SANDBUR SEED ECOLOGY AND CONTROL IN BERMUDAGRASS TURF AND PASTURES

By

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SANDBUR SEED ECOLOGY AND CONTROL IN BERMUDAGRASS TURF AND PASTURES

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Abstract:

Two experiments were initiated in Perkins, Oklahoma to evaluate and compare control methods of 22 turf herbicide products for southern sandbur (*Cenchrus echinatus* L.). Bermudagrass [*Cynodon dactylon* (L.) Pers.] and sandbur were rated by visual percentage injury, coverage, and sandbur control. At 15 weeks after treatment (WAT), all treatments, excluding oryzalin, showed increased sandbur control compared to the non-treated. Oxadiazon controlled 75% of the sandbur and resulted in the best control at 15 WAT. However, PRE products lost their efficacy and sandbur recovered by 18 WAT where no treatment was better than the non-treated. In POST trials, a few herbicides injured bermudagrass and caused delays in healthy growth. At 6 WAT, thiencarbazone-methyl + foramsulfuron + halosulfuron-methyl, amicarbazone, topramezone, and mesotrione caused the highest bermudagrass injury at 20%. Fortunately, by 9 WAT, the bermudagrass began to recover and no treatment thinned the bermudagrass stands. Trifloxysulfuron provided 4 weeks of continuous control at 68%; however, sandbur began to recover by 8 WAT and control decreased to 28%. By 8 WAT, no treatment controlled sandbur more than 40%.

Pasture trials were initiated near Hennessey, Oklahoma to evaluate and compare control methods of 10 herbicide products for longspine sandbur [*Cenchrus longispinus* (Hack.) Fern.]. Bermudagrass and sandbur were rated by visual percentage injury, coverage, and sandbur control. Of all 10 products, imazapic and glyphosate applied POST caused up to 9 weeks of bermudagrass injury with injury peaking at 40 and 55%, respectively. Imazapic and glyphosate also controlled the longspine sandbur most effectively, offering 70 and 98 percent control at 3 WAT and between 75 and 90% control at 9 WAT. Although nicosulfuron + metsulfuron methyl (MSM) and nicosulfuron + MSM + pendimethalin did not control sandbur as efficiently as glyphosate and imazapic, they did cause significant inflorescence suppression without causing unrecoverable bermudagrass injury.

Two greenhouse experiments were initiated in Stillwater, Oklahoma to evaluate and compare bur deformities and seed viability. The experiments were factorial in design with factor 1: application timing, and factor 2: herbicide. Results from both studies indicated that early applications made on 1 to 3 week old sandbur plants can cause significant decrease in seed viability and floret production.

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CHAPTER ONE

SOUTHERN SANDBUR CONTROL IN BERMUDAGRASS TURF

Abstract

Field experiments were initiated in Perkins, Oklahoma in 2014 at Perkins Park and in 2015 at Perkins Cemetery to evaluate sandbur (*Cenchrus ssp*.) control using herbicide in bermudagrass [*Cynodon dactylon* (L.) Pers.] turf. PRE and POST applications were separated into two experiments at the same locations. Sandbur cover in non-treated plots averaged 15% at 18 weeks after treatment (WAT). Of the PRE applications of herbicides, all treatments, excluding oryzalin, showed increased sandbur control compared to non-treated at 15 WAT. Oxadiazon controlled sandbur most effectively up to 75% at 15 WAT. However, herbicide products applied PRE lost their efficacy, and sandbur recovered by 18 WAT. None of PRE treatments were significantly better than the non-treated controls. In POST trials, a few herbicides injured bermudagrass and caused delays in healthy growth. At 6 WAT, thiencarbazone-methyl + foramsulfuron + halosulfuron-methyl, amicarbazone, topramezone, and mesotrione caused the highest bermudagrass injury of 20%. However, by 9 WAT, the bermudagrass began to recover and no significant loss of bermudagrass cover was found. Control of sandbur was found most effective with trifloxysulfuron for 4 weeks at 68%; however, by 8 WAT, sandburs plants began to recover

and control decreased to 28%. By 8 WAT, no treatment provided more than 40% control of sandbur.

Introduction

Several sandbur species affect turfgrass systems and pastures in the Southern Great Plains including southern sandbur (*Cenchrus echinatus* L.), field sandbur (*Cenchrus spinifex* Cav.), and longspine sandbur [*Cenchrus longispinus* (Hack.) Fern.]. Sandburs behave as summer annuals or short-lived perennials, and they grow well in disturbed and sandy-loam soils (Funderburg et al., 2011).

Sandburs grow 20 to 80 centimeters in height and branch outward forming large mats (Barnard, 2014). Sandburs have a smooth, open leaf sheath with fine hairs along the margin. The ligule is ciliate with a few hairs near the collar. The leaf blades are flat and narrow. The stem is round and may have a reddish tint ascending from the base of the shoot (Uva et al., 1997). The seed head is a raceme with compact inflorescence of sharp, spiny burs attached directly to the floral stalk (Barnard, 2014). A floret of a sandbur can contain as many as 10 to 30 burs per spike and 2 to 3 seed within each bur (Wicks et al., 1999).

Sandbur species emerge early in the year about mid-April when the soil temperature and moisture becomes favorable, and they can germinate throughout the summer season (Boydston, 1989). Within the bur, the seed formed in the top portion of a bur is larger and has a lower level of dormancy than that of the second or third seed (Boydston, 1989). Twentyman (1974) showed that innate dormancy in sandbur is controlled by the position of the seed within the bur. The primary seed is the first of the seed to ripen. The secondary seed tend to lose dormancy more slowly and persist in the soil for more than a year (Twentyman, 1974). The different levels of dormancy for the seed provide a greater variety in germination times so that the seed do not germinate all at once within the bur. The burs can overwinter on or near the soil surface, and the seed can lay dormant for many years (Boydston, 1989). Dormancy differences in the sandbur seedbank can result in germination throughout a season or over several years from the initial seed source (Boydston, 1984). Thus, the dormancy is a common problem when controlling seedbank populations.

Sandburs are undesirable in turf due to the production of burs. In turf management, sandburs have sharp spinules with backward pointing barbs that make them very painful and a nuisance (Wicks et al., 1999). When the burs puncture the skin, their barbs make removal painful because they attached similarly to that of a very small fish hook. Often times, this can result in splinters stuck under the skin. Burs are notorious for tangling themselves in pet hair and puncturing tires of small equipment (Barnard, 2014). Pets or animals can easily get them between pads in their paws, and riding a bicycle through an infested park can lead to flat tires.

Monosodium methanearsonate (MSMA) is an organic arsenical herbicide family member that has been used to control various grass and broadleaf species (Keigwin, 2013). Currently, its mode of action is unknown (Mallory-Smith et al., 2003). At 0.91 kg of product per acre, MSMA was considered an effective way to control sandbur species in bermudagrass turf (Keigwin, 2013). However, registration of this herbicide was canceled to the general public in September 2009 due to the rising concern that the organic arsenic residue in the soil would convert into inorganic arsenic compounds and pollute fresh water (Keigwin, 2013). MSMA can now only be used on cotton (*Gossypium spp*), sod farms, golf courses, and highway rights-of-way (EPA, 2016). Since the phase-out of registration of MSMA, there have been no identified herbicides products which control sandburs effectively after germination in turf without causing damage to the bermudagrass turf. Products shown in Table 1 are some herbicides currently labeled as control methods for sandbur.

In turf management, one of the best control methods for sandbur is by maintaining a well fertilized soil (Kendig et al., 2006) to increase lawn quality, density and thus competition of turfgrass with sandbur. Sandburs thrive in well-drained, sandy to sandy loam soils that may be unfavorable for other grass species (Boydston, 1989). By improving turf management with fertilization and appropriate water scheduling, the desired turf will improve in density and height and can reduce the sandbur numbers by competition. Mowing is often an ineffective method of control for sandburs as they have a low growth habit, branching out close to the ground (Smith et al., 2013). As the plants recover and adapt, they can produce burs below the mowing height. Future research is needed to evaluate additional options for sandbur control in turf landscapes and to increase the quality of recreation and residential landscapes. The purpose of this study is to evaluate certain herbicide products sprayed PRE and POST sandbur germination, and determine the most effective method to control sandburs in bermudagrass.

Materials and Methods

Herbicide experiments were conducted at a local park in Perkins, Oklahoma in 2014 and duplicate studies at the Perkins cemetery in 2015 to evaluate efficacy of several products to control sandbur. Experiments were established as randomized complete block designs with four replications of treatment and 1.8 x 1.8 square meter plot sizes. The treatments were applied using a CO_2 pressurized bicycle-type sprayer calibrated to apply 280 L ha^{-1}. Treatments in the PRE application experiment were: indaziflam (Specticle®) at 70 g ai ha^{-1}, pendimethalin (Pendulum Aquacap®) at 1651 g ai ha^{-1} as a single application and a split application spaced 3 weeks apart, oxadiazon (Ronstar® Flo) at 2245 g ai ha^{-1}, dithiopyr (Dimension® Ultra) at 4264 g ai ha^{-1}, prodiamine (Barricade® 4FL) at 1048 g ai ha^{-1}, oryzalin (Surflan® Flex) at 1683 g ai ha^{-1}, simazine (Simazine® 4L) at 1120 g ai ha^{-1}, thiencarbazone-methyl + foramsulfuron + halosulfuron-methyl (Tribute® Total) at 136 g ai ha^{-1}, and a non-treated control. The PRE experiments were administered on 1 Apr 2014 and 20 Mar 2015 with PRE applications. Application of treatments were in late afternoon with air temperature at 15˚C and a relative humidity of 53%. Soil temperature was 17˚C at a depth of 4 cm. Wind velocity was 162 m s^{-1} and cloud cover was 0%. Treatments in 2015 were applied late afternoon with air temperature at 15˚C and a relative humidity of 57%. Soil temperature was 15˚C. Wind velocity was 112 m s^{-1} and cloud cover was 100%.

In the POST application experiment, treatments included one herbicide applied PRE: pendimethalin (Pendulum Aquacap®) at 1651 g ai ha^{-1}, and ten herbicides applied POST: quinclorac (Drive®) at 275 g ai ha^{-1}, metsulfuron-methyl (Manor®) at 42 g ai ha^{-1}, dicamba + iodosulfuron + thiencarbazone-methyl (Celsius® WG) at 176 g ai ha^{-1}, foramsulfuron (Revolver®) at 33 g ai ha^{-1}, trifloxysulfuron-sodium (Monument® 75WG) at 445 g ai ha^{-1}, 2, 4-D (2, 4-D® LV 400) at 531 g ai ha^{-1}, thiencarbazone-methyl + foramsulfuron + halosulfuron-methyl (Tribute® Total) 136 g ai ha^{-1}, amicarbazone (Xonerate®) at 245 g ai ha^{-1}, topramezone (Pylex®) at 24 g ai ha^{-1}, mesotrione (Tenacity®) at 23 g ai ha^{-1}, and a non-treated control. The POST application experiment was initiated 11 Jul 2014 and 19 Jun 2015. Application of these treatments were applied mid-morning with air temperature at 21˚C and a relative humidity of

63%. Soil temperature was 27˚C. Wind velocity was 215 m/s and cloud cover was 0%. Treatments in 2015 were applied in late afternoon with air temperature at 20˚C and a relative humidity of 65%. Soil temperature was 24˚C. Wind velocity was 188 m/s and cloud cover was 20%.

Visual percent bermudagrass injury, percent sandbur control, and number of sandbur plants per plot were taken for evaluation. Data were managed in ARM 9.2 and subjected to ANOVA. Means were separated using Fisher's protected LSD at α=0.05.

Weather permitting, plots were mowed once a week with a gas-powered push lawn mower at a cutting height of approximately 5 cm. Soil sample tests were ran for both 2014 and 2015 sites for pH, macronutrients, and micronutrient reports prior to treatments.

Results

In the PRE application experiments, bermudagrass was not injured by any treatment in either year. At 15 WAT, all treatments, excluding oryzalin, showed increased sandbur control (Table 1). Oxadiazon controlled sandburs up to 75% and resulted in the best control at 15 WAT (Table 1). However, products applied as PRE lost their efficacy, and sandburs rebounded by 18 WAT when no treatment was significantly better than the non-treated control (Table 1). Sandbur cover in non-treated plots averaged 15% at 18 WAT (Table 2). Oxadiazon controlled sandbur most effectively, decreasing sandbur cover to only 6% by 18 WAT (Table 2). Pendimethalin, dithiopyr, oryzalin, and simazine also significantly decreased sandbur cover compared to the non-treated control.

In POST application experiments, a few herbicides injured bermudagrass and caused delays in healthy growth. At 6 WAT, thiencarbazone-methyl + foramsulfuron + halosulfuron-methyl, amicarbazone, topramezone, and mesotrione caused the highest bermudagrass injury of 22%, 23%, 20%, and 20%, respectively (Table 3). Topramezone caused bleaching symptoms of the bermudagrass, while thiencarbazone-methyl + foramsulfuron + halosulfuron-methyl, amicarbazone, and mesotrione caused chlorosis. By 9 WAT, the bermudagrass began to recover (Table 3). No treatment thinned bermudagrass stands, and bermudagrass cover never decreased below 75% at 6, 9, or 11 WAT (Table 4). For sandbur control, trifloxysulfuron provided 4 weeks of control at 68% compared to the non-treated at 0%; however, by 8 WAT, sandbur plants began to recover and control decreased to 28% (Table 5). By 8 WAT, no treatment controlled sandburs more than 40% (Table 5).

Conclusion

This research indicates pendimethalin, dithiopyr, oryzalin, and simazine can significantly decrease sandbur cover (Table 1) in a stand of bermudagrass turf. Overall, oxadiazon provided the best control, but all treatments applied PRE lost efficacy before the end of the summer growing season. By 18 WAT, sandbur in all plots began to recover and increase in numbers, with no significant differences between herbicide treatments. Split applications of all products applied PRE should be considered to improve the length of control in the season. Rainfall is also important to ensure proper activation of these products in a timely manner after application.

In the POST-applied herbicide trials, trifloxysulfuron showed the most promise, providing 68% control at 4 WAT; however, by 8 WAT, sandbur began to recover and control decreased to 28%

(Table 5). Several products have the potential to injure bermudagrass, and, at 6 WAT, thiencarbazone-methyl + foramsulfuron + halosulfuron-methyl, amicarbazone, topramezone, and mesotrione caused the highest bermudagrass injury at 22%, 23%, 20% and 20%, respectively. All bermudagrass recovered by 9 WAT, but the bleaching injury caused by topramezone took slightly longer to recover. No treatments applied POST were identified which could effectively provide sandbur control at greater than 90% as reported by the *Initial Scientific Report of MSMA/DSMA* for monosodium acid methanearsonate herbicide (MSMA) (EPA, 1975). Additional research will be needed to identify suitable products to manage sandbur after emergence.

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Tables and Figures

Table 1. The percent control of southern sandbur in PRE applied experiment for 15 and 18 weeks after treatment in Perkins, Oklahoma.

		Sandbur Control (WAT)[1]	
Treatment	Rate	15	18
		------------------------%------------------------	
non-treated		0_{c}	0_{b}
Indaziflam	70 g ai ha^{-1}	54_{ab}	30_{a}
pendimethalin	1651 g ai ha^{-1}	41_{b}	55_{a}
oxadiazon	2245 g ai ha^{-1}	75_{a}	43_{a}
dithiopyr	4261 g ai ha^{-1}	35_{b}	47_{a}
prodiamine	1048 g ai ha^{-1}	52_{ab}	37_{a}
oryzalin	1682g ai ha^{-1}	29_{cb}	50_{a}
pendimethalin split	1170 g ai ha^{-1} 1651 g ai ha^{-1}	52_{ab}	53_{a}
simazine	1121 g ai ha^{-1}	42_{b}	45_{a}
thiencarbazone-methyl + foramsulfuron + halosulfuron-methyl	136 g ai ha^{-1}	48_{ab}	36_{a}
LSD[2]		34	33

[1] . Abbreviations: WAT, weeks after treatment
[2] . LSD-means within the same column followed by the same letter are not significantly different at p=0.05.

Table 2. The percent cover of sandburs in PRE applied experiment for 18 weeks after treatment in Perkins, Oklahoma.

Treatment	Rate	Sandbur cover 18 (WAT)[1]
	---g ai ha^{-1}---	----------%---------
non-treated		15 a
indaziflam	70	12 ab
pendimethalin	1651	8 b
oxadiazon	2245	6 b
dithiopyr	4264	8 b
prodiamine	1048	11 ab
oryzalin	1683	8 b
pendimethalin split	1170 1651	9 ab
simazine	1120	8 b
thiencarbazone-methyl + foramsulfuron + halosulfuron-methyl	136	11 ab
LSD[2]		7

[1] . Abbreviations: WAT, weeks after treatment
[2] . LSD-means with the same letter are not significantly different.

Table 3. Percent bermudagrass injury 6 and 9 weeks after POST treatments at Perkins, OK.

		Bermudagrass injury	
		6 (WAT)[1]	9 (WAT)[1]
Treatment	Rate		
	---g ai ha^{-1}---	-----------------------%-----------------------	
non-treated		7a	2bc
pendimethalin[2]	1651	7a	0c
quinclorac	275	10a	0c
metsulfuron methyl	42	8a	0c
thiencarbazone-methyl + dicamba + Iodosulfuron	176	14a	0c
foramsulfuron	33	8a	0c
trifloxysulfuron	445	8a	0c
2, 4-D	531	13a	0c
thiencarbazone-methyl + foramsulfuron + halosulfuron-methyl	136	22a	6ab
amicarbazone	245	23a	3abc
topramezone	25	20a	7a
mesotrione	23	20a	3abc
LSD[3]		19	5

[1] . Abbreviations: WAT, weeks after treatment

[2]. Pendimethalin was applied 8 weeks prior to POST treatments, corresponding 6 and 9 WAT, respectively.

3. Means in the same column followed by the same letter are not significantly different using Fishers protected LSD at a=0.05

Table 4. Percent bermudagrass cover at 6, 9, and 11 weeks after POST treatments in Perkins, Oklahoma.

		Bermudagrass cover		
		6(WAT)[1]	9(WAT)[1]	11(WAT)[1]
Treatment	Rate			
	---g ai ha^{-1}---	------------------------%------------------------		
non-treated		78_{ab}	86_{a}	86_{abc}
pendimethalin[2]	1651	81_{ab}	86_{a}	84_{abc}
quinclorac	275	80_{ab}	86_{a}	83_{bc}
Metsulfuron-methyl	42	81_{ab}	86_{a}	86_{abc}
thiencarbazone-methyl + dicamba + Iodosulfuron	176	79_{ab}	87_{a}	83_{c}
foramsulfuron	33	80_{ab}	87_{a}	86_{abc}
trifloxysulfuron	445	81_{ab}	87_{a}	84_{abc}
2, 4-D	531	84_{a}	83_{a}	86_{abc}
thiencarbazone-methyl + foramsulfuron + halosulfuron-methyl	136	75_{b}	88_{a}	88_{a}
amicarbazone	245	79_{ab}	83_{a}	87_{ab}
topramezone	25	76_{ab}	83_{a}	86_{abc}
mesotrione	23	79_{ab}	86_{a}	87_{ab}
LSD[3]		8	8	4

[1] . Abbreviations: WAT, weeks after treatment

[2] . Pendimethalin was applied 8 weeks prior to POST treatments, corresponding 14, 17, and 19 WAT, respectively.

3. Means were separated using Fishers protected LSD at a=0.05

Table 5. Percent sandbur control at 4 and 8 weeks after POST treatments in Perkins, Oklahoma.

		Sandbur control	
		4 (WAT)[1]	8 (WAT)[1]
Treatment	Rate		
	---g ai ha^{-1}---	----------------------%-----------------------	
non-treated		0_{c}	0_{b}
pendimethalin[2]	1651	43_{ab}	23_{ab}
Quinclorac	275	38_{ab}	20_{ab}
metsulfuron methyl	42	25_{bc}	28_{ab}
thiencarbazone-methyl + dicamba + Iodosulfuron	176	27_{bc}	36_{a}
foramsulfuron	33	28_{bc}	20_{ab}
trifloxysulfuron	445	68_{a}	28_{ab}
2, 4-D	531	43_{ab}	22_{ab}
thiencarbazone-methyl + foramsulfuron + halosulfuron-methyl	136	31_{abc}	38_{a}
Amicarbazone	245	40_{ab}	37_{a}
Topramezone	25	31_{abc}	28_{ab}
Mesotrione	23	38_{abc}	22_{ab}
LSD[3]		40	33

1. Abbreviations: WAT, weeks after treatment
2. Pendimethalin was applied 8 weeks prior to POST treatments, corresponding 12 and 16 WAT, respectively.
3. Means were separated using Fishers protected LSD at a=0.05.

CHAPTER TWO

SANDBUR CONTROL IN BERMUDAGRASS AGRICULTURAL PASTURES

Abstract

Field experiments were conducted west of Hennessey, Oklahoma in 2014 and 2015 in a bermudagrass grazing pasture to evaluate control of longspine sandbur (Genus species authority) provided by herbicide applications. Field ratings included bermudagrass injury, sandbur control, sandbur inflorescence suppression, forage production, and sandbur height. Bermudagrass, in both years, was not significantly injured by any treatment except for glyphosate and imazapic. By 5 weeks after treatment (WAT), glyphosate and imazapic were providing 46% and 56% injury to bermudagrass, respectively, and injury remained evident through 9 WAT. Glyphosate and imazapic controlled longspine sandbur most effectively, achieving 98% and 71%, respectively, as early as 3 WAT with controlled levels at 9 WAT of 90% and 75%, respectively. No other treatments in the experiments provided more than 50% control of sandburs. Several herbicides suppressed inflorescence production including: nicosulfuron + metsulfuron methyl (MSM), imazapic, glyphosate, and nicosulfuron + MSM + pendimethalin between 77% and 98% at 7 WAT compared to the non-treated control. The average height of non-treated sandbur in the field at 5 and 7 WAT was approximately 30 and 28 cm, respectively. At 15 weeks after PRE application (7 weeks after POST application), sandbur treated with pendimethalin at both low

and high rates had heights of 37 cm (low rate) and 39 cm (high rate). Nicosulfuron + MSM, imazapic, glyphosate, and nicosulfuron + MSM + pendimethalin showed significantly decreased height compared to the non-treated control at both 5 and 7 WAT. However, glyphosate and imazapic had the most suppressed plant growth at 5 WAT with 7 cm and 8 cm, respectively.

Introduction

Sandbur species [*Cenchrus spps*] can be very troublesome weeds in forage and grazing pastures. High populations of sandbur can be detrimental to forage production and can reduce the quality and stand life of desirable forage plants in grazing pastures and hayfields by crop competition (Green et al., 2006). The fruit of sandburs or broadleaves such as puncturevine [*Tribulus terrestris*] in pastures can cause irritation to the eyes and skin of livestock due to their sharp spines brushing against their face as they graze (Singh et al., 2006). Some animals may require veterinary care increasing the cost of production.

Several sandbur species affect forage production in agricultural systems: southern sandbur (*C. echinatus* L.), longspine sandbur [*C. longispinus* (Hack.) Fern.], and field sandbur (*C. spinifex* Cav.). Sandburs behave as summer annuals or weak perennials, and they grow well in disturbed and sandy-loam soils (Funderburg et al., 2011).

Management methods for sandbur in agriculture programs include grazing, appropriate fertility programs, and controlled burning (Funderburg et al., 2011). Sandbur populations can be suppressed if overgrazing of a pasture was avoided and bermudagrass or native grasses were allowed to grow and compete with sandburs (Funderburg et al., 2011). Improving the density and height of bermudagrass by applying proper fertility also assists the bermudagrass in competing for water, sunlight, and nutrition (Funderburg et al., 2011). Controlled burns and dormant season tillage will kill few sandbur seed along the soil surface. However, the burn will stimulate germination of a large number of the sandburs to grow at once. With appropriate timing, an effective herbicide applied POST can be used to manage the population and decrease the seed bank in the field (Funderburg et al., 2011).

There are currently four herbicide products labeled as effective in the control of sandbur: Nicosulfuron + MSM (Pastora®), imazapic (Plateau®), glyphosate (Roundup PowerMax®), and pendimethalin (Prowl® H_2O). Future research is needed to evaluate other products and provided more additional control methods for sandburs. Improved management strategies for sandburs occurring in the Southern Great Plains will increase the quality and value of bermudagrass produced in this region. This experiment will analyze several herbicide products for their effectiveness in control of sandbur in bermudagrass pastures.

Materials and Methods

Hennessey Field

An experiment was initiated on a bermudagrass pasture near Hennessey, Oklahoma in 2014 and duplicated in 2015 to evaluate efficacy of several herbicide products applied PRE and POST to control sandbur. The experimental design was a randomized complete block design with four replications of 2.4 m wide X 3.0 m long treated plots. The bermudagrass pasture site had a tilled fire strip along the fence line that became infested with longspine sandbur (Figures 1 and 2). The fire strip provided good visual effects of bermudagrass and sandbur responses to herbicide treatments.

The nine treatments included in the 2014 experiment were pendimethalin (Prowl® H_2O) at 2130 g ai ha^{-1} + 4464 g ai ha^{-1} as a single application, a split application (spaced 4 weeks apart) of pendimethalin at 4464 g ai ha^{-1} + nicosulfuron-methyl + metsulfuron-methyl (Pastora®) at 75 g ai ha^{-1}, nicosulfuron-methyl + metsulfuron-methyl (MSM) at 75 g ai ha^{-1}, imazapic (Plateau®) at 70 g ai ha^{-1}, aminopyralid (Milestone®) at 70 g ai ha^{-1}, quinclorac (Drive) at 839 g ai ha^{-1}, glyphosate (Roundup Pro Max) at 366 g ai ha^{-1}, 2, 4-D (2, 4-D LV 400) at 531 g ai ha^{-1}, and a non-treated check. The 2014 study was treated with first treatment, pendimethalin, at morning on 18 Apr 2014 and later treated on 2014 June 12, with herbicide products applied POST emergent. At the time of the 18 April 2014 application, the air temperature was 19˚C with 36% relative humidity at x m. Wind velocity was recorded at 121 m s^{-1}. On 12 Jun 2014, the air temperature was 27˚C with 55% relative humidity. The wind velocity was recorded at 150 m/s.

The 2015 experiment was treated with the first treatment, pendimethalin, at noon on 2015 April 10, and later treated on 2015 June 19, with herbicide products applied POST. Treatments for the 2015 study included 13 treatments: pendimethalin (Prowl H_2O) at 2130 g ai ha^{-1} + 4464 g ai ha-1 as single applications and a split application spaced 4 weeks apart with pendimethalin at 4464 g ai ha-1 + nicosulfuron-methyl + MSM (Pastora) at 75 g ai ha-1, nicosulfuron-methyl + MSM (Pastora) at 75 g ai ha-1, imazapic (Plateau) at 70 g ai ha-1, aminopyralid (Milestone) at 70 g ai ha-1, quinclorac (Drive) at 839 g ai ha-1, glyphosate (Roundup Max) at 366 g ai ha-1, 2, 4-D (2, 4-D LV 400) at 531 g ai ha-1, 2, 4-D + aminopyralid (GrazonNext) at 1179 g ai ha^{-1} , and nicosulfuron + MSM + aminopyralid at 75 g ai ha^{-1} + 1179 g ai ha^{-1}. On 2015 April 10, the air temperature was 22˚C with 35% relative humidity. Wind velocity was recorded at 80 m/s. On 2015 June 19, the air temperature was 32˚C with 54% relative humidity. The wind velocity was recorded at 185 m/s.

Visual percent bermudagrass injury, percent sandbur control, seedhead suppression, and sandbur height were taken. Forage was collected 16 WAT and fresh and dry weight recorded. Seedheads were collected from each treatment to analyze under a scanning electron microscope to evaluate the sandburs spines for deformities and to evaluate seed viability by germination testing. All data were managed in ARM 9.2 and analyzed in SAS 9.4.

Scanning Electron Microscopy

Seedheads of the sandburs were collected from each treatment to analyze under a scanning electron microscope to evaluate the sandburs spines for deformities. Burs were collected from the field 16 WAT and placed in an oven for 3 d. Once dry, the burs were washed for 15 min in an ultrasonicator using acetone as a washing agent.

The burs were placed on double-sided sticky carbon stub stands and were sputter coated, which is the process of applying an ultra-thin coating of electricity-conducting metal, before being placed under the electron microscope (Robbins, 2015). Whole bur pictures were taken at 20x to 25x magnification, and spinules of burs were analyzed at 250x and 775x magnification for quality assessment.

2015 Germination Testing

Burs collected from the field were stored in a cool room at 5 to 10˚C for 12 weeks of cold stratification. In 2015, the second generation of burs was planted in 10 cm square pots for a germination test to evaluate seed viability for florets collected from treated parent plants. Burs were planted 2.5 cm deep in potting soil. Pots were watered daily and were maintained at a 16hour photoperiod with 28/24˚C day/night temperatures in the greenhouse. Plants that emerged were counted and recorded for number of viable seed.

Results

At 3 WAT, bermudagrass was not significantly injured by any treatment except for imazapic with 25% injury (Table 1). Bermudagrass in imazapic plots was stunted and necrosis was noticeable on all above ground plant tissues. By 5 WAT glyphosate and imazapic injured bermudagrass 46% and 56%, respectively (Table 1). Glyphosate and imazapic injury remained evident through 9 WAT, 43 and 53%, respectively (Table 1), and recovery from glyphosate injury to bermudagrass took the entire season. The treatments of 2, 4-D, pendimethalin, aminopyralid, and quinclorac did not significantly injure bermudagrass stands compared to the non-treated.

Glyphosate and imazapic controlled longspine sandbur most effectively at 98 and 71%, respectively, as early as 3 WAT and continued through 9 WAT at 90% and 75%, respectively (Table 2). No other treatment controlled sandbur more than 50%. Several treatments also affected longspine sandbur height in the field. The average height of non-treated sandbur in the field at 5 and 7 WAT was approximately 26 cm and 28.4 cm, respectively (Table 3). Fifteen weeks after PRE application (7 weeks after POST application), pendimethalin at both rates significantly increased sandbur height to 37 cm at the low rate and 39 cm at the high rate of pendimethalin. Nicosulfuron + MSM, imazapic, glyphosate, and nicosulfuron + MSM +

pendimethalin showed significantly decreased height compared to non-treated at both 5 and 7 WAT.

Gyphosate and imazapic had the most suppressed plant growth at 5 WAT of 7 cm and 8 cm, respectively.However, several herbicides suppressed inflorescence production by 7 WAT (Table 4). Nicosulfuron + MSM, imazapic, glyphosate, and nicosulfuron + MSM + pendimethalin significantly suppressed inflorescence production 77 to 98% compared to the nontreated. By 9 WAT, suppression of the inflorescence production had slightly decreased but no more than 63%. Effective suppression of floral production through fewer florets and less crowded inflorescences may lead to decreases in burs returned to the soil seedbank and decreases in longspine sandbur populations over time.

2015 Germination Testing

Longspine burs collected from all treatment plots in Hennessey grazing pasture site were planted in a greenhouse germination test to evaluate the viability of the seed. Plants were germinated within 2 weeks after planting and count ratings were recorded. At the first week after germination, non-treated plots averaged 4.8 germinated seedlings out of 10 planted burs (Table 6). Treatments pendimethalin at both low and high rates, nicosulfuron + MSM, nicosulfuron + MSM + pendimethalin, glyphosate, and quinclorac resulted in significantly lower germinated seedlings between 1 to 2 compared to the non-treated.

Scanning Electron Microscopy

Whole inflorescences were harvested from each plot to collect florets to take an image under a scanning electron microscope (SEM). Figure 3a and 3b are micrographs of a non-treated floret and close up view of a spine for comparison between treated burs. Normal spines appear pointed and sharp with a consistent cover of backward barbs along the surface (Figure 3a) resembling that of a fish hook (Figure 3b). Glyphosate and low rate pendimethalin treatments did not exhibit any deformities of the bur structure or the spine (Figures 7a and b; 12a and b). Other treatments exhibited varying degrees of deformity and structural changes in floret appearance and function.

The 2, 4-D treated plants did not exhibit any deformity of the bur structure (Figure 5a); however, there were deformities of the tips of the spine (Figure 5b) with several spines exhibiting bent or curved spine tips. Aminopyralid treated plants were severely deformed in overall floret structure (Figure 6a) with poorly concealed seed and with barbs on the spine slightly appressed to the surface (Figure 6b). Imazapic treated plants had smaller florets than non-treated plants, with spines longer and thinner, and barbs of the spine appressed along the surface (Figure 8a and b). Nicosulfuron + MSM treated plants had severe deformities of the floret structure, where the floret poorly covered the seed, and the spines were short, thin, and brittle; barbs of the spine for this treatment were also appressed along the surface and damaged (Figure 9a and b). Nicosulfuron + MSM + pendimethalin treated plants had small florets with short compacted spines (Figure 10a); however, spines were not as severely damaged as nicosulfuron + MSM alone, but barbs were still appressed along the surface (Figure 10b). Plants treated with the high rate of pendimethalin exhibited a smaller, thinner structure with poor concealment of the seed (Figure 11a); the spine was very thin with some barbs appressed along the surface (Figure 11b). With a low rate of pendimethalin treatment, burs were undamaged and looked normal (Figure 12). Quinclorac showed little sign of deformity. The burs did not exhibit any deformity of the bur structure (Figure 13a); however there were slight curves to the spine tips (Figure 13b). Burs treated with nicosulfuron + MSM + aminopyralid showed severe deformities and damage. The burs were small and the barbs were brittle or appressed along the surface (Figure 14a and b). The combined treatments of 2, 4-D and aminopyralid exhibited many small burs with deformities to the spines and tips (Figure 15a and b). Imazaquin caused suppression of the barbs along the surface of the spines and brittleness to the bur (Figure 16a and b).

Conclusion

All three herbicides; glyphosate, imazapic, and nicosulfuron + MSM, labeled for sandbur control in pastures effectively controlled longspine sandbur in the Hennessey trials. Glyphosate and imazapic resulted in the best control option, providing between 70 and 98% control. However, these two herbicides also caused significant injury to bermudagrass. While bermudagrass treated with glyphosate slowly began to recover between 5 and 9 WAT, the bermudagrass treated with imazapic remained steady at 50% injury. Eytcheson, in 2011, had similar results with glyphosate and imazapic. Field sandbur was controlled effectively, 87% in 2009 and 100% in 2010; however, at 3 WAT the bermudagrass had significant injury of up to 50% (Eytcheson, 2009). Nicosulfuron + MSM + pendimethalin provided the best sandbur control in this study at 3 WAT (40%) without causing significant bermudagrass injury compared to glyphosate and imazapic.

Imazapic, nicosulfuron + MSM, glyphosate, and nicosulfuron + MSM + pendimethalin significantly suppressed inflorescence production 60 to 98% compared to the non-treated. The germination test in 2015 resulted in small viability percentage for these herbicides, including pendimethalin and quinclorac. Effective suppression of floral production through fewer florets and less crowded inflorescences may lead to decreases in burs returned to the soil seedbank and decreases in longspine sandbur populations over time. Later-emerging sandbur plants tend to produce less seed to add to the seedbank in the field (Soltani et al., 2009). Imazapic and glyphosate also showed significantly decreased height compared to non-treated (Table 10). The decrease in height of longspine sandbur plants may allow increased competition for other forage that could help choke out sandbur.

Sandbur floret deformity or damage by herbicide application could provide another control option for effective suppression of viable seed and may cause sandburs to become harmless to people and livestock. Through a scanning electron microscope, we analyzed the treated florets to the non-treated florets of the field. Glyphosate and low rate pendimethalin treatments did not exhibit any deformities of the bur structure or the spine. The 2, 4-D and aminopyralid treatments showed several spines exhibiting bent or curved spine tips. However, aminopyralid showed more deformity in the bur structure with poor concealment of the seed. Imazapic and a high rate of pendimethalin showed the florets to be smaller and thinner, and resulting in poor concealment of their seed. Both treatments resulted in smaller, thinner spines with appressed barbs along the surface. Nicosulfuron + MSM treatment showed the most severe damage where the floret poorly covered the seed, and the spines were short, thin, and brittle. Nicosulfuron + MSM + pendimethalin also damaged the floret but not near as much as nicosulfuron + MSM alone.

Of the treatments in this study, nicosulfuron + MSM + pendimethalin provided significant sandbur control (40%) without causing severe reduction in bermudagrass. Florets of this treatment also caused damage to the floret and a decrease in viability of seed.

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TABLES AND FIGURES

Table 1. Percent bermudagrass injury 3, 5, 7, and 9 weeks after POST applications near Hennessey, Oklahoma.

		Bermudagrass injury			
		3 (WAT)[1]	5 (WAT)[1]	7 (WAT)[1]	9 (WAT)[1]
Treatment	Rates				
	--g ai ha^{-1}--	----------------------------	%	------------------------------	
nontreated		0	0	0	0
pendimethalin[2] (H)	4464	1	0	3	2
pendimethalin[2] (L)	2130	3	0	3	1
nicosulfuron-methyl					
+ metsulfuron-methyl	75	9	19	20	18
imazapic	70	25	56	53	51
aminopyralid	70	8	7	6	5
quinclorac	839	7	4	2	2
glyphosate	366	16	46	43	31
nicosulfuron-methyl					
+ metsulfuron-methyl	75				
+ pendimethalin	2130	9	16	14	2
2, 4-D	531	3	0	5	4
$LSD_{0.05}$		10	13	12	21

[1]Abbreviations: (WAT) weeks after treatment.

[2]Pendimethalin was applied 8 weeks prior to POST treatments corresponding to 3, 5, 7, and 9 WAT, respectively.

Table 2. Percent longspine sandbur control 3, 5, 7, and 9 weeks after POST applications near Hennessey, Oklahoma.

		Sandbur control			
		3 (WAT)	5 (WAT)	7 (WAT)	9 (WAT)
Treatments	Rates				
	--g ai ha^{-1}--	------------------------------	%	------------------------------	
non-treated		0	0	0	0
pendimethalin[2] (H)	4464	1	1	0	0
pendimethalin[2] (L)	2130	1	2	1	0
nicosulfuron-methyl					
+ metsulfuron-methyl	75	26	15	16	8
imazapic	70	71	75	77	75
aminopyralid	70	1	0	1	0
quinclorac	839	1	0	1	0
glyphosate	366	98	94	96	90
nicosulturon-methyl					
+ metsulfuron-methyl	75				
+ pendimethalin	2130	40	35	33	28
2,4-D	531	1	1	1	0
LSD[3]		66	71	69	79

[1]Abbreviations: WAP, weeks after planting.

[2]Pendimethalin was applied 8 weeks prior to POST treatments.

[3]Means were separated using Fishers protected LSD at a=0.05.

Table 3. Longspine sandbur height (cm) near Hennessey, Oklahoma pooled across site years 2014 and 2015 for 5 and 7 weeks after treatment.

		Sandbur Height	
		5 (WAT)	7 (WAT)
Weeks After Treatment	Rating		
	--g ai ha^{-1}--	-----------------cm-----------------	
non-treated		26_b	28_b
pendimethalin[2] (H)	4464	40_a	39_a
pendimethalin[2] (L)	2130	36_a	37_a
nicosulfuron + metsulfuron methyl	75	18_c	20_c
imazapic	70	8_d	12_e
aminopyralid	70	28_b	28_b
quinclorac	839	29_b	28_b
glyphosate	366	8_d	15_{de}
nicosulfuron + metsulfuron methyl + pendimethalin	75 2130	17_c	18_{cd}
2,4-D	531	29_b	26_b
LSD[3]		19	16

[1]Abbreviations: WAP, weeks after planting

[2]Pendimethalin was applied 8 weeks prior to POST treatments

[3]Means were separated using Fishers protected LSD at a=0.05. Means within columns sharing a common letter are not significantly different.

Table 4. Longspine sandbur inflorescence suppression near Hennessey, Oklahoma for 7 and 9 weeks after treatment.

Weeks After Treatment	Rates	Sandbur Suppression 7 (WAT)	9 (WAT)
	--g ai ha^{-1}--	------------%------------	
non-treated		10$_{c}$	4$_{b}$
pendimethalin[2] (H)	4464	0$_{c}$	0$_{b}$
pendimethalin[2] (L)	2130	0$_{c}$	0$_{b}$
nicosulfuron			
+ metsulfuron-methyl	75	78$_{b}$	63$_{a}$
Imazapic	70	87$_{ab}$	75$_{a}$
Aminopyralid	70	8$_{c}$	8$_{b}$
Quinclorac	839	3$_{c}$	2$_{b}$
Glyphosate	366	98$_{a}$	82$_{a}$
nicosulturon			
+ metsulfuron methyl	75 +		
+ pendimethalin	2130	82$_{ab}$	74$_{a}$
2,4-D	531	16$_{c}$	18$_{b}$
LSD[3]		20	14

[1]Abbreviations: WAP, weeks after planting.

[2]Pendimethalin was applied 8 weeks prior to POST treatments.

[3]Means were separated using Fishers protected LSD at a=0.05. Means within columns sharing a common letter are not significantly different.

Table 5. Forage harvest weight from Hennessey, Oklahoma.

Treatment	Rates	Forage Harvest 2014	Forage Harvest 2015
	--g ai ha^{-1}--	--------kg--------	
non-treated		2863$_{cd}$	1818
pendimethalin[2] (H)	4464	4138$_{ab}$	1368
pendimethalin[2] (L)	2130	3288$_{bc}$	1918
nicosulfuron + metsulfuron methyl	75	1750$_{cde}$	1368
Imazapic	70	1750$_{cde}$	1450
Aminopyralid	70	5417$_{a}$	1133
Quinclorac	839	3963$_{ab}$	2418
Glyphosate	366	1050$_{e}$	2118
nicosulturon + metsulfuron methyl + pendimethalin	75 + 2130	1300$_{ed}$	2168
2,4-D	530	3700$_{ab}$	1483
LSD[3]		1813	NS

[1]Abbreviations: WAP, weeks after planting.

[2]Pendimethalin was applied 8 weeks prior to POST treatments.

[3]Means were separated using Fishers protected LSD at a=0.05. Letters indicate significant differences between treatments within a rating date.

Table 6. Number of germinated burs one week after planting (WAP) for longspine sandburs collected from Hennessey, Oklahoma.

Treatment	Rates	Germinated seed 1 WAP[1]
	--g ai ha^{-1}--	
non-treated		5a
pendimethalin[2] (H)	4464	1b
pendimethalin[2] (L)	2130	2b
nicosulfuron + metsulfuron-methyl	75	1b
imazapic	70	2ab
aminopyralid	70	2ab
quinclorac	839	1b
glyphosate	366	1b
nicosulfuron + metsulfuron-methyl + pendimethalin	75	1b
2, 4-D	531	2ab
LSD[3]		3

[1]Abbreviations: WAP, weeks after planting

[2]Pendimethalin was applied 8 weeks prior to POST treatments

[3]Means were separated using Fishers protected LSD at a=0.05. Letters indicate significant differences between treatments within a rating date.

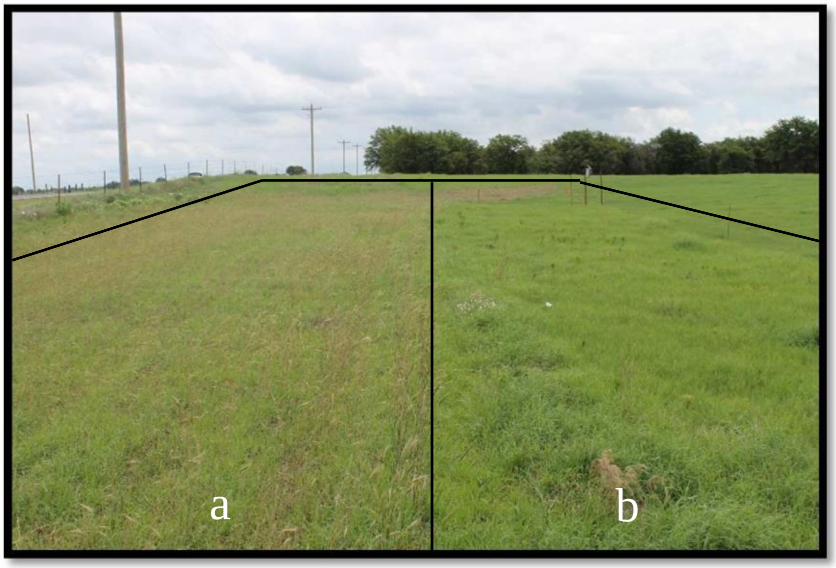

Figure 1. 2014 and 2015 Hennessey, Oklahoma trial layouts. Fire strip of pasture runs along fence line infested with longspine sandbur (left side) and bermudagrass pasture (right side).

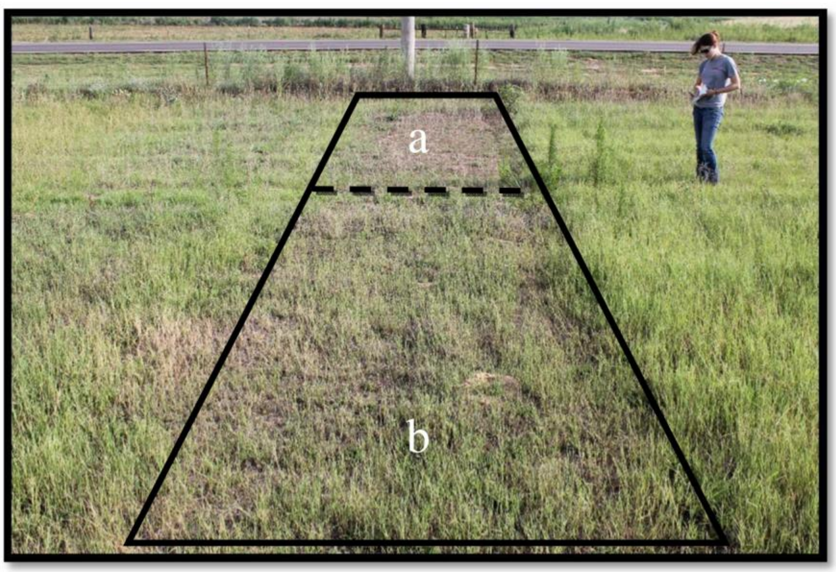

Figure 2. 2014 and 2015 Hennessey, Oklahoma trial layouts. Fire strip of pasture runs along fence line infested with longspine sandbur (Top) and bermudagrass pasture (Bottom).

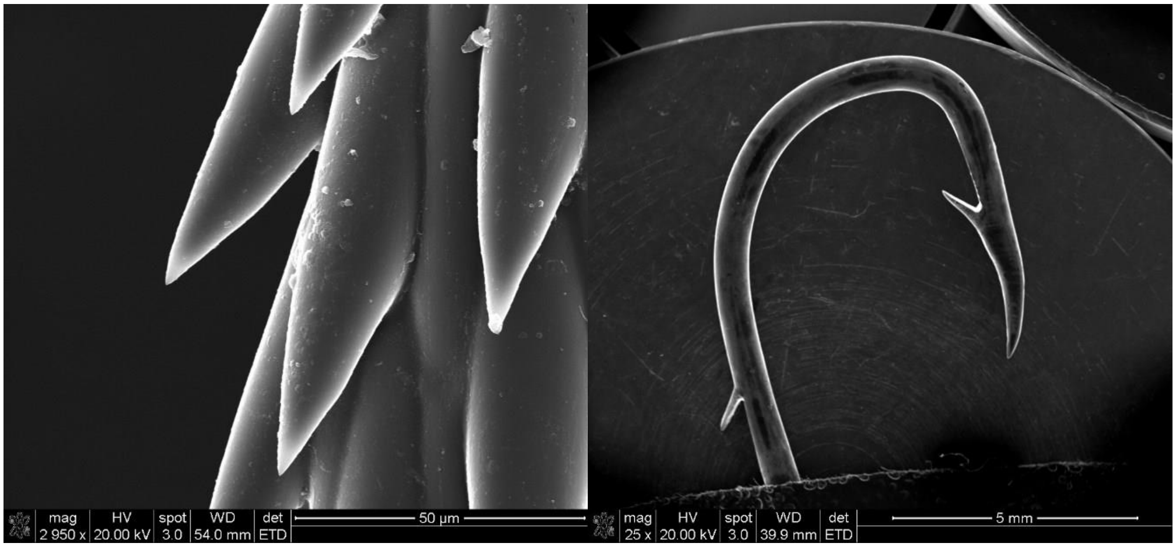

Figure 3. Scanning Electron Microscope image of: a) barbs on longspine sandbur spine and b) a fish hook.

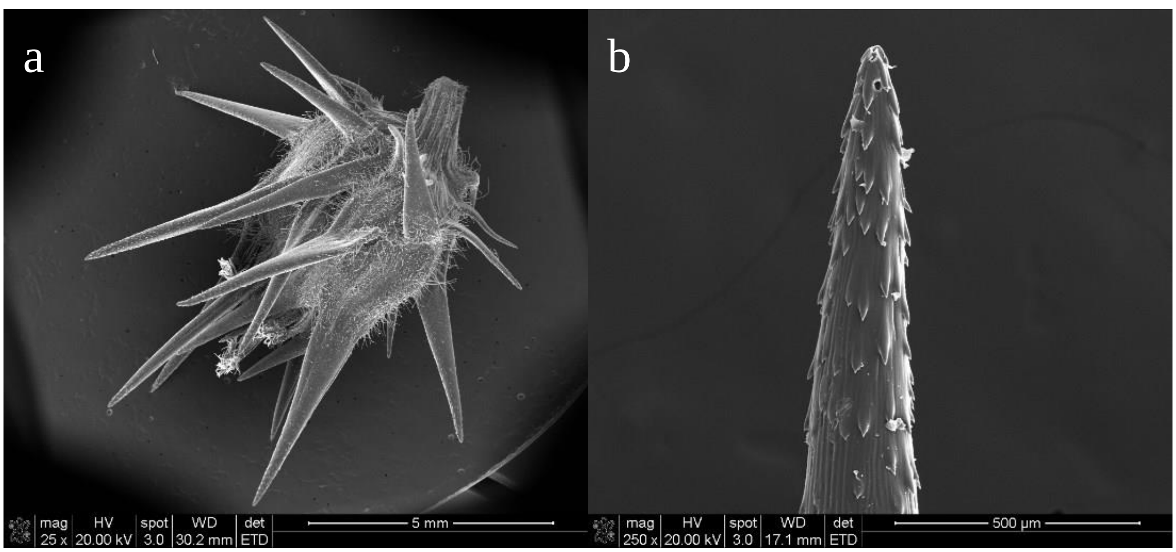

Figure 4. Scanning Electron Microscope image of non-treated southern sandbur: a) floret; b) close up of a single spine.

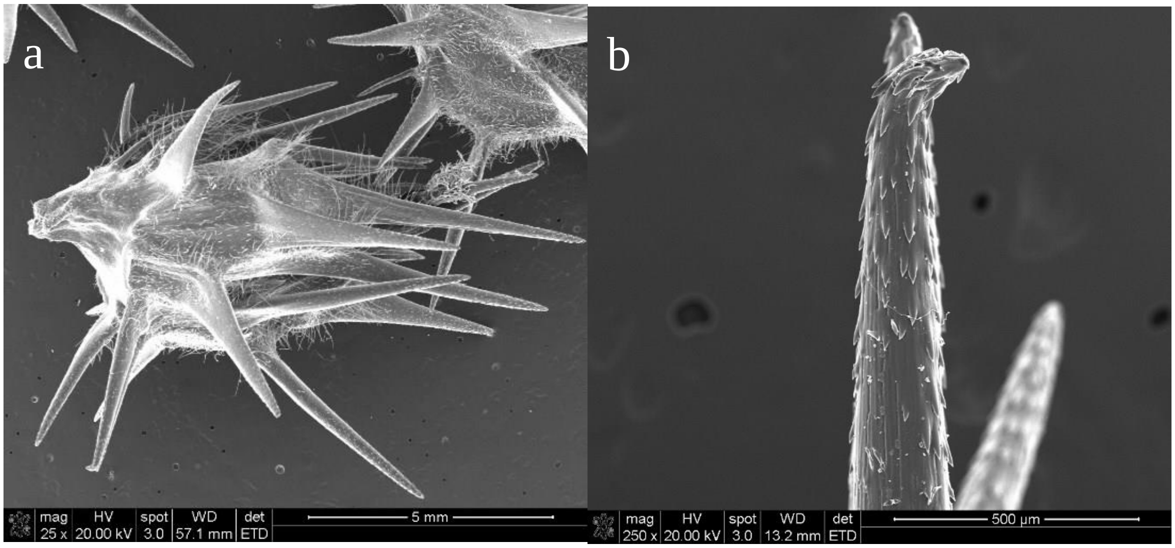

Figure 5. Scanning Electron Microscope image of southern sandbur treated with 2, 4-D: a) floret; b) close up of a single spine.

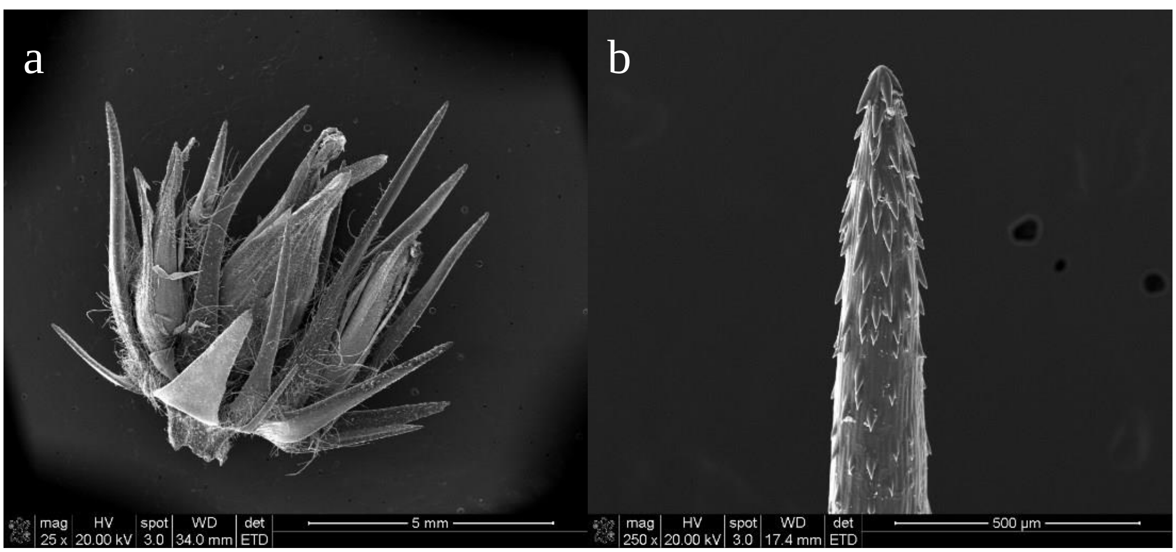

Figure 6. Scanning Electron Microscope image of southern sandbur treated with aminopyralid: a) floret; b) close up of a single spine.

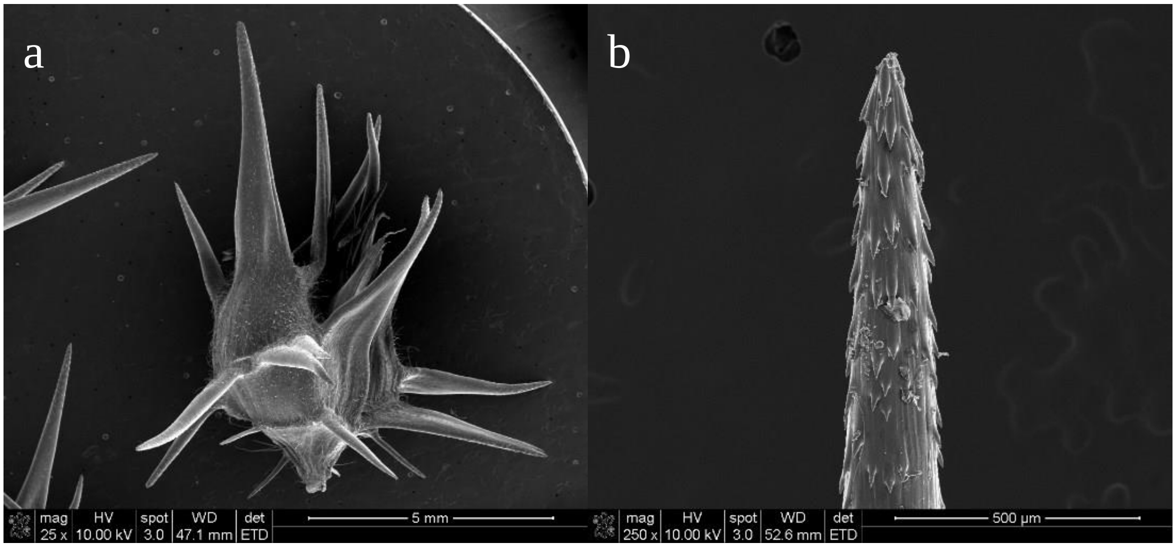

Figure 7. Scanning Electron Microscope image of southern sandbur treated with glyphosate: a) floret; b) close up of a single spine.

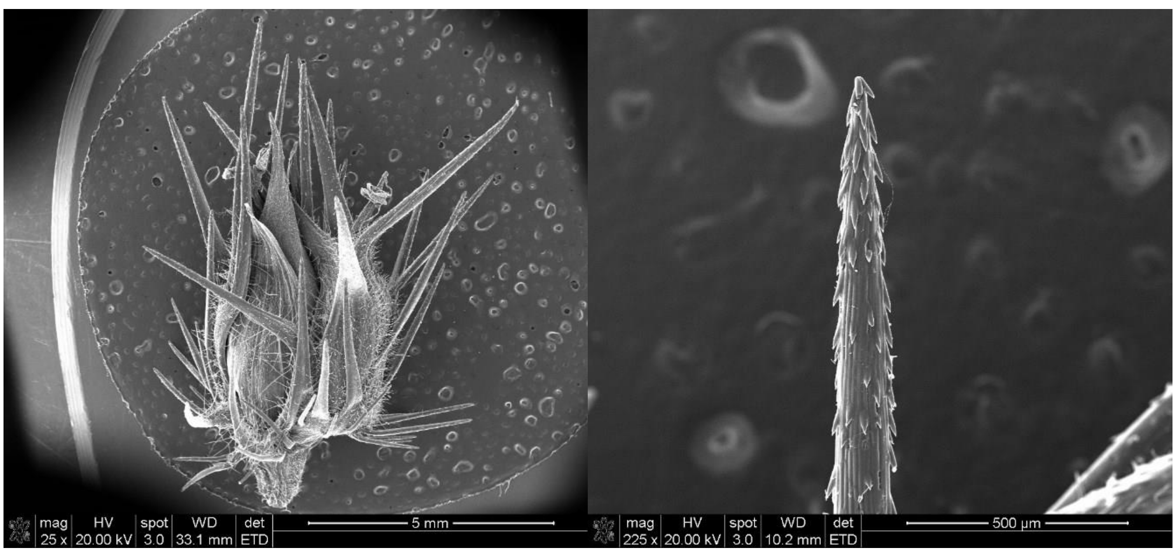

Figure 8. Scanning Electron Microscope image of southern sandbur treated with imazapic: a) floret; b) close up of a single spine.

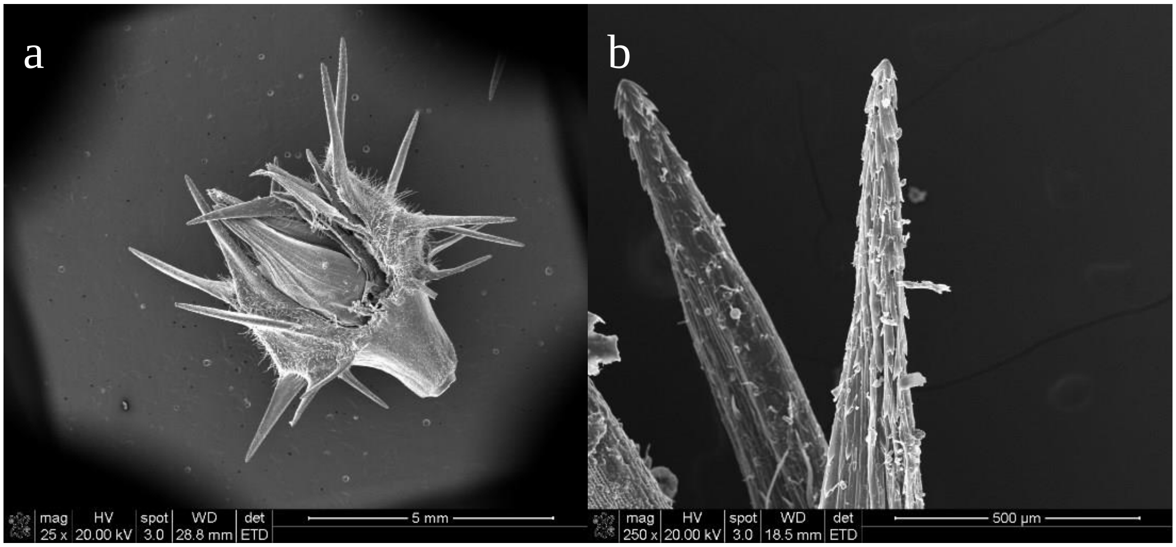

Figure 9. Scanning Electron Microscope image of southern sandbur treated with nicosurlfuron + MSM: a) floret; b) close up of a single spine.

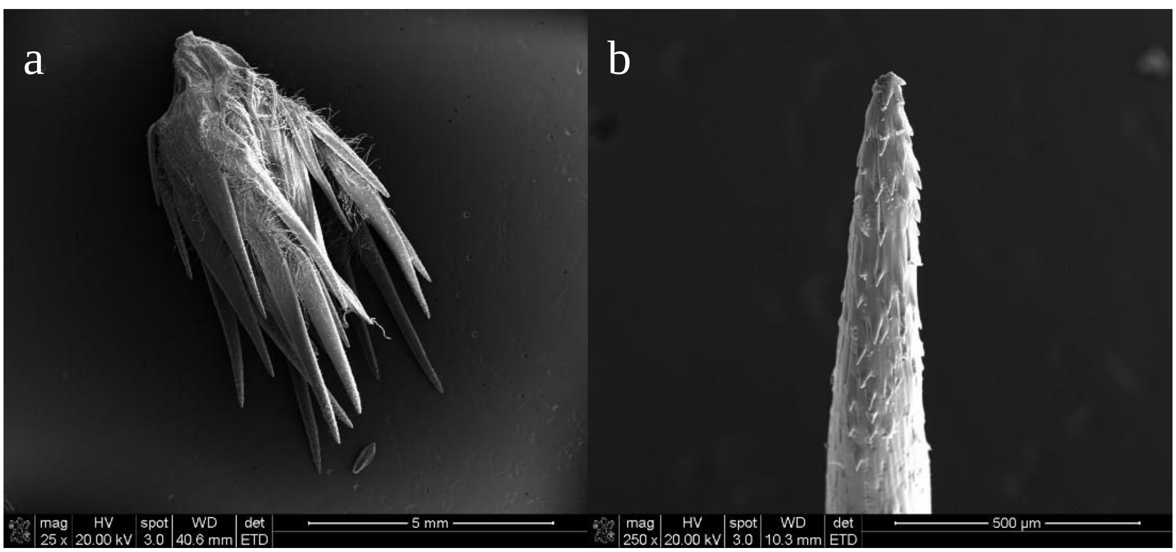

Figure 10. Scanning Electron Microscope image of southern sandbur treated with nicosulfuron + MSM + pendimethalin: a) floret; b) close up of a single spine.

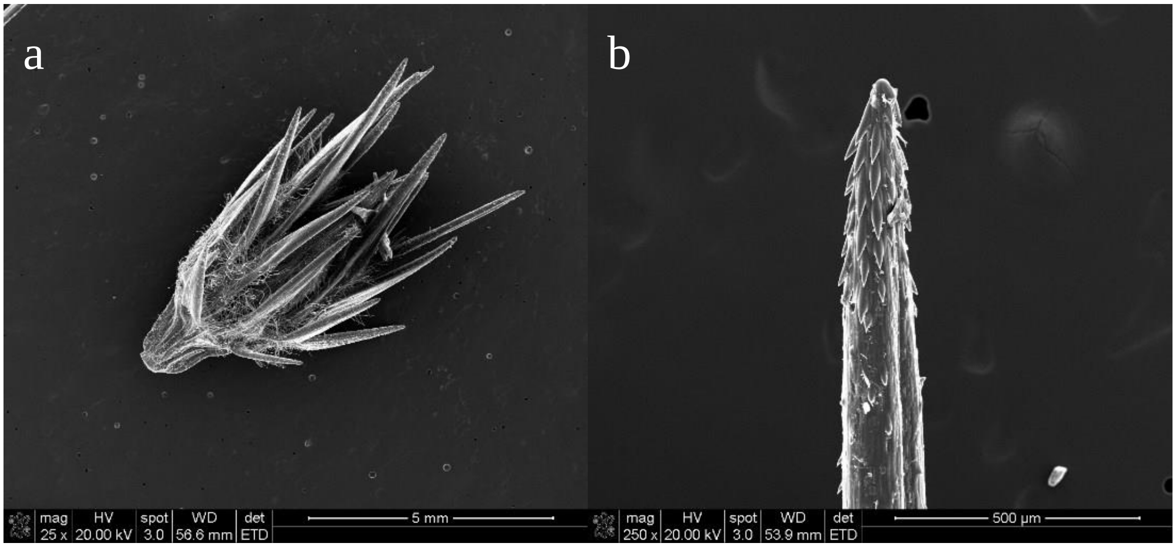

Figure 11. Scanning Electron Microscope image of southern sandbur treated with a high rate of pendimethalin: a) floret; b) close up of a single spine.

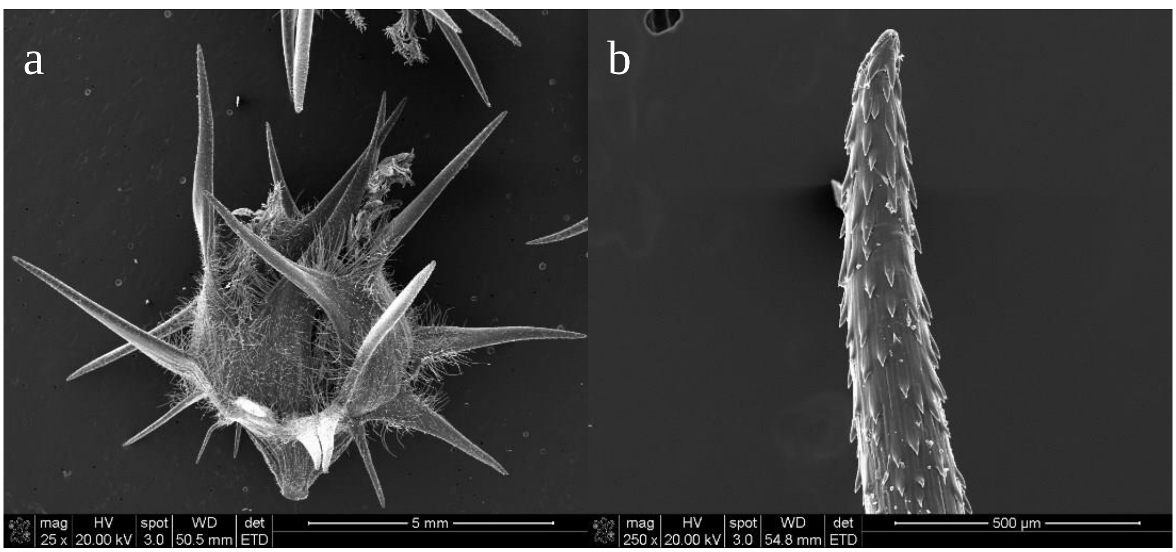

Figure 12. Scanning Electron Microscope image of southern sandbur treated with low rate of pendimethalin: a) floret; b) close up of a single spine.

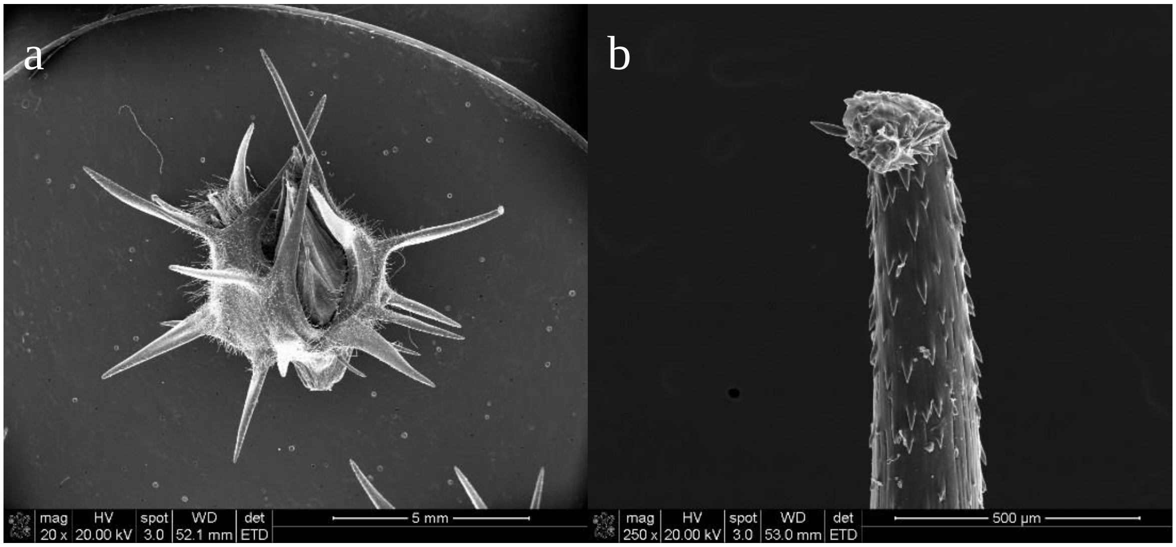

Figure 11. Scanning Electron Microscope image of southern sandbur treated with quinclorac: a) floret; b) close up of a single spine.

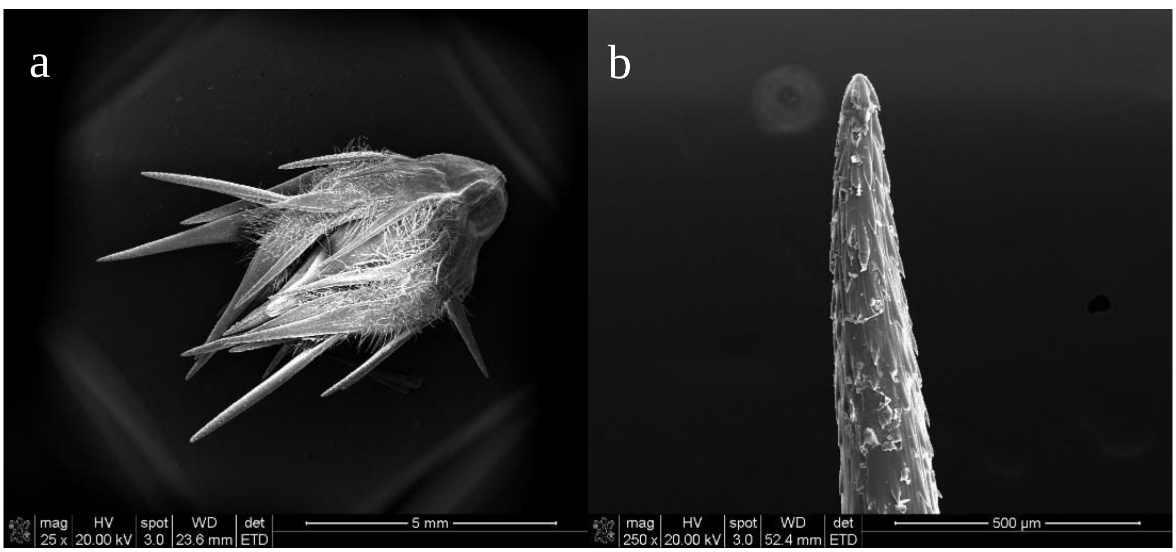

Figure 12. Scanning Electron Microscope image of southern sandbur treated with nicosulfuron + MSM + aminopyralid: a) floret; b) close up of a single spine.

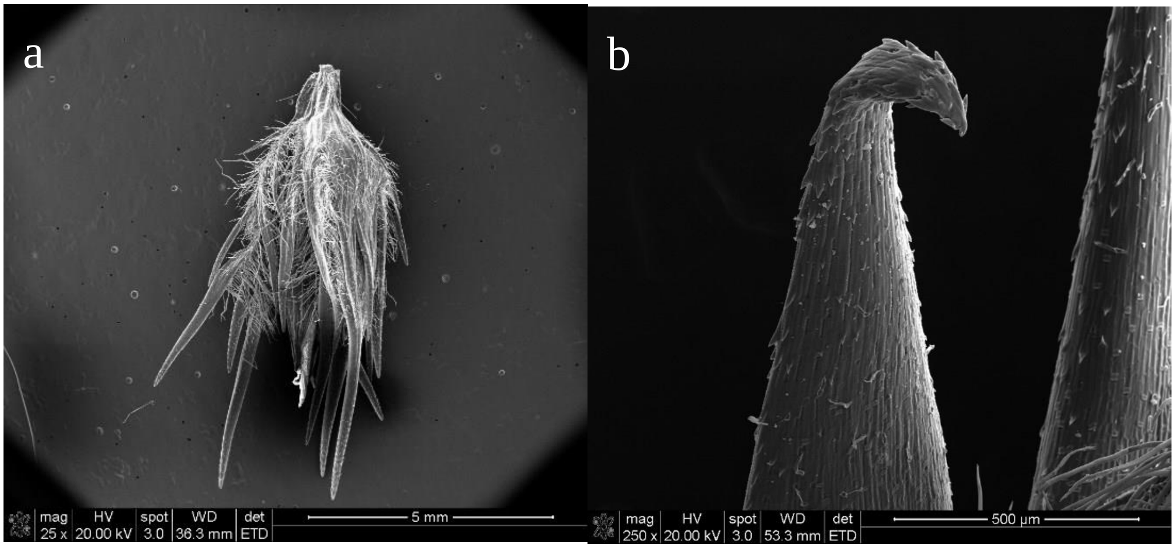

Figure 13. Scanning Electron Microscope image of southern sandbur treated with 2, 4-D + aminopyralid: a) floret; b) close up of a single spine.

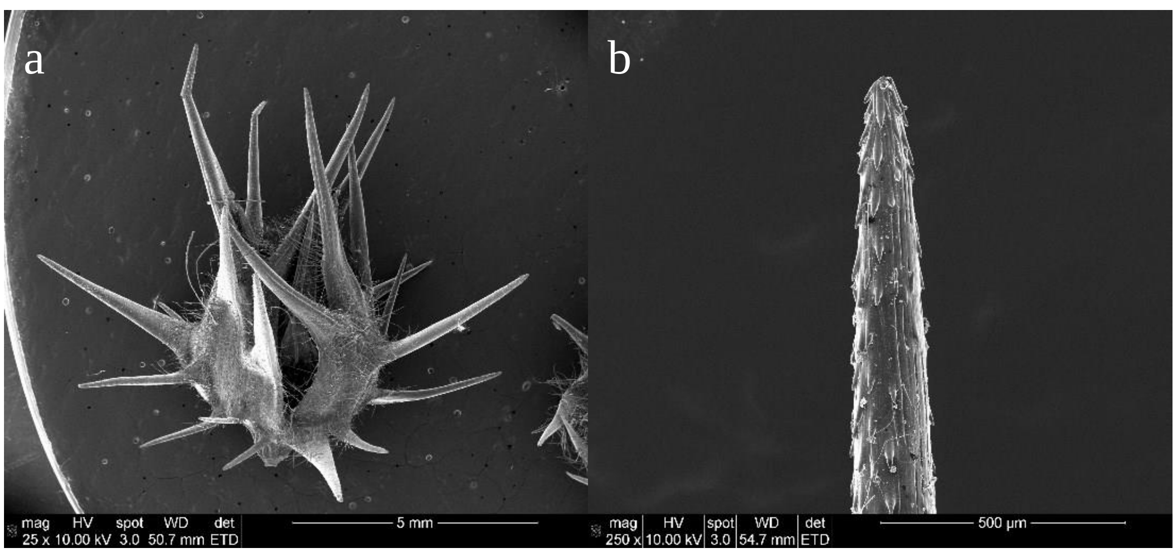

Figure 14. Scanning Electron Microscope image of southern sandbur treated with imazaquin: a) floret; b) close up of a single spine.

Figure 15. Scanning Electron Microscope image of southern sandbur treated with 2, 4-D + aminopyralid: close up of a single spine tip.

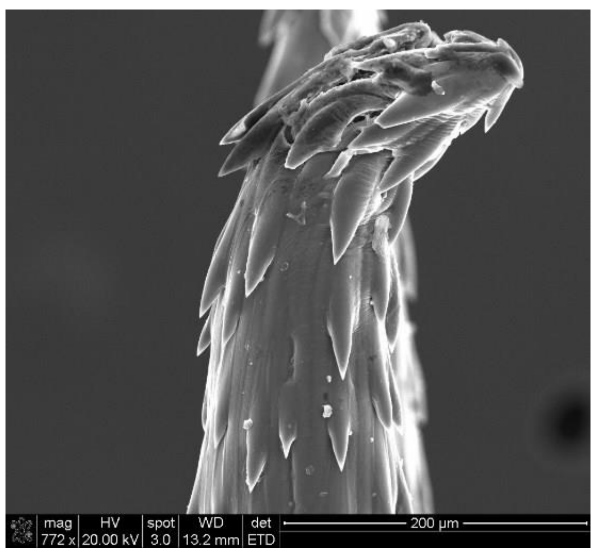

Figure 16. Scanning Electron Microscope image of southern sandbur treated with 2, 4-D: close up of a single spine tip.

CHAPTER THREE

SANDBUR INFLORESCENCE DEFORMITY USING POST HERBICIDE APPLICATION

Abstract

Sandburs (*Cenchrus spps*.) are a nuisance in bermudagrass (*Cynodon spps*.) pastures and bermudagrass turf. Each sandbur species' seedhead is a raceme with compact inflorescence clusters of sharp, spiny burs attached directly to the floral stalk. These burs can become harmful to livestock and humans by puncturing or irritating the skin with their sharp spines. The purpose of this study was to deform or damage the sandbur head by using POST herbicide applications so they may become harmless to humans and livestock.

Greenhouse experiments were initiated in Stillwater, Oklahoma in 2014 to evaluate bur deformity and seed viability after POST herbicide applications at different application timings. One week old sandburs treated with either 2, 4-D or aminopyralid alone in this experiment decreased the number of florets produced compared to older plants at treatment. Early applications at approximately 2-leaf stages increased the risk of herbicide injury by phenoxy herbicides. Plants treated at 1 and 2 weeks of age resulted in the lowest germination percentage of 19 to 37% compared to 3-, 4-, and 5-week-old plants at treatment. Three- and four-week-old plants treated with 2, 4-D + aminopyralid also resulted in a significant decrease in germination compared to the non-treated at 14% (3-week-old) and 27% (4-week-old). At 1, 2, and 4 weeks,

imazapic treated plants resulted in zero germination from harvested burs. Nicosulfuron + MSM resulted in the best germination suppression for all five weeks with treated 3-week-old plants having the highest germination of 4%. The most sensitive application timings to apply herbicide products at POST application for bur deformity appeared to be between 1- and 3-week-old sandburs during their high growth development.

Introduction

Several sandbur species affect residential and recreational turfgrass in the Southern Great Plains (SGP) including southern sandbur (*Cenchrus echinatus*), field sandbur (*Cenchrus spinifex*), and longspine sandbur (*Cenchrus longispinis*).

Each sandbur species' seedhead is a raceme with compact inflorescence clusters of sharp, spiny burs attached directly to the floral stalk (Barnard, 2014). A floret of a sandbur can contain as many as 10 to 30 burs per spike (Wicks et al., 1999), with each bur containing as many as 1 to 3 seed. These plants are undesirable due to their burs with extremely sharp spinules with backward-pointing barbs (Wicks et al., 1999).

With the loss of MSMA, chemical control of sandbur is limited. Currently there are collectively four products labeled to control sandburs in agriculture and turf management: pendimethalin (Prowl H_2O), imazapic (Plateau), nicosulfuron + metsulfuron methyl (MSM, Pastora), and glyphosate (Roundup).

The herbicide 2,4-dichlorophenoxyacetic acid (2, 4-D) is one of the first selective, synthetic auxin herbicides to be widely and commonly used to control annual and perennial broadleaf weeds (Song, 2014). As a selective herbicide, 2, 4-D is used to control certain types of weeds by using synthetic auxin to mimic natural auxins in plants at a molecular level. Natural auxins are important phytohormones that play crucial roles in plant growth and development.

The symptoms induced by auxinic herbicides in plants are similar to plants induced by high concentrations of natural auxin, indole-3-acetic acid (IAA) (Song, 2014). At low doses of auxin, it promotes plant growth. However, at high concentrations it drives plant overgrowth. Leaves of treated plants become stunted and cupped, stems become swollen and twist at odd angles, and the plant exhibits abnormal growth (Song, 2014). This leads to disruption of normal biological processes and ends in cell death.

Predominately, 2, 4-D is selective herbicide to dicot plants without affecting monocots. This method of resistance of monocots is not yet understood; however, some early research suggests that the selectivity of an auxinic herbicide is due to limited translocation or rapid degradation of auxin, the altered perception of auxin in monocots, or the difference in vascular anatomy between monocots and dicots (Mattsson et al., 1999). In monocots, the vascular tissues are scattered in bundles and lack a vascular cambium. In dicots, the vascular tissues are formed in rings and possess cambium (Song, 2014).

However, there have been cases in selective auxin herbicide injury in monocot crops. Dicamba injury in wheat and barley is similar to symptoms caused by 2, 4-D. Late applications of dicamba in wheat and barley have been known to cause stem and leaves to layover and result in floret sterility, while late tiller stage applications can cause stunting and delayed seed heading (Cavanaugh et al., 2013).

The purpose of this research was to evaluate various herbicide products applied POST for damage to vegetative or floral portions of the sandbur plant. If treatments can be found that deform the bur of sandbur florets, these treatments would possibly prevent the burs from causing physical harm to people or livestock.

Materials and Methods

2, 4-D, Aminopyralid Timing Study

Four experiments were initiated at a greenhouse in Stillwater, Oklahoma in 2014 to evaluate the efficacy of herbicide products applied POST to deform sandbur florets at different growth stages. Three of the experiments were a 5 by 4 factorial treatment design, factor one being timing of application and factor two being herbicide treatment with four replications. Southern sandburs were planted in 10 cm^2 pots. Plants germinated approximately 7 days after planting, and after every germination, a new set was planted for a total of 5 germinated sets. A week after the last set germinated, treatments were applied. The studies included application timings from one to five week old plants and 3 post-emergent treatments: 2, 4-D (2, 4-D LV400) at 531 g ai ha^{-1}, aminopyralid + 2, 4-D (GrazonNext) at 1179 g ai ha^{-1}, aminopyralid (Milestone) at 70 g ai ha^{-1}, and a non-treated check. Plants were watered daily, and were maintained at 16-hour photoperiods with 28/24˚C day/night temperatures in the greenhouse.

Additional Post-emergent Timing Study

Two other experiments were initiated in the greenhouse as a 5 by 9 factorial, factor one being application timing and factor two being treatment. Southern sandbur was planted in 10 cm^2 pots at 2.5 cm deep and germinated 7 days apart for 5 weeks after the last set germinated. Plants were watered daily, and were maintained at 16-hour photoperiods with 28/24˚C day/night temperatures in the greenhouse. The studies included application timings from 1 to 5 week old plants and 8 herbicide treatments: dicamba (Dicamba) at 841 g ai ha^{-1}, triclopyr (Remedy) at 841 g ai ha^{-1}, imazapic (Plateau) at 70 g ai ha^{-1}, glyphosate (Roundup) at 530 g ai ha^{-1}, pyroxasulfone (Zidua) at 105 g ai ha^{-1}, nicosulfuron + metsulfuron methyl (MSM) (Pastora) at 75 g ai ha^{-1}, aminocyclopyrachlor (Method) at 89 g ai ha^{-1}, aminopyralid (Milestone) at 70 g ai ha^{-1}, and a non-treated check. Visual percent injury, plant quality on an index scale of 1 to 10 (1= good quality, 10= poor or deformed quality), and number of florets produced were recorded. Florets were harvested as they matured for germination testing.

Germination Testing

Burs were harvested and stored in a cool room at 5 to 10°C for 12 weeks of cold stratification. In 2014, the second generation of burs were planted in 10 cm^2 pots for a germination test to evaluate seed viability of florets collected from treated parent plants. Pots were watered daily and were maintained at a 16-hour photoperiod with 28/24˚C day/night temperatures in the greenhouse. Plants that emerged were counted and recorded for the number of viable seed.

Results

Florets Produced

The most sensitive application timings usually coincide with periods of high growth development and reproductive activity (NuFarm, 2005). In this experiment, sandburs applied within 1 to 3 weeks after germination resulted in higher percentage of bur damage and deformities. Sandburs treated at 2 and 3 weeks with 2, 4-D + aminopyralid resulted with severe deformities of the inflorescence and the plant (Figure 1a and 1b). The inflorescence was soft to the touch and spines laid flat against the bur (Figure 1a). The plants exhibited swollen nodes and twisting of the stem (Figure 1b). One-week-old sandburs treated with either 2, 4-D or aminopyralid alone in this study decreased the number of florets produced compared to older plants at treatment (Table 1). Sandburs treated at 1 week after germination with 2, 4-D and aminopyralid alone exhibited blasted inflorescence (Figure 2 and 3). Early applications at approximately the 2-leaf stages increase the risk of herbicide injury by phenoxy herbicides (Orr et al., 1996). One-week-old sandbur treated with 2, 4-D + aminopyralid showed no significant decrease in floret production compared to older plants at treatment, although it nearly doubled the amount of florets compared to the one-week-old non-treated plants.

Germination Testing

Plants treated at one and two weeks of age resulted in the lowest germination percentage, 19 to 37%, compared to 3-, 4-, and 5-week-old plants at treatment (Table 2). Three and 4 week old plants treated with 2, 4-D + aminopyralid also resulted in a significant decrease in germination compared to the non-treated control with 14% (3-week-old) and 27% (4-week-old) (Table 2). Individually, 2, 4-D and aminopyralid showed no significant decrease in germination compared to the non-treated control.

Imazapic and nicosulfuron + MSM in the additional POST application timing studies resulted in the lowest germination percentages of all treatments in this study (Table 3). At 1, 2, and 4 weeks, imazapic treated plants resulted in zero germination from harvested burs (Table 3). Nicosulfuron

+ MSM resulted the best germination suppression for all five weeks with treated 3-week-old plants having the highest germination of 4% (Table 3). Weeks 1 and 2 resulted in 0% of germination, and weeks 4 and 5 barely reached 1% germination (Table 3). Pyroxasulfone resulted in good control of germination from burs produced by plants treated at 2 and 3 weeks old with only 2% and 0% germination exhibited, respectively, compared to the non-treated with 46% and 13% germination.

Conclusion

Both studies indicate that early herbicide application timings for sandbur made between 1 and 3 weeks after germination can significantly decrease seed viability and decrease florets produced by treated plants. In the 2, 4-D, aminopyralid study, 1-week-old sandburs treated with either 2, 4D or aminopyralid alone decreased the number of florets produced compared to older plants at treatment (Table 1). One- and two-week-old plants also produced the lowest germination percentages compared to the older plants of this study. The additional POST experiment resulted in low seed viability of imazapic, nicosulfuron + MSM, and pyroxasulfone. Imazapic treatment at 1, 2, and 4 weeks resulted in 0% (Table 2). Nicosulfuron + MSM resulted in the best decrease in seed viability of all 5 age groups with 0% for 1- and 2-week-old plants and with very low germination percentages at 3-, 4-, and 5-week-old plants. No other studies have evaluated sandbur viability with respect to timing and treatment used. Additional work will be needed to evaluate targeted rates at the identified timings to more effectively manage sandbur populations with POST applications.

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Tables and Figures

Table 1. Number of florets produced per plant by treatment and age of plants at application.

		Florets Produce				
		1(WAA)[2]	2 (WAA)	3 (WAA)	4 (WAA)	5 (WAA)
Treatment	Rates					
	--g ai h^{-1}--	---Number of florets---				
non-treated		8_{ab}	17_a	17_a	14_a	16_a
2, 4-D	531	9_{ab}	16_a	16_a	14_a	18_a
aminopyralid	70	7_b	22_a	18_a	12_a	21_a
aminopyralid + 2, 4-D	1179	15_a	15_a	18_a	12_a	17_a
LSD[1]		7	10	13	7	7

[1]Means were separated using Fishers protected LSD at a=0.05. Letters indicate significant differences between treatments within a rating date.

[2]Abbreviation: week age at application (WAA).

Table 2. Percent germination of burs harvested from herbicide by timing study.

		Germination of Harvested Burs				
		1 (WAA)[2]	2 (WAA)	3 (WAA)	4 (WAA)	5 (WAA)
Treatment	Rates					
	--g ai h^{-1}--	---------------	---------------	%	---------------	---------------
non-treated		25a	31a	34ab	50a	48a
2,4-D	531	31a	23a	55a	43ab	59a
aminopyralid	70	33a	19a	27b	48a	49a
aminopyralid +2,4-D	1179	21a	37a	20b	23b	41a
LSD[1]		22	19	22	24	18

[1]Means were separated using Fishers protected LSD at a=0.05. Letters indicate significant differences between treatments within a rating date.

[2]Abbreviation: week age at application (WAA).

Table 3. Percent germination of burs harvested from herbicide by timing study.

		Germination of Harvested Burs				
		1 (WAA)[2]	2 (WAA)	3 (WAA)	4 (WAA)	5 (WAA)
Treatment	Rates					
	--g ai ha^{-1}--	---------------	---------------	%	---------------	---------------
non-treated		35$_{ab}$	46$_{a}$	13$_{bc}$	34$_{ab}$	53$_{a}$
dicamba	841	49$_{a}$	44$_{a}$	35$_{ab}$	46$_{ab}$	46$_{ab}$
triclopyr	841	41$_{ab}$	42$_{a}$	35$_{ab}$	29$_{abc}$	35$_{ab}$
imazapic	70	0$_{c}$	0$_{b}$	9$_{bc}$	0$_{d}$	33$_{ab}$
glyphosate	530	16$_{bc}$	45$_{a}$	55$_{a}$	22$_{bcd}$	47$_{ab}$
pyroxasulfone	105	13$_{bc}$	2$_{b}$	0$_{c}$	25$_{abcd}$	41$_{ab}$
nicosulfuron + metsulfuron-methyl	75	0$_{c}$	0$_{b}$	4$_{c}$	1$_{cd}$	2$_{c}$
aminocyclopyrachlor	89	28$_{abc}$	13$_{b}$	21$_{bc}$	39$_{ab}$	36$_{ab}$
aminopyralid +2,4-D	1179	21$_{abc}$	27$_{ab}$	14$_{bc}$	51$_{a}$	23$_{bc}$
LSD[1]		33	24	30	26	20

[1]Means were separated using Fishers protected LSD at a=0.05. Letters indicate significant differences between treatments within a rating date.

[2]Abbreviation: week age at application (WAA).

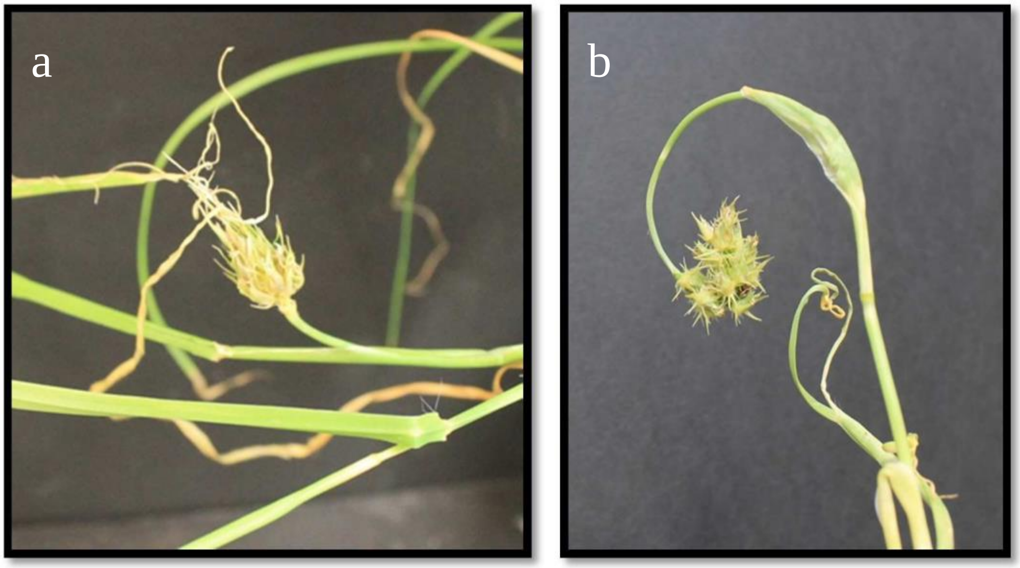

Figure 1. Images of longspine sandbur treated with 2, 4-D + aminopyralid: a) 2 week old sandbur at treatment b) 3 week old sandbur at treatement.

Figure 2. Image of longspine sandbur treat with aminopyralid: Blasted seedhead of 1 week old sandbur at treatment.

Figure 3. Images of longspine sandbur treat with 2, 4-D: 1 week old sandbur at treatment

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