulum or flower head. Horseweed produces small achenes with a pappus of bristles that allow it to disperse by wind or water (Weaver 2001).

The reproductive biology of horseweed further contributes to its ability to be such a successful weed. In a study conducted by Smisek et al., using paraquat resistance as a marker, less than 5% of outcrossing occurred during horseweed reproduction (1998). Self-pollination occurs more readily since the majority of flowers are pollinated prior to the capitula fully opening (Smisek et al. 1998). This allows for faster, more abundant seed production. According to Weaver (2001), seed takes approximately three weeks from fertilization to maturation.

Horseweed seed is light and can be carried long distances. In a study conducted by Regehr and Bazzaz, seed produced from horseweed was carried 122 meters downwind (1979). It may be dispersed in many ways but most commonly seeds are dispersed by wind or water. In another study by Kelley and Bruns (1975), large quantities of seeds were found in rivers and canals that were located near field populations of horseweed. Another factor that is believed to contribute to seed dispersal in this species is plant height. Regehr and Bazzaz (1979) suggest that tall plants, which produce less seed in proportion to biomass, may be this way to improve fitness by providing a greater dispersal advantage rather than producing a greater number of seed. Horseweed seed longevity has not been studied in great depth. Comes et al. (1978) studied germination of horseweed seeds stored every three months the first year and every 12 months following up to five years and found that 90% germination occurred at 12 months of dry storage. This number declined to 1% after 5 years of storage. Contrary to this, Tsuyuzaki and Kanda (1996), found viable seed in the seedbank of a 20 year old abandoned pasture where horseweed plants were not present.

Emergence in horseweed has been studied to a further extent in some parts of the world. It was found that flowering occurred much earlier in spring emerging plants versus fall emerging plants in Ontario, Canada (Tozzi and Van Acker 2014). They reasoned that due to the lack of rosette production in spring emerging plants, plants were able to bolt and flower quicker compared to fall plants that had spent energy developing rosettes to survive the winter (2014). At various locations in Tennessee, Main et al. (2006) found the highest emergence timings to be in September, October, and April. Though no horseweed emergence studies have been conducted in Oklahoma, a study in Eastern Kansas found that the majority of horseweed emergence occurs in the fall (McCall 2018).

Horseweed Management

Chemical

As of today, there are 37 documented unique cases of herbicide resistance in horseweed throughout the United States (Heap 2018). Since the first recorded case in 1994, horseweed resistance has become a growing concern in the agricultural community. Horseweed resistance to four herbicide modes of action have been recorded. These include photosystem I inhibitors (i.e. paraquat), photosystem II inhibitors (i.e. atrazine), Enolpyruvyl Shikimate -3- Phosphate (EPSP) synthase inhibitors (i.e. glyphosate), and Acetolactate Synthase (ALS) inhibitors (i.e. metsulfuron) (Heap 2018). Horseweed plants resistant to glyphosate and ALS inhibitors have been recorded in Oklahoma (A.1.) (Heap 2018). This justifies the need to incorporate herbicide resistance management strategies when controlling this species. These include the incorporation of multiple herbicide modes of action along with implementation of various methods of weed control besides chemical (Beckie 2006). However, as new herbicides are developed, it is imperative to determine their effectiveness at managing weed populations, evaluate their likelihood of crop injury, and gain a better understanding of how their efficacy might be affected by different environmental conditions.

There are several herbicides available for postemergence horseweed control in wheat. Still effective, widely used, and one of the oldest chemistries available is 2,4-D. Approximately 20% of the southern Great Plains region utilizes 2,4-D for broadleaf weed control in wheat (USDA-NASS 2018). In a field study conducted by Kruger et al. (2010), 90% control of horseweed control was observed with 560 g ha^{-1} of 2,4-D ester when applied to plants greater than 30 cm tall. A study by Wiese et al. (1995) in fallow conditions found that 2,4-D ester at the same rate was effective at controlling horseweed and had a cost as low as $11.40 per hectare (Weise et al. 1995). Similar to 2,4-D, MCPA is an older chemistry developed around the same time and can be an effective option for horseweed control in wheat; however, control with this product alone is often less compared to 2,4-D alone or when in tank mix with another herbicide (Kruger et al. 2010; Mahoney et al. 2016).

Another common synthetic auxin used for horseweed management is dicamba. A study conducted in a fallow field in Indiana found it to be 97% effective at controlling glyphosate resistant horseweed greater than 30 cm in size when applied at 280 g ae ha^{-1} (Kruger et al. 2010). Another Group 4 herbicide, fluroxypyr, was tested on both glyphosate resistant and susceptible horseweed rosettes at 156 g ae ha^{-1} with an average of 85% control among those treated (Kumar et al. 2017).

Newer to the market is a product containing halauxifen-methyl (halauxifen) plus florasulam. Halauxifen was developed by Dow AgroSciences and is one of two newer synthetic auxin herbicides recently developed by the company. It is labelled for use in wheat, barley, and triticale and was first available to growers in 2017. Like 2,4-D and dicamba, it mimics the hormone indole-3-acetic acid (IAA) within the plant and induces uncontrollable cell division eventually leading to plant death of those species that are susceptible (Epp et al. 2016).

Though 2,4-D, MCPA, and dicamba can potentially effectively control horseweed, these herbicides have restrictive application timings in wheat. For example, it is recommended that dicamba and some formulations of 2,4-D are applied prior to jointing in wheat to prevent crop injury. Additionally, 2,4-D cannot be applied until wheat is fully tillered and horseweed rosettes are often found competing with wheat before wheat has reached the tillering growth stage. MCPA has the widest application window and can be applied from 3- to 4-leaf stage up until early boot; however, as mentioned previously, control with this product can be variable. Halauxifen plus florasulam can be applied from the 2-leaf to flag leaf emergence stage in wheat which provides growers with an additional auxin that can be applied prior to tillering and after jointing in wheat.

ALS herbicides also offer effective control of horseweed; however, herbicide resistant biotypes exist, especially those that belong to the sulfonylurea family (Heap 2017). Herbicides in this family such as chlorsulfuron and metsulfuron-methyl (metsulfuron) can still be effective against horseweed if repeated use has not occurred in the past or resistant populations have not moved in from nearby fields through equipment, etc. According to a study conducted in fallow by Weise et al., metsulfuron applied at 5 g ha^{-1} and chlorsulfuron applied at 13 g ha^{-1} controlled 30 cm tall horseweed

95% (1995). This study also determined that the highest level of control occurred when applications were made when horseweed was 30 cm tall and growing vigorously compared to 5 and 10 cm tall. However, this could have been a result of drought stress (Weise et al. 1995). Other ALS chemistries available for control of horseweed in wheat include triasulfuron and thifensulfuron. In the same study by Weise et al., both triasulfuron + surfactant and thifensulfuron + surfactant achieved 97% horseweed control applied at the 14-leaf stage (Weise et al. 1995).

A study conducted by Kumar et al. (2017) using seed collected from various glyphosate resistant and susceptible horseweed populations from Nebraska and Montana achieved 93% control of glyphosate susceptible plants from Nebraska with halauxifen + florasulam, each applied at 5.25 g ai/ae ha^{-1}. Similar results were found when tested on glyphosate resistant horseweed from Nebraska; however, efficacy was lowered to 85% in glyphosate resistant horseweed from Montana (Kumar et al. 2017). Similar results were observed with shoot dry weight reduction in the glyphosate resistant horseweed population from Montana with 78% reduction while glyphosate susceptible and resistant plants from Nebraska were reduced 89% and 86% respectively (Kumar et al. 2017).

Lastly, some photosystem II inhibitors are available for postemergence control of horseweed in winter wheat including metribuzin and bromoxynil. A study in wheat by Mahoney et al. (2016) determined a premix of bromoxynil plus pyrasulfotole (an HPPD inhibitor) to have 95% control of glyphosate resistant horseweed ranging in size from 3 to 5 cm in height. Kumar et al. (2017) also found that horseweed was controlled 82% to 88% following use of bicyclopyrone, another HPPD inhibitor, plus bromoxynil applied at 37 and 175 g ai ha^{-1}, respectively, when plants were 8 to 10 cm in diameter. In a study testing Balance GT soybean tolerance to isoxaflutole, an active ingredient that is in the same mode of action as pyrasulfutole and bicyclopyrone, Ditschun et al. (2015) observed 95% control of glyphosate resistant horseweed that was 10 cm or less in height or diameter using a rate of 912 g ai ha^{-1}.

Mechanical

Traditionally, horseweed has not been considered a major agronomic pest due to its susceptibility to tillage (Bhowmik and Bekeck 1993). When tillage practices are implemented, horseweed severity is lessened. This was shown in a study conducted by Kapusta (1979), in which horseweed plants were counted in conventional tillage, moderate tillage, and no-till systems. The conventional and moderate tillage plots had zero horseweed plants for all three years of the study; however, the no-till plots ranged from 12 to 96 plants per plot depending on the year (1979).

However, since conservation tillage and no-till acres have increased, horseweed has become one of the most problematic weeds for farmers (Buhler and Owen 1997; Weise et al. 1995). According to a survey conducted by the Weed Science Society of America in 2017, horseweed is considered the third most problematic weed for producers in the United States (WSSA 2017). VanGessel mentions that glyphosate resistant horseweed is one of the most common and problematic weeds for no-till soybean growers (2001). An example of horseweed impact occurred in 1990 where a study conducted in a no-till field in Michigan found soybean yield to be reduced by 83% from the presence of 150 horseweed plants per m^{-2} (Bruce and Kells 1990). Another issue that makes horseweed so problematic in no-till systems is its ability to continuously germinate. According to a germination study by Nandula et al., horseweed germination reached 61%

under a 13 hour photoperiod accompanied by 24/20 C (2006). These average temperatures occur for approximately five months in Oklahoma (Oklahoma Mesonet 2018). Buhler and Owen warn that because horseweed can continue to germinate into the growing season of no-till corn and soybean spring management applications are recommended (1997).

Though evidence has been found to support yield loss in crops like corn or soybean there is little evidence supporting yield loss in wheat due to horseweed presence. A study in Ontario, Canada tested three different weed management practices and determined their effect on weed density as well as crop yield in a corn, soybean, and wheat rotation. While corn and soybean were found to be more susceptible to higher weed pressure, wheat yield did not seem to be affected by high weed densities (Swanton et al. 2002). Though other weeds were present in each cropping system, horseweed was one of the major weed species recorded during the wheat growing season. Additional work needs to be conducted to determine whether horseweed has a negative impact on wheat yield, but it is important to note that this is not the only deleterious effect horseweed can have on wheat production. The presence of green horseweed plants at time of at harvest is often witnessed in the southern Great Plains. Harvest aids can be applied to limit their impact if one is willing to invest in the cost of treatment. If plants are not managed, they may lead to unnecessary equipment costs due to wear on equipment; and potential discounts at the elevator from excessive grain moisture or dockage resulting from weed seeds present in harvested wheat (Lyon et al. 1994; Fast et al. 2009).

Cultural

Since horseweed resistance to herbicides is common, implementing several methods for management is critical. Crop rotation allows for diversification in chemicals used and is a common practice in conservation and no-till farming systems where mechanical weed control is used sparingly or not at all. A survey conducted in Indiana found that growers who planted soybeans for two or more years had greater issues with horseweed management in comparison to those who utilized crop rotation (Gibson et al. 2006). When growers rotated from corn to soybean the following growing season (or vice versa), horseweed was considered to be a problematic summer annual by less than 7% of growers as compared to 13% who planted soybean two years in a row (Gibson et al. 2006). Using crop rotation allows for the use of varied herbicide chemistries and can disrupt pest cycles, including weed cycles. If effective chemical control occurs, this reduces the amount of weed seed produced, which can eventually reduce overall weed presence by depleting horseweed seed in the soil.

Another cultural method that is not very common in agricultural systems but is common in range is fire. When horseweed seeds are dispersed they are generally located either on top of the soil surface or close to the soil surface under no-till management (Bhowmik and Bekeck 1993). The potential use of fire before planting, after harvest, or especially in a fallow situation could help reduce the amount of horseweed seed in the seed bank. However, if this management option were utilized, incorporating multiple burns will likely be necessary due to the life cycle of horseweed (DiTomaso et al. 2006). For example, to deplete the seedbank of yellow starthistle (*Centaurea solstitialis* L.), a winter annual, yearly burns were implemented for 3 years (DiTomaso et al. 2006). Another study performed on four different weedy annual species, including Japanese brome (*Bromus japonicas* Houtt.) at various fuel loads, found that Japanese brome emergence was reduced from nearly 100% in the nontreated control to 10 to 20% with only 100 g m^{-2} of fuel load while emergence was reduced to almost 0% at a 400 g m^{-2} fuel load (Vermeire and Rinella 2009). Though there are not many examples like this found in agricultural systems, fire is a reasonable tool to be implemented for managing annual weeds such as horseweed and should not be ruled out.

The use of planting cover crops is another cultural method that has been researched and offers many benefits outside of weed control. Benefits include reduced soil erosion, lowered soil temperatures, maintaining soil moisture, addition of organic matter, and increased weed suppression (Sosnoskie et al. 2012). Cover crops are useful as a weed control strategy primarily due to the competition they provide (Price and Norsworthy 2013), especially since horseweed favors bare, open patches to germinate best (Bhowmik and Bekeck 1993). Most cover crops are terminated prior to successful reproduction and therefore supply a residue that can be planted into. This residue is what contributes to soil organic matter, reduces weed germination, and provides cover to conserve soil moisture (Burgos and Talbert 1996). Though not a primary benefit of the use of cover crops, it is also theorized that many cover crop species may have allelopathic mechanisms that inhibit growth of other species; however, this has proven difficult to determine (Price and Norsworthy 2013; Burgos and Talbert 1996; Sosnoskie et al. 2012).

A study conducted in 2011 looked at the effect of different cover crops on weed control and yield in sweet corn (O'Reilly et al. 2011). Data was collected in the fall and spring prior to sweet corn planting and major fall weeds included horseweed, chickweed (*Stellaria media* L.), and henbit (*Lamium amplexicaule* L.). The study included several cereal species along with oilseed radish (*Raphanus sativus* L. var. *oleoferus*), which is a species that is known for its allelopathic properties (Vaughn and Boydston 1997). O'Reilly et al. found that oilseed radish treatments in the fall had 131 g m^{-2} less weed biomass compared to the no-cover control (2011). These results suggest that the use of cover crops could reduce the amount of weed seed in the seed bank over time while also contributing to soil improvement (Blanco-Canqui et al. 2013). Additionally, since horseweed seed usually germinates best when located in the top two cm of soil, the use of a cover crop with good vigor that can establish and grow quickly could potentially reduce horseweed populations by shading out germinating seeds and out-competing those that have already established.

Horseweed Management in Oklahoma

In 2017, Oklahoma wheat production totaled 98 million bushels with an average yield per acre of 34 bushels (USDA-NASS 2018). Winter wheat production in that same year brought in over 379 million dollars followed closely by cotton at 362 million dollars. According to Lollato et al. (2017), dual-purpose wheat is being utilized on approximately 8 million acres across southern Kansas, Oklahoma, and Texas. Therefore, the importance of winter wheat production is unparalleled due to its utilization by so many as a forage for cattle production and also for grain production.

Weed management is at the top of the list of challenges for Oklahoma wheat producers and horseweed is a critical weed in the state. Horseweed populations also are occurring at higher rates now than ever before due to many of the issues discussed previously such as varying germination timing, change in tillage practices, and increase in herbicide resistance. Producers are looking to different methods for horseweed control.

Historically, tillage has been the primary method to reduce horseweed populations along with in-season herbicide applications of ALS and auxin chemistries. Burndown treatments of glyphosate, paraquat, and auxins also are often used during the fallow period. Currently, glyphosate and ALS resistant weed species exist in Oklahoma, limiting the number of herbicide options that once existed to successfully manage horseweed. Additionally, the potential development of herbicide resistance is always a concern if heavy reliance on a particular mode of action continues to occur over an extended period of time with little variability of management practices within that system.

Horseweed management is a concern for summer crop producers in Oklahoma. There are many options available in row crops to control horseweed especially with the recent developments in auxin tolerant cotton, corn, and soybean; however, there is good reason to be cautious of becoming dependent on this technology since the first glyphosate resistant horseweed was documented after only three years of using RoundUp Ready soybeans (VanGessel 2001). Utilizing different modes of action outside of Group 4 and Group 9 herbicides will help reduce this potential as well as utilizing other methods of weed control. Herbicide use is not the only method available for horseweed control. Tillage is still an effective tool and can be implemented at various times, even in-season for our systems that have a relatively wide row spacing. Cultural factors such as field selection, row spacing, crop rotation, and cover crops also can reduce the amount of chemical management used in many cropping systems.

Finally, fallow period weed management is critical when managing horseweed. According to Pinchak et al., 30-80% of wheat planted in the Southern Great Plains region is grazed at some point (1996). In this region, utilizing wheat acreage as dual-purpose for cattle grazing and grain production is practiced. Often if this is implemented, a wheat-fallow-wheat system is in place and proper management of fallow ground is necessary to maintain this cycle. The fallow period is something many farmers use to essentially “rest” a field for a period of time. However, since they plan to return to that field and begin using it for production again, weed control is still important to conserve moisture and prevent the buildup of weed seed in the soil seed bank (Buhler et al. 2008). This can be accomplished by implementing different practices, a popular one being cover crops. According to an OSU extension document, cover crops can be used to aid in weed control and also help maintain soil moisture, increase organic matter, and prevent soil erosion (Warren et al. 2013). It also is possible, if the right cover crop is planted, for grazing to occur during the fallow period which is a popular practice in Oklahoma (Warren et al. 2013). Some summer cover crops include cowpea, sudangrass, millet, and sorghum.

Overall, although effective horseweed management options exist in wheat management cropping systems, strategies can become limited when considering constraints that might be present within a particular operation. For instance, although tillage is an effective means to control horseweed, if a producer implements no-till practices, this strategy is not a viable option. Therefore, the need to reevaluate the effectiveness of older herbicides or evaluation of newer herbicide options will be necessary.

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CHAPTER II

HORSEWEED (*Conyza canadensis* L.) MANAGEMENT IN OKLAHOMA WINTER WHEAT

ABSTRACT

Quelex® (halauxifen + florasulam), Sentrallas® (thifensulfuron + fluroxypyr), and Talinor® (bromoxynil + bicyclopyrone) are three new postemergence premix herbicides developed for control of broadleaf weeds in winter wheat. These herbicides along with older products were evaluated for their control of horseweed (*Conyza canadensis* L.) at in Oklahoma in the spring of 2017 and 2018. Visual weed control was estimated every two weeks throughout the growing season and wheat yield was collected from three of the six site years. Horseweed size ranged from 5 to 20 cm at time of application wheat growth stage range. Across all site years, halauxifen + florasulam achieved greater than 90% control with the exception of two treatments at Altus in 2018 and one at Ponca City in 2018. Thifensulfuron + fluroxypyr + dicamba achieved greater than 90% control at all site years except at Ponca City in 2017. However, when dicamba was replaced with MCPA, control at all site years was lower. Halauxifen + florasulam and thifensulfuron + fluroxypyr were both effective at controlling a wide range of horseweed rosette sizes across all locations while control with other treatments varied depending on presence of herbicide resistance, weed size, and tank mix partners.

INTRODUCTION

Horseweed (*Conyza canadensis* L.), often called marestail, is a common weed found in pastures, agricultural fields, riparian areas, and roadsides in Oklahoma. It is native to North America (Holm et al. 1997) and is a member of the Asteraceae family (Gleason and Cronquist 1963). It is an erect herb, growing up to 2.5 meters tall. It has a panicle inflorescence with individual capitula containing yellow disk and white ray flowers. When fertilized, these capitula can produce thousands of tiny seeds. Like many members of the Asteraceae family, these seeds have an attachment known as a pappus that aid in seed dispersal (Weaver 2001).

According to a survey conducted by the Weed Science Society of America in 2017, horseweed is considered the third most problematic weed for producers in the United States (WSSA 2017). Horseweed has many adaptive abilities that contribute to its success as a weed. A study using paraquat resistance as a marker found that less than 5% outcrossing occurred during horseweed reproduction. Therefore, self-pollination occurs more readily since the majority of flowers are pollinated prior to the capitula fully opening (Smisek et al. 1998). Generally, this allows for faster, more abundant seed production. A study by Bhowmik and Bekeck found that horseweed plants can produce up to 200,000 seeds per single plant that can then be dispersed up to 122 meters downwind (Bhowmik and Bekeck 1993, Regehr and Bazzaz 1979). Horseweed seed is unique in that it has no dormancy period thus once the seed contacts the soil surface, it can germinate if conditions are suitable (Buhler and Owen 1997). Therefore, though horseweed is traditionally considered a winter annual, it has the ability to behave like a summer annual under certain conditions (Weaver 2001, Buhler and Owen 1997).

Though horseweed has many attributes that make it successful, traditionally it has not been considered a major agronomic pest due to its susceptibility to tillage (Bhowmik and Bekeck 1993). However, since conservation tillage and no-till acres have increased, horseweed has become one of the most problematic weeds for farmers involved in these systems (Brown et al. 1988; VanGessel MJ 2001). As mechanical control of this plant decreases, chemical management often increases, further selecting for herbicide resistant biotypes and ultimately complicating a producers weed management decisions. If plants are not managed, they may lead to unnecessary equipment costs and/or discounts at the elevator due to excessive grain moisture from green plants at harvest or dockage from weed seeds present in harvested grain (Lyon et al. 1994; Fast et al. 2009).

As of today, there are 39 documented unique cases of horseweed resistance to a site of action in a specific state within the United States (Heap 2018). Among these documented cases horseweed is resistant to four herbicide modes of action. These include photosystem I inhibitors (i.e. paraquat), photosystem II inhibitors (i.e. atrazine), Enolpyruvyl Shikimate -3- Phosphate (EPSP) synthase inhibitors (i.e. glyphosate), and Acetolactate Synthase (ALS) inhibitors (i.e. metsulfuron). In Oklahoma, horseweed plants resistant to glyphosate and ALS inhibitors have been documented (A.1.) (Heap 2018).

There are several herbicides available for POST horseweed control in wheat. Still effective, widely used, and one of the oldest chemistries available is 2,4-D. Approximately 20% of the southern Great Plains region utilizes 2,4-D for broadleaf weed control in wheat (USDA-NASS 2018). Similar to 2,4-D, MCPA is an older chemistry developed around the same time and can be an effective option for horseweed control in wheat; however, control with this product alone is often less compared to 2,4-D alone or in tank mix with another herbicide (Kruger et al. 2010; Mahoney et al. 2016). Similar to 2,4-D, other common, synthetic auxins used for horseweed management are dicamba and fluroxypyr (Kruger et al. 2010; Mahoney et al. 2016).

Another commonly used group of herbicides applied PRE and POST in wheat are those that inhibit the ALS enzyme. If resistance to these herbicides is not present, they can be effective at controlling many broadleaf and grass weeds, including horseweed (Weise et al. 1995). Currently, there are 160 recorded species that are resistant to ALS herbicides, therefore this mode of action has the largest number of resistant species compared to all other modes. Additionally, according to Heap, wheat cropping systems have the highest number of ALS resistant weed species (2018). Three of the five ALS herbicides used in this study have been documented to have resistance in horseweed (Heap 2018).

A newer premix of both a synthetic auxin and an ALS inhibitor, halauxifen-methyl (halauxifen) and florasulam, has been introduced to the marker. Halauxifen was developed by Dow AgroSciences and is one of two newer synthetic auxin herbicides recently developed by that company. It is labelled for use in wheat, barley, and triticale and was first available to growers in 2017. Halauxifen + florasulam is applied at a single use rate of 5.25 g ae ha^{-1} and 5.25 g ai ha^{-1}, respectively. Following application, many crops (corn, rye, sorghum, cotton, and soybean) can be planted after three months. Application timing for best control of horseweed is recommended at a height of 10 cm or less (Anonymous 2018).

Syngenta also has recently released a new broadleaf herbicide in small grains. The premix contains a 4-hydroxyphenylpyruvate dioxygenase (HPPD) inhibitor, bicyclopyrone, and a photosystem II inhibitor, bromoxynil, and is labeled for POST broadleaf weed control in wheat and barley. It is labeled for use at 37 g ai ha^{-1} of bicyclopyrone and 175 g ai ha^{-1} of bromoxynil to 49 g ai ha^{-1} of bicyclopyrone and 233 g ai ha^{-1} of bromoxynil. Additionally, it is packaged in conjunction with CoAct+™, a spray additive. In addition to CoAct+™, it is recommended that a crop oil concentrate be used as well. Application timing is recommended for horseweed up to a 7.5 cm rosette size. Corn can be planted any time after application, but 10 to 12 months must pass before planting cotton, sorghum, and soybean (Anonymous 2016). Finally, a new premix being marketed by FMC containing an ALS inhibitor, thifensulfuron and a synthetic auxin, fluroxypyr, is labeled for use in wheat, barley and oats. The maximum rate labeled for a single application is 22 g ai ha^{-1} of thifensulfuron and 114 g ae ha^{-1} of fluroxypyr for weeds 10 cm or smaller. Corn, sorghum, wheat, barley and oats may be planted any time after application however all other crops must have an interval of 120 days before planting (Anonymous 2015-2016).

The need for newer herbicide chemistries, incorporation of multiple modes of action, and the application of various methods of weed control besides chemical is evident to effectively manage horseweed. However, as new herbicide products are developed, it is imperative to determine their effectiveness at managing weed populations, evaluate their likelihood of crop injury, and gain a better understanding of how they will perform in different environments across a region. The goal of this study was to evaluate horseweed control with previously available products as well as newer products at three locations across Oklahoma.

MATERIALS AND METHODS

Field experiments were conducted in Altus, Perkins, and Ponca City, Oklahoma during the 2016 to 2017 and 2017 to 2018 winter wheat growing season (October to June). However, field seasons are referred to as the year harvest took place in. During the 2017 field season, Altus, OK (34.51ºN, -098.99ºW, elevation was 419 m) was planted to wheat while Perkins, OK (35.99ºN, -097.04ºW, elevation was 287 m) and Ponca City, OK (36.62ºN, -097.02ºW, elevation was 365 m) were fallow. Additionally Ponca City was planted to wheat in 2018. All fields were planted using a grain drill with 19.05 cm row spacing. Altus was on a Hollister silty clay loam soil (fine, smectitic, thermic Typic Haplusterts). Perkins consisted of two different soil types: Konawa fine sandy loam (fine-loamy, mixed, active, thermic Ultic Haplustalfs) with 1% or more organic matter and Pulaski fine sandy loam (coarse-loamy, mixed, superactive, nonacid, thermic Udic Ustifluvents) with 1% or less organic matter. Ponca City was on a Norge silt loam (fine-silty, mixed, active, thermic Udic Paleustolls).

In general, rainfall at each location was less during the 2018 field season as compared to the 2017 field season. During the 2017 field season, Altus received 31.2 cm, Perkins (33.1 cm), and Ponca City (36.4 cm). While the 2018 field season, Altus received 19.9 cm, Perkins (29.4 cm), and Ponca City (31.4 cm). For harvested sites, rainfall was determined from planting date to harvest date. For fallow sites, rainfall was determined from herbicide application date to date of final rating (Table 2.1) (Oklahoma Mesonet 2018).

All studies were arranged in a randomized complete block design with 3 to 4 replications. Individual plots were 4.1 m wide by 7.6 or 9.1 m in length. Horseweed densities per plot ranged from five to 300 plants per plot. Herbicide applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 93 L ha^{-1}. All treatments were applied POST. Herbicides used consisted of: Quelex®) (halauxifen + florasulam), Sentrallas® (thifensulfuron + fluroxypyr), and Talinor® (bicyclopyrone + bromoxynil). Along with these, several older herbicides were included for comparison purposes (Table 2.2). All herbicide treatments were applied using water as the carrier except for two treatments that were applied using 28% UAN as the sole carrier. Those treatments contained halauxifen + florasulam alone or halauxifen + florasulam + MCPA. All treatments containing an ALS herbicide included a non-ionic surfactant at 0.25 % v/v. Herbicides and application rates are listed in Table 2.2 and specific herbicide treatments are listed in Table 2.3 and 2.4. Fertilization and disease control were standard for grain only wheat production in the southern Great Plains (Hunger et al. 2018; Raun et al. 2006).

Visual control estimates were recorded approximately every two weeks beginning at 14 days to 56 days after treatment (DAT) using a scale of 0 to 100 percent, where 0 equals no weed control and 100 equals complete control. Wheat injury was also evaluated using a scale of 0 to 100, where 0 equals no injury and 100 equals wheat death. Regarding wheat growth stage, all herbicides were applied within the recommended timing per their label and no injury was observed. Wheat was harvested with a

Wintersteiger (Wintersteiger Inc, Salt Lake City, UT) small plot combine. Due to the presence of glume blotch at Altus in 2018, stand height was reduced and therefore harvesting with the small plot combine was not possible. Instead, two 3 meter rows were harvested per plot using hand held battery powered shears. Samples were later threshed to separate grain from the chaff using a Vogel Nursery Thrasher (Bill's Welding, Pullman, WA).

A univariate analysis was performed on all responses in order to test for stable variance (Version 9.4, SAS Institute Inc., SAS Campus Drive, NC). No data sets were transformed as transformation did not increase stabilization. Data sets were analyzed using PROC MIXED with the pdmix 800 macro described by Saxton (1998) and treatments were separated by Fisher's Protected LSD at an alpha level of $P < 0.05$. In the model, fixed effects included herbicide treatment and random effects included replication. Horseweed visual control and yield for each location in 2017 and 2018 were assessed independently due to significant year and location effects ($P < 0.05$).

RESULTS AND DISCUSSION

Altus 2017

Horseweed rosettes at Altus in 2017 were approximately 5 cm on average and most treatments achieved 90% control or greater. The highest level of horseweed control (99%) was achieved by thifensulfuron + fluroxypyr + dicamba. All seven treatments containing halauxifen + florasulam controlled horseweed greater than 90% with the lowest level of control (93%) following halauxifen + florasulam + MCPA + UAN. The greatest level of control achieved with halauxifen + florasulam included the addition of dicamba and resulted in 98% control. All treatments with 90% control or greater were statistically similar with the exception of chlorsulfuron + metsulfuron + dicamba at 88% control, which controlled horseweed less than thifensulfuron + fluroxypyr + dicamba and halauxifen + florasulam + dicamba. All other treatments achieved similar levels of horseweed control with the exception of bicyclopyrone + bromoxynil and chlorsulfuron + metsulfuron + MCPA, and metsulfuron + 2,4-D which ranged in control from 76% to 82% and were all statistically similar. Yield at this location was not statistically significant.

Altus 2018

Contrary to the 2017 year, the largest horseweed plants across any year or location were present at Altus in 2018 with a rosette size of approximately 20 cm and some plants already bolting. Overall, the greatest control was achieved with treatments containing halauxifen + florasulam. All treatments containing this premix were statistically similar with the exception of halauxifen + florasulam + MCPA + UAN, which controlled horseweed 99% compared to halauxifen + florasulam alone and halauxifen + florasulam + dicamba, which controlled horseweed 83% and 86%, respectively. Both tank mixes containing chlorsulfuron + metsulfuron were statistically similar to the majority of halauxifen + florasulam treatments as well as both tank mixes containing the premix thifensulfuron + fluroxypyr (Table 2.4). Control with these treatments ranged from 83% with halauxifen + florasulam alone to 94% with halauxifen + florasulam + MCPA.

2,4-D, dicamba, and both tank mixes containing metsulfuron were statistically similar with horseweed control ranging from 76% to 78%. Control with thifensulfuron +

fluroxypyr + MCPA (85%) also was statistically similar to these treatments. The lowest control was observed with bromoxynil + bicyclopyrone at 25%. Yield from this location was highly variable due to disease pressure and sampling error that exists with extrapolating yield from hand harvested subsamples. Due to this, it is difficult to determine whether herbicide treatment is responsible for the yield differences

Perkins 2017

At application, the average rosette size at Perkins in 2017 was 10 cm. All treatments at this location were statistically similar with control greater than 92% except for 2,4-D, bromoxynil + bicyclopyrone, dicamba, and thifensulfuron + fluroxypyr + MCPA. Control with dicamba (91%) and thifensulfuron + fluroxypyr + MCPA (90%) was statistically similar to three of the twelve treatments with greater than 92% control. Control with 2,4-D (85%) was statistically similar to control achieved with dicamba applied alone and thifensulfuron + fluroxypyr + MCPA. Horseweed control following bicyclopyrone + bromoxynil was the lowest at 64%.

Perkins 2018

Horseweed rosettes at Perkins in 2018 at time of application were around 5 cm. Similar to 2017 at this location, all treatments with 95% control or greater were statistically similar. Halauxifen + florasulam alone and with UAN achieved 93% and 91% control, respectively, and were statistically similar to one another. Control with thifensulfuron + fluroxypyr was lowered to 68% from 98% when MCPA was used in place of dicamba. Similarly, control with 2,4-D and bicyclopyrone + bromoxynil were statistically similar at 64% and 63% control, respectively. Finally, when MCPA was used in place of dicamba with the premix of chlorsulfuron + metsulfuron, control was lowered to 55%.

Ponca City 2017

In 2017, horseweed rosettes at Ponca City averaged 15 cm in diameter and some plants had begun bolting. All treatments containing halauxifen + florasulam were statistically similar and achieved 93% control or greater. Thifensulfuron + fluroxypyr + dicamba also provided a similar level of control at 87% control. Lower control (77%) but still statistically similar to this was observed when MCPA replaced dicamba as a tank mix partner with thifensulfuron + fluroxypyr as well as with chlorsulfuron + metsulfuron + dicamba, which achieved 81% control. Dicamba alone controlled horseweed 74% and was statistically similar to control following metsulfuron + 2,4-D (70%) and 2,4-D alone and chlorsulfuron + metsulfuron + MCPA, which both provided 67% control. Bromoxynil + bicyclopyrone and metsulfuron + dicamba were statistically similar but provided the lowest levels of control at 63 and 61%, respectively.

Ponca City 2018

At Ponca City in 2018, horseweed rosettes were an average of 10 cm in diameter at the time of application. Four treatments achieved 99% control. Three of these treatments contained halauxifen + florasulam in tank mix with dicamba or MCPA (with or without UAN). The fourth treatment was thifensulfuron + fluroxypyr + dicamba. Control of horseweed for all treatments containing halauxifen + florasulam were statistically similar except for halauxifen + florasulam + 2,4-D, which provided 87% control. This treatment was only similar to three of the seven treatments containing the halauxifen + florasulam premix where control ranged from 90% with halauxifen +

florasulam alone to 96% when applied with UAN as the carrier. Other treatments that performed statistically similar included chlorsulfuron + metsulfuron + dicamba and dicamba alone. Also statistically similar but with control greater than 75% was metsulfuron + dicamba, 2,4-D alone, and bromoxynil + bicyclopyrone at 70%. The lowest control ranged from 64% to 60% with thifensulfuron + fluroxypyr + MCPA, chlorsulfuron + metsulfuron + MCPA, and metsulfuron + 2,4-D. Yield at this location was not statistically significant and therefore it is concluded that herbicide treatment did not affect yield.

Overall, in 2017, horseweed control with treatments containing halauxifen + florasulam were statistically similar at each location and all treatments achieved 90% control or greater. Control with halauxifen + florasulam in 2018 was more variable with the lowest control (83%) observed at Altus in 2018, however six of the seven treatments that contained halauxifen + florasulam at this location were statistically similar. Similar results were observed in a study by Kumar et al. using seed collected from various glyphosate resistant and susceptible horseweed populations from Nebraska and Montana where at least 92% control was observed at the same rate of halauxifen + florasulam used in this (2017). However, efficacy was lowered to 85% in glyphosate resistant horseweed from Montana (2017). Control with halauxifen + florasulam, especially when in tank mix, had the most consistent control across all site years. Reasons for this might be because horseweed is more susceptible to halauxifen than the other auxins tested in this study or that a synergistic effect is occurring between halauxifen and florasulam. A study by Kniss et al. (2011) determined that MCPA in combination with imazamox provided increased control of feral rye (*Secale cereale*) compared to when imazamox was applied alone.

Control with 2,4-D across site years was variable, however it was generally more effective when applied at smaller rosette sizes. A similar trend also was observed with dicamba. This is consistent with work from Seibert et al. (2004), who observed that red morningglory (*Ipomoea coccinea*) control was greater when 2,4-D was applied when plants were less than 60 cm in height (2004). In a field study conducted by Kruger et al. (2010), 90% control of glyphosate resistant horseweed was observed with 560 g ha^{-1} of 2,4-D ester when applied to plants greater than 30 cm tall. A study by Wiese et al. (1995) in fallow conditions found that 2,4-D ester at the same rate was effective at controlling similar sized horseweed. This is contrary to the results found in this study where 2,4-D at 524 g ae ha^{-1} only achieved greater than 90% control at Altus in 2017 when rosettes were 5 cm. At all other site years, horseweed control with 2,4-D was less than 85%. Lack of adequate control was often a result of regrowth observed from larger plants following application. Mahoney et al. (2016) observed similar control (89%) when 2,4-D was applied at 528 g ai ha^{-1} to 3 to 5 cm tall glyphosate resistant horseweed eight weeks after application. At Altus and Perkins in 2018, large temperature fluctuations occurred soon after application which also could have contributed to differences in control.

Several studies have confirmed the effectiveness of different ALS herbicides at controlling horseweed (Weise et al. 1995; Kumar et al. 2017). According to a production technology report from Oklahoma State Extension, 2.5 to 7.5 cm horseweed rosettes were controlled almost 100% following an application of chlorsulfuron + metsulfuron (Armstrong 2011). However, with the extensive use of these products in the last 35+

years, lowered efficacy due to herbicide resistance has been recorded (Heap 2018). In this study, a statistical decrease was observed at four of the six site years when MCPA replaced dicamba in tank mix. These differences are likely due to reduced sensitivity of horseweed to MCPA compared to dicamba. Mahoney et al. (2016), determined glyphosate resistant horseweed to be controlled 67% 8 WAT with 630 g ae ha^{-1} of MCPA while Kruger, et al. (2010) controlled 97% of 30 cm glyphosate resistant horseweed plants with dicamba 28 DAT. Similarly, control with thifensulfuron + fluroxypyr + dicamba was numerically greater than thifensulfuron + fluroxypyr + MCPA at all site years, however only Perkins and Ponca City in 2018 were statistically different.

Control with metsulfuron + 2,4-D or with dicamba was greater than 95% at Perkins in both years. However, at all other site years, control with both metsulfuron + 2,4-D and metsulfuron + dicamba was less than 85% except at Altus in 2017 where the tank mix with dicamba achieved 90% control. Differences across locations could be a result of historical use of metsulfuron. At Altus in 2017, ALS resistance to chlorsulfuron and metsulfuron is present however resistance is not present in 100% of the horseweed population, therefore control with chlorsulfuron or metsulfuron is still possible especially when a tank mix partner is included in the application. At Perkins, it is possible that efficacy was improved because weed size at application timing was within the recommended timing for metsulfuron and also because ALS resistance is not suspected at this site.

In 2017, Kumar et al. found that 8 to 10 cm glyphosate resistant horseweed from Montana and Nebraska was controlled 82 to 96% following use of bicyclopyrone + bromoxynil applied at 212 g ai ha^{-1} three weeks after application. These results vary drastically from those found in this study. Bicylopyrone + bromoxynil at 281 g ai ha $^{-1}$ never provided horseweed control of 80%. This product contains an HPPD inhibitor as well as a photosystem II inhibitor, therefore the symptomology appeared quickly and initially seemed severe. However, often between four and six weeks after application, regrowth began appearing and almost always resulted in a flowering plant. It is likely that the control differences observed with this herbicide compared to others are a result of the extended period of monitoring control that took place in this experiment.

Horseweed management in Oklahoma has become increasingly important due to its adaptive biology and herbicide resistance potential. Results from this study provide producers with an update on herbicide management of horseweed in winter wheat. Overall, several treatments were effective at controlling horseweed across multiple locations and stages of horseweed growth. However, the presence of ALS resistance did contribute to a treatments success or lack of success and should be considered when producers are designing a management plan.

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Table 2.1. Agronomic practices at Altus, Perkins, and Ponca City, Oklahoma in 2016-2017 and 2017-2018 seasons.

Year	Location	Wheat variety	Planting date	Herbicide application date	Total in season rainfall (cm)	Harvest date
2017	Altus	Bentley	November 17	March 10	31.2[a]	May 30
2017	Perkins	-	-	March 31	33.1[b]	-
2017	Ponca City	-	-	March 27	36.4	-
2018	Altus	Bentley	November 20	April 4	19.9	June 8
2018	Perkins	-	-	April 16	29.4	-
2018	Ponca City	LCS Chrome	November 20	April 16	31.4	June 14

[a] All rainfall data collected from the Oklahoma Mesonet (mesonet.org).

[b] For fallow sites, rainfall was determined from application timing to last rating.

Table 2.2. Herbicides and application rates for 2017 and 2018 trials at Altus, Perkins, and Ponca City, Oklahoma.

Herbicide common names	Brand names or designations	Application rates	Manufacturer
2,4-D Ester[a]	2, 4-D Ester LV 6	280 g ae ha^{-1} [b] 524 g ae ha^{-1} [c]	WinField United, St. Paul, MN, http://www.winfieldunited.com
Bicyclopyrone + bromoxynil	Talinor®	48 g ai ha^{-1} 233 g ai ha^{-1}	Syngenta Crop Protection, Greensboro ,NC, http://www.syngenta.com
Dicamba	Banvel®	70 g ae ha^{-1} [d] 140 g ae ha^{-1} [e]	Arysta LifeScience, Cary,NC, http://www.arysta.com
Halauxifen + florasulam	Quelex®	5.25 g ae ha^{-1} 5.25 g ai ha^{-1}	Dow AgroSciences, Indianapolis, IN, http://www.dowagro.com
MCPA Ester	MCPA Ester 4	350 g ae ha^{-1} [f] 560 g ae ha^{-1} [g]	DuPont, Wilmington, DE, http://www.dupont.com
Metsulfuron	Ally XP®	4.2 g ai ha^{-1}	FMC Agricultural Solutions, Philadelphia, PA, http://www.fmc.com

Chlorsulfuron + metsulfuron	Finesse® Cereal and Fallow	20.8 g ai ha^{-1}	DuPont, Wilmington, DE, http://www.dupont.com
Pyroxsulam	PowerFlex HL®	18.4 g ai ha^{-1}	Dow AgroSciences, Indianapolis, IN, http://www.dowagro.com
Thifensulfuron + fluroxypyr	Sentrallas®	22 g ai ha^{-1} 114 g ae ha^{-1}	DuPont, Wilmington, DE, http://www.dupont.com

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[a] Nonionic surfactant at 0.25% (v/v) was included with all ALS herbicides.

[b] Rate for 2,4-D when tank mixed with halauxifen + florasulam.

[c] Rate for 2,4-D applied alone.

[d] Rate for dicamba when tank mixed with halauxifen + florasulam or metsulfuron.

[e] Rate for dicamba when tank mixed with chlorsulfuron + metsulfuron, thifensulfuron + fluroxypyr, and applied alone.

[f] Rate for MCPA when tank mixed with halauxifen + florasulam.

[g] Rate for MCPA when tank mixed with metsulfuron + chlorsulfuron or thifensulfuron + fluroxypyr.

Table 2.3. Percent horseweed control seven to eight weeks after application in Altus, Perkins, and Ponca City, Oklahoma in 2017.

	Altus	Perkins	Ponca City
Herbicide treatment[a]	5 cm[b]	10 cm	15 cm
	------------------------	%	------------------------
2,4-D[c]	93 ab[d]	85 c	67 ef
Bromoxynil + bicyclopyrone	76 d	64 d	63 f
Dicamba	93 ab	91 bc	74 de
Chlorsulfuron + metsulfuron + dicamba	88 bc	100 a	81 cd
Chlorsulfuron + metsulfuron + MCPA	78 d	100 a	67 ef
Halauxifen + florasulam	95 ab	99 a	96 ab
Halauxifen + florasulam + 28% UAN[e]	97 ab	100 a	98 a
Halauxifen + florasulam + 2,4-D	95 ab	100 a	99 a
Halauxifen + florasulam + dicamba	98 a	100 a	100 a
Halauxifen + florasulam + MCPA + 28% UAN	93 ab	95 ab	93 ab
Halauxifen + florasulam + MCPA	95 ab	100 a	97 a
Halauxifen + florasulam + pyroxsulam	95 ab	100 a	96 ab
Metsulfuron + 2,4-D	82 cd	100 a	70 ef
Metsulfuron + dicamba	90 abc	95 ab	61 f
Thifensulfuron + fluroxypyr + dicamba	99 a	93 ab	87 bc
Thifensulfuron + fluroxypyr + MCPA	91 abc	90 bc	77 cde

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[a] Nonionic surfactant at 0.25% (v/v) was included with all ALS herbicides.

[b] Weed size at time of application.

[c] 2,4-D alone applied at 524 g ai ha^{-1} and in tank mix at 280 g ae ha^{-1}. Bicyclopyrone + bromoxynil applied at 282 g ai ha^{-1}. Dicamba applied alone and in tank mix with chlorsulfuron + metsulfuron or thifensulfuron + fluroxypyr at 140 g ae ha^{-1}. Dicamba applied at 70 g ae ha^{-1} in tank mix with halauxifen + florasulam or metsulfuron. Chlorsulfuron + metsulfuron applied at 20.8 g ai ha^{-1}. In tank mix with chlorsulfuron + metsulfuron or thifensulfuron + fluroxypyr, MCPA was applied 560 g ae ha^{-1}. In tank mix with halauxifen + florasulam, MCPA was applied at 350 g ae ha^{-1}. Halauxifen + florasulam applied at 5.25 g ae ha^{-1} and 5.25 g ai ha^{-1}, respectively. Pyroxsulam was applied at 18.4 g ai ha^{-1}. Metsulfuron was applied at 4.5 g ai ha^{-1}. Thifensulfuron + fluroxypyr was applied at 22 g ai ha^{-1} and 114 g ae ha^{-1}, respectively.

[d] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P < 0.05$.

[e] Water was used as the carrier for all treatments except those noted with 28% UAN where UAN was used as the sole carrier.

Table 2.4. Percent horseweed control seven to eight weeks after application at Altus, Perkins, and Ponca City, Oklahoma in 2018.

	Altus	Perkins	Ponca City
Herbicide treatment[a]	20 cm[b]	5 cm	10 cm
	-------------------------	%	-------------------------
2,4-D[c]	78 de[d]	64 e	77 d
Bromoxynil + bicyclopyrone	25 f	63 e	70 de
Dicamba	77 de	96 ab	89 ab
Chlorsulfuron + metsulfuron + dicamba	88 bc	97 ab	94 ab
Chlorsulfuron + metsulfuron + MCPA	88 bc	55 f	63 e
Halauxifen + florasulam	83 cde	93 bc	90 ab
Halauxifen + florasulam + 28% UAN[e]	90 abc	91 c	96 ab
Halauxifen + florasulam + 2,4-D	90 abc	97 ab	87 bc
Halauxifen + florasulam + dicamba	86 bcd	97 a	99 a
Halauxifen + florasulam + MCPA + 28% UAN	99 a	96 ab	99 a
Halauxifen + florasulam + MCPA	94 ab	96 ab	99 a
Halauxifen + florasulam + pyroxsulam	91 abc	95 abc	91 ab
Metsulfuron + 2,4-D	76 e	97 ab	60 e
Metsulfuron + dicamba	78 de	99 a	78 cd
Thifensulfuron + fluroxypyr + dicamba	92 abc	98 a	99 a
Thifensulfuron + fluroxypyr + MCPA	85 bcde	68 d	64 e

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[a] Nonionic surfactant at 0.25% (v/v) was included with all ALS herbicides.

[b] Weed size at time of application.

[c] 2,4-D alone applied at 524 g ai ha^{-1} and in tank mix at 280 g ae ha^{-1}. Bicyclopyrone + bromoxynil applied at 282 g ai ha^{-1}. Dicamba applied alone and in tank mix with chlorsulfuron + metsulfuron or thifensulfuron + fluroxypyr at 140 g ae ha^{-1}. Dicamba applied at 70 g ae ha^{-1} in tank mix with halauxifen + florasulam or metsulfuron. Chlorsulfuron + metsulfuron applied at 20.8 g ai ha^{-1}. In tank mix with chlorsulfuron + metsulfuron or thifensulfuron + fluroxypyr, MCPA was applied 560 g ae ha^{-1}. In tank mix with halauxifen + florasulam, MCPA was applied at 350 g ae ha^{-1}. Halauxifen + florasulam applied at 5.25 g ae ha^{-1} and 5.25 g ai ha^{-1}, respectively. Pyroxsulam was applied at 18.4 g ai ha^{-1}. Metsulfuron was applied at 4.5 g ai ha^{-1}. Thifensulfuron + fluroxypyr was applied at 22 g ai ha^{-1} and 114 g ae ha^{-1}, respectively.

[d] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P < 0.05$.

[e] Water was used as the carrier for all treatments except those noted with 28% UAN where UAN was used as the sole carrier.

Table 2.5. Winter wheat yield at Altus and Ponca City, OK in 2017 and 2018.

	Altus	Altus	Ponca City
Herbicide treatment[a]	2017	2018	2018
	----------------------	kg ha^{-1}	------------------------
Nontreated	2821	837 abc[b]	1406
2,4-D[c]	2507	623 abcde	1543
Bromoxynil + bicyclopyrone	2604	584 bcde	1494
Dicamba	2420	529 cde	1240
Chlorsulfuron + metsulfuron + dicamba	2463	378 e	1377
Chlorsulfuron + metsulfuron + MCPA	2333	617 abcde	1377
Halauxifen + florasulam	2572	937 a	1407
Halauxifen + florasulam + 28% UAN	2485	568 bcde	1856
Halauxifen + florasulam + 2,4-D	2713	667 abcde	1358
Halauxifen + florasulam + dicamba	2702	526 cde	1514
Halauxifen + florasulam + MCPA + 28% UAN[e]	2290	872 ab	1465
Halauxifen + florasulam + MCPA	2322	815 abcd	1445
Halauxifen + florasulam + pyroxsulam	2176	929 a	1358
Metsulfuron + 2,4-D	2734	783 abcd	1543
Metsulfuron + dicamba	2266	608 bcde	1231
Thifensulfuron + fluroxypyr + dicamba	2398	511 de	1280
Thifensulfuron + fluroxypyr + MCPA	2626	834 abc	1455

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[a] Nonionic surfactant at 0.25% (v/v) was included with all ALS herbicides.

[b] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P < 0.05$.

[c] 2,4-D alone applied at 524 g ai ha^{-1} and in tank mix at 280 g ae ha^{-1}. Bicyclopyrone + bromoxynil applied at 282 g ai ha^{-1}. Dicamba applied alone and in tank mix with chlorsulfuron + metsulfuron or thifensulfuron + fluroxypyr at 140 g ae ha^{-1}. Dicamba applied at 70 g ae ha^{-1} in tank mix with halauxifen + florasulam or metsulfuron. Chlorsulfuron + metsulfuron applied at 20.8 g ai ha^{-1}. In tank mix with chlorsulfuron + metsulfuron or thifensulfuron + fluroxypyr, MCPA was applied 560 g ae ha^{-1}. In tank mix with halauxifen + florasulam, MCPA was applied at 350 g ae ha^{-1}. Halauxifen + florasulam applied at 5.25 g ae ha^{-1} and 5.25 g ai ha^{-1}, respectively. Pyroxsulam was applied at 18.4 g ai ha^{-1}. Metsulfuron was applied at 4.5 g ai ha^{-1}. Thifensulfuron + fluroxypyr was applied at 22 g ai ha^{-1} and 114 g ae ha^{-1}, respectively.

[e] Water was used as the carrier for all treatments except those noted with 28% UAN where UAN was used as the sole carrier.

CHAPTER III

SMALLSEED FALSEFLAX (*Camelina microcapa* Andrz. Ex DC.) MANAGEMENT IN OKLAHOMA WINTER WHEAT

ABSTRACT

Three new herbicide premixes have recently been introduced for weed control in wheat. These include: Quelex® (halauxifen + florasulam), Sentrallas® (thifensulfuron + fluroxypyr), and Talinor® (bromoxynil + bicyclopyrone). These herbicides along with older products were evaluated for their control of smallseed falseflax (*Camelina microcarpa* Andrz. Ex DC.) in winter wheat in Oklahoma during the spring of 2017 and 2018 growing season. Visual weed control was estimated every two weeks throughout the growing season and wheat yield was collected both years. Smallseed falseflax size was approximately six cm at time of application in both years. Dicamba alone achieved 90% control of smallseed falseflax while control with all other treatments were greater than 95% with the exception of halauxifen + florasulam + pyroxsulam (85%) and bromoxynil + bicyclopyrone (86%). Overall wheat yield was greater in 2017 compared to 2018 but was not affected by herbicide treatment in either year. All treatments containing an ALS herbicide achieved adequate control therefore resistance is not suspected in this population.

INTRODUCTION

A native to Europe, smallseed falseflax (*Camelina microcarpa* Andrz. Ex DC.), from here on referred to as falseflax, was first introduced to North America in the 19th century, likely as a contaminate in flax seed *(Linum usitatissimum* L.) and other crops (Francis and Warwick 2009). Since its introduction is has been a common weed found in agricultural crops but has recently been considered as a potential oil seed crop (Royer and Dickinson 1999; Francis and Warwick 2009). Selective screening for ALS resistant varieties has even been conducted for this purpose (Walsh et al. 2012). As a pest, it is most commonly found in cool season crops such as winter wheat but also is found in field pea and spring wheat in the northern United States and Canada (Francis and Warwick 2009). Though falseflax has not been noted by producers in Oklahoma to be of high economic importance, it is still an undesired species competing on a wide geographical area.

Falseflax can look similar to horseweed (*Conyza canadensis* L.), a weed that has a considerable impact on agriculture. Much like horseweed, falseflax is a winter annual that develops a basal rosette covered in dense hairs. However, the leaves of this rosette are not lobed like horseweed. As falseflax matures, it develops an erect stem that is either simple or branched. According to Francis and Warwick, it can reach one meter in height (2009). Like many species in the Brassicaceae family, it has a raceme inflorescence with a terminal cluster of small, four-petaled, and pale yellow flowers (Francis and Warwick 2009). Once pollinated, these flowers develop into small, round siliques or “pods” with a persistent style (Francis and Warwick 2009). According to OA Stevens, falseflax is capable of producing almost 13,000 seeds per plant (1957). If present at harvest in grain cropping systems, this could lead to many consequences including dockage at the elevator.

Other potential reasons for concern of falseflax presence outside of crop competition include herbicide resistance as well as potential out-crossing with other mustard species. Through a whole plant dose-response study, Hanson et al. (2004) confirmed ALS resistance to metsulfuron and chlorsulfuron occurring naturally in a falseflax population in Oregon. This was the result of a single point mutation within falseflax that in other studies has resulted in resistance to four of the five chemical groups that make up the ALS mode of action (Hanson et al, 2004; Tranel and Wright 2002). Use of ALS herbicides in small grain producing regions is high and therefore the continued development of herbicide resistant species is of great concern.

Perhaps even more concerning is that the alleles that confer for ALS resistance are dominant over the susceptible when exposure to an ALS herbicide occurs. According to Tranel and Wright, even under heterozygous conditions, the resistant alleles are still selected for (2002). Thus, the resistant alleles can spread through both seed and pollen (Tranel and Wright 2002). According to a study presented at the 13th International Rapeseed Congress, a close relative of falseflax, known as gold of pleasure or largeseed falseflax (*Camelina sativa* (L). Crantz), has the ability to effectively cross-pollinate and produce seeds with falseflax (Seguin-Swartz, et al. 2011). Largeseed falseflax also has the ability to fertilize and produce viable seed with *Camelina alyssum* (Mill.) Thell. Thus, if not already present, the ability of these species to inherit ALS resistance is possible from falseflax (Seguin-Swartz, et al. 2011). Both of these species have been recorded in North America (Francis and Warwick 2009; Frankton and Mulligan 1987).

Management of falseflax in grain producing grass crops can be accomplished in several ways. Control of many broadleaf weeds in grass crops is achieved most commonly by the use of either ALS inhibiting herbicides or synthetic auxin herbicides; however, few studies have been conducted specifically on control of falseflax. If not resistant, group two herbicides including metsulfuron and chlorsulfuron are effective at controlling falseflax. According to an extension fact sheet by Oklahoma State University, metsulfuron, imazamox, propoxycarbazone, sulfosulfuron, pyroxsulam, and premixes of halauxifen + florasulam, metsulfuron + chlorsulfuron, and thifensulfuron + fluroxypyr are all effective at controlling falseflax that is not ALS resistant (Lofton et al. 2017). Other herbicide options include group four herbicides like dicamba, MCPA, 2,4-D, or 4-Hydroxyphenylpyruvate dioxygenase (HPPD)/ Photosystem II (PS II) premixes of pyrasulfotole + bromoxynil or bicyclopyrone + bromoxynil (Lofton et al. 2017).

MATERIALS AND METHODS

Field experiments were conducted at Lahoma, Oklahoma (36.39ºN, -98.11ºW) during the 2016-2017 and 2017-2018 winter wheat growing seasons (October to June). Field seasons are referred to as the year harvest took place in. All fields were planted using a grain drill with 19 cm row spacing. Soil was primarily composed of a Grant Silt loam (fine-silty, mixed, superactive, thermic Udic Argiustolls). During the 2017 field season, Lahoma received 45.2 cm of rain while the 2018 field season received only 23.1 cm (Table 3.1) (Oklahoma Mesonet 2018).

All studies were arranged in a randomized complete block design with three to four replications. Individual plots were 4.1 m wide by 7.6 or 9.1 m in length. Herbicide applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 93 L ha^{-1}. All treatments were applied POST. Herbicides used consisted of three newer premixes labelled for use in wheat: Quelex® (halauxifen + florasulam), Sentrallas® (thifensulfuron + fluroxypyr), and Talinor® (bicyclopyrone + bromoxynil). Along with these, several other products labeled in wheat for broadleaf weed control were included for comparison purposes. All herbicide treatments were applied using water as the carrier except for two treatments that were applied in 28% UAN. Treatments applied in UAN contained florasulam + haluxifen alone or tank mixed with MCPA. All treatments containing an ALS herbicide contained a nonionic surfactant at 0.25 % v/v^-. Herbicides and application rates are listed in Table 3.2 and specific herbicide treatments are listed in Table 3.3. Fertilization and disease control were standard for grain only wheat production in the southern Great Plains (Hunger et al. 2018; Raun et al. 2006).

Visual control estimates were recorded approximately every two weeks beginning at 14 days after treatment (DAT) up to 56 DAT using a scale of 0 to 100 percent, where 0 equals no weed control and 100 equals complete control. Wheat injury was also evaluated using a scale of 0 to 100, where 0 equals no injury and 100 equals wheat death. Regarding wheat growth stage, all herbicides were applied within the recommended timing per their label and no injury was observed. Wheat was harvested with a Wintersteiger (Wintersteiger Inc, Salt Lake City, UT) small plot combine on June 12, 2017 and June 12, 2018.

A univariate analysis was performed on all responses to test for stable variance (Version 9.4, SAS Institute Inc., SAS Campus Drive, NC). No data sets were transformed as transformation did not increase stabilization. Data sets were analyzed using PROC MIXED with the pdmix 800 macro described by Saxton (1998) and treatments were separated by Fisher's Protected LSD at an alpha level of $P < 0.05$. In the model, fixed effects included herbicide treatment and random effects included replication. Falseflax visual control estimates for 2017 and 2018 were averaged over year due to no significant year effect ($P > 0.05$). For wheat yield, 2017 and 2018 yields were assessed separately due to a significant year effect ($P < 0.05$).

RESULTS AND DISCUSSION

Weed Control and Wheat Yield

Averaged across years, falseflax control was 85% or greater for all treatments with no statistical separation. Falseflax was controlled 90% or greater for all treatments with the exception of halauxifen + florasulam + pyroxsulam and bromoxynil + bicyclopyrone, which controlled falseflax 85% and 86%, respectively. Dicamba alone achieved 90% control while all other treatments controlled falseflax 95% or greater.

Grain yield for each year was significantly different ($P < 0.05$), but treatment did not affect grain yield in either year ($P > 0.05$). Yield in 2017 averaged 2,955 kg ha^{-1} while yield in 2018 averaged 2,211 kg ha^{-1}. A higher yield in 2017 was likely due to an increased amount of rainfall received in 2017 compared to 2018 (Table 3.1). Similar trends were observed in the Oklahoma State Wheat Variety Trials conducted at Lahoma in 2016-2017 and 2017-2018. The mean yield for all varieties at Lahoma after the 2017 harvest was 3,968 kg ha^{-1} while the mean yield for all varieties after 2018 harvest was 2,152 kg ha^{-1}.

A major benefit from the relatively high level of control provided by all herbicide treatments is that producers battling falseflax have several options. They also have options with a relatively wide range in price as dicamba or 2,4-D alone can cost as little as several dollars per hectare. The high efficacy of the treatments tested allows winter wheat producers the opportunity to rotate through the use of multiple herbicide modes of action to control falseflax thus reducing the potential to select for herbicide resistance in this species. Additionally, due to the high efficacy of all treatments containing an ALS herbicide, herbicide resistance is not suspected in this population contrary to what Hanson et al. found in a population in Oregon (2009).

Since there has been little work done on the management of falseflax, it is necessary to compare studies performed on similar species. A study in wheat by Geier et al., found that pyroxsulam at 18 g ai ha^{-1} was 95% effective at controlling blue mustard (*Chorispora tenella* (Pall.) DC) at the fall POST timing however control was lowered to 77% at the spring POST timing. Results in this study found that control was lowered when pyroxsulam was tank mixed with halauxifen + florasulam compared to halauxifen + florasulam alone. This could be a result of antagonism occurring when these products are mixed together. Research is currently being conducted to answer this question. Results of the use of bromoxynil + bicyclopyrone has not been recorded in the literature on any mustard species however volunteer canola (*Brassica napus* (L.)), field pennycress (*Thalspi arvense* (L.), flixweed (Descurainia sophia (L.) Webb ex Prantl), London rocket (*Sisymbrium irio* (L.)), blue mustard, tumble mustard (*Sisymbrium altissimum* (L.)), wild mustard (*Sinapsis arvensis* (L.)), shepherd's-purse (*Capsella bursa-pastoris* (L.) Medik), and tansymustard (*Descurainia pinnata* (Walter) Britton) are all listed as controlled by the highest rate on the product label (Anonymous 2018). Similar mustard plants are listed as controlled when used at the highest labelled rate on the thifensulfuron + fluroxypyr label as well (Anonymous 2016). Further work looking specifically at control of mustard species using these newer products is needed.

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Table 3.1. Agronomic practices at Lahoma, Oklahoma in 2016-2017 and 2017-2018 seasons.

Year	Wheat variety	Planting date	Herbicide application date	Total in season rainfall (cm)	Harvest date
2017	Endurance	October 14	March 9	45.2[a]	June 12
2018	Spirit Rider	October 2	March 21	23.1	June 12

[a] All rainfall data collected from the Oklahoma Mesonet (www.mesonet.org).

Table 3.2. Herbicides and application rates for 2017 and 2018 trials at Lahoma, Oklahoma.

Herbicide common names	Brand names or designations	Application rates	Manufacturer
2,4-D Ester[a]	2, 4-D Ester LV 6	280 g ai ha^{-1} [b] 524 g ai ha^{-1} [c]	WinField United, St. Paul, MN, http://www.winfieldunited.com
Bicyclopyrone + bromoxynil	Talinor®	48 g ai ha^{-1} 233 g ai ha^{-1}	Syngenta Crop Protection, Greensboro ,NC, http://www.syngenta.com
Dicamba	Banvel®	70 g ai ha^{-1} [d] 140 g ai ha^{-1} [e]	Arysta LifeScience, Cary,NC, http://www.arysta.com
Halauxifen + florasulam	Quelex®	5.25 g ae ha^{-1} 5.25 g ai ha^{-1}	Dow AgroSciences, Indianapolis, IN, http://www.dowagro.com
MCPA Ester	MCPA Ester 4	350 g ae ha^{-1} [f] 560 g ae ha^{-1} [g]	DuPont, Wilmington, DE, http://www.dupont.com
Metsulfuron	Ally XP®	4.2 g ai ha^{-1}	FMC Agricultural Solutions, Philadelphia, PA, http://www.fmc.com

Metsulfuron + chlorsulfuron	Finesse® Cereal and Fallow	20.8 g ai ha^{-1}	DuPont, Wilmington, DE, http://www.dupont.com
Pyroxsulam	PowerFlex HL®	18.4 g ai ha^{-1}	Dow AgroSciences, Indianapolis, IN, http://www.dowagro.com
Thifensulfuron + fluroxypyr	Sentrallas®	22 g ai ha^{-1} 114 g ae ha^{-1}	DuPont, Wilmington, DE, http://www.dupont.com

[a] Nonionic surfactant at 0.25% (v/v) was included with all ALS herbicides.

[b] Rate for 2,4-D when tank mixed with halauxifen + florasulam.

[c] Rate for 2,4-D applied alone.

[d] Rate for dicamba when tank mixed with halauxifen + florasulam or metsulfuron.

[e] Rate for dicamba when tank mixed with chlorsulfuron + metsulfuron, thifensulfuron + fluroxypyr, and alone.

[f] Rate for MCPA when tank mixed with halauxifen + florasulam.

[g] Rate for MCPA when tank mixed with metsulfuron + chlorsulfuron or thifensulfuron + fluroxypyr.

Table 3.3. Percent falseflax control seven to eight weeks after application and winter wheat yield in Lahoma, Oklahoma in 2017 and 2018.

Herbicide treatment[a]	Control 6 cm[b]	Yield 2017	Yield 2018
	------ % ------	------------- kg ha^{-1}	--------------
Nontreated	-	2734	2007
2,4-D[c]	99	2822	1877
Bromoxynil + bicyclopyrone	86	2442	2307
Dicamba	90	2549	2007
Chlorsulfuron + metsulfuron + dicamba	99	2363	2190
Chlorsulfuron + metsulfuron + MCPA	100	2568	2476
Halauxifen + florasulam	95	2803	2398
Halauxifen + florasulam + 28% UAN[e]	98	2695	2463
Halauxifen + florasulam + 2,4-D	100	2676	2177
Halauxifen + florasulam + dicamba	96	2490	1916
Halauxifen + florasulam + MCPA + 28% UAN	100	2617	2359
Halauxifen + florasulam + MCPA	99	2510	1981
Halauxifen + florasulam + pyroxsulam	85	2930	2646
Metsulfuron + 2,4-D	99	2363	2242
Metsulfuron + dicamba	97	2412	2255
Thifensulfuron + fluroxypyr + dicamba	97	2676	2138
Thifensulfuron + fluroxypyr + MCPA	99	2461	2151

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[a] Nonionic surfactant at 0.25% (v/v) was included with all ALS herbicides.

[b] Weed size at time of application.

[c] 2,4-D alone applied at 524 g ai ha^{-1} and in tank mix at 280 g ae ha^{-1}. Bicyclopyrone + bromoxynil applied at 282 g ai ha^{-1}. Dicamba applied alone and in tank mix with chlorsulfuron + metsulfuron or thifensulfuron + fluroxypyr at 140 g ae ha^{-1}. Dicamba applied at 70 g ae ha^{-1} in tank mix with halauxifen + florasulam or metsulfuron. Chlorsulfuron + metsulfuron applied at 20.8 g ai ha^{-1}. In tank mix with chlorsulfuron + metsulfuron or thifensulfuron + fluroxypyr, MCPA was applied 560 g ae ha^{-1}. In tank mix with halauxifen + florasulam, MCPA was applied at 350 g ae ha^{-1}. Halauxifen + florasulam applied at 5.25 g ae ha^{-1} and 5.25 g ai ha^{-1}, respectively. Pyroxsulam was applied at 18.4 g ai ha^{-1}. Metsulfuron was applied at 4.5 g ai ha^{-1}. Thifensulfuron + fluroxypyr was applied at 22 g ai ha^{-1} and 114 g ae ha^{-1}, respectively.

[e] Water was used as the carrier for all treatments except those noted with 28% UAN where UAN was used as the sole carrier.

APPENDICES

Table A.1. Percent visual control and biomass of a horseweed population from Altus, OK following various rates of metsulfuron.

Metsulfuron dose[a]	Control[b]	Biomass
---------- g ai ha^{-1} -----------	-------------- % -------------	---------------- g --------------
0[c]	0 c[d]	-
4.2	80 b	0.144 a
8.4	90 ab	0.0977 ab
16.8	81 b	0.0399 b
33.6	100 a	0.0274 b

[a] Horseweed rosettes at time of application ranged from 6 to 10 cm.

[b] Percent visual control and dry biomass 28 days after application.

[c] Nonionic surfactant at 0.25% (v/v) was included.

[d] Means within a column followed by the same letter are not significantly different according to Fisher’s Protected LSD test at $P < 0.05$.

Table A.2. Percent visual control and biomass of a horseweed population from Altus, OK following various rates of chlorsulfuron.

Chlorsulfuron dose[a]	Control[b]	Biomass
---------- g ai ha^{-1} -----------	-------------- % -------------	---------------- g --------------
0[c]	0 b[d]	-
17.3	64.5 a	0.125 a
34.6	68.5 a	0.0961 a
69.2	78.5 a	0.0858 a
138.4	80 a	0.1018 a

[a] Horseweed rosettes at time of application ranged from 6 to 10 cm.

[b] Nonionic surfactant at 0.25% (v/v) was included.

[c] Percent visual control and dry biomass 28 days after application.

[d] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P < 0.05$.

Table A.3. Percent visual control and biomass of a horseweed population from Lahoma, OK following various rates of metsulfuron.

Metsulfuron dose[a]	Control[b]	Biomass
---------- g ai ha^{-1} -----------	-------------- % -------------	---------------- g --------------
0[c]	0 b[d]	-
4.2	99.8 a	0.0179 a
8.4	99.8 a	0.0225 a
16.8	100 a	0.028 a
33.6	100 a	0.0091 a

[a] Horseweed rosettes at time of application ranged from 6 to 10 cm.

[b] Percent visual control and dry biomass 28 days after application.

[c] Nonionic surfactant at 0.25% (v/v) was included.

[d] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P < 0.05$.

Table A.4. Percent visual control and biomass of a horseweed population from Lahoma, OK following various rates of chlorsulfuron.

Chlorsulfuron dose[a]	Control[b]	Biomass
---------- g ai ha^{-1} -----------	-------------- % -------------	---------------- g --------------
0[c]	0 b[d]	-
17.3	86.5 a	0.0419 a
34.6	88 a	0.025 a
69.2	90.5 a	0.0246 a
138.4	97.8 a	0.0182 a

[a] Horseweed rosettes at time of application ranged from 6 to 10 cm.

[b] Percent visual control and dry biomass 28 days after application.

[c] Nonionic surfactant at 0.25% (v/v) was included.

[d] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P < 0.05$.

VITA

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