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Response of grain sorghum to low rates of glufosinate and nicosulfuron

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Research Article

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Abstract

Previous research has shown that glufosinate and nicosulfuron at low rates can cause yield loss to grain sorghum. However, research has not been conducted to pinpoint the growth stage at which these herbicides are most injurious to grain sorghum. Therefore, field tests were conducted in 2016 and 2017 to determine the most sensitive growth stage for grain sorghum exposure to both glufosinate and nicosulfuron. Field test were designed with factor A being the herbicide applied (glufosinate or nicosulfuron). Factor B consisted of timing of herbicide application including V3, V8, flagleaf, heading, and soft dough stages. Factor C was glufosinate or nicosulfuron rate where a proportional rate of 656 g ai ha^{-1} of glufosinate and 35 g ai ha^{-1} of nicosulfuron was applied at 1/10×, 1/50×, and 1/250×. Visible injury, crop canopy heights (cm), and yield were reported as a percent of the nontreated. At the V3 growth stage visible injury of 32% from the 1/10× rate of glufosinate and 51% from the 1/10× rate of nicosulfuron was observed. This injury was reduced by 4 wk after application (WAA) and no yield loss occurred. Nicosulfuron was more injurious than glufosinate at a 1/10× and 1/50× rate when applied at the V8 and flagleaf growth stages resulting in death of the shoot, reduced heading, and yield. Yield losses from the 1/10× rate of nicosulfuron were observed from V8 through early heading and ranged from 41% to 96%. Yield losses from the 1/50× rate of nicosulfuron were 14% to 16% at the flagleaf and V8 growth stages respectively. The 1/10× rate of glufosinate caused 36% visible injury 2 WAA when applied at the flagleaf stage, which resulted in a 16% yield reduction. By 4 WAA visible injury from either herbicide at less than the 1/10× rate was not greater than 4%. Results indicate that injury can occur, but yield losses are more probable from low rates of nicosulfuron at V8 and flagleaf growth stages.

Introduction

In Arkansas, grain sorghum is often grown adjacent to rice (*Oryza sativa* L.), corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], or cotton (*Gossypium hirsutum* L.). Due to its ability to perform well in hot, dry climates it may even be planted in nonirrigated field corners of these other crops (Bennet et al. 1990). When environmental conditions are favorable, herbicides applied to these crops can move off-target, resulting in injury to nearby grain sorghum (Al-Khatib and Peterson 1999). Off-target movement of herbicides released from an unshielded sprayer can range from a rate of 1/100× to 1/10× (Al-Khatib and Peterson 1999). The injury to nontolerant crops from off-target movement can differ depending on the herbicide, sensitivity of crop, and growth stage of the plant (Hanks 1995; Miller 1993).

Glufosinate (Weed Science Society of America [WSSA] Group 10) is a herbicide often used in cotton and soybean fields to control glyphosate-resistant Palmer amaranth (*Amaranthus palmeri* S. Wats.). Applications of glufosinate result in decreased production of glutamine synthetase in susceptible plants. Glutamine synthetase is an enzyme necessary in the conversion of glutamate and ammonia to the amino acid glutamine (Coetzer and Al-Khatib 2001; Devine et al. 1993). Glufosinate-resistant crop varieties were created using the gene bialophos (*bar*) from *Streptomyces hygroscopius*, a bacterium. Phosphinothricin acetyltransferase enzyme is expressed by the *bar* gene, conferring resistance to glufosinate (Culpepper et al. 2009). Currently, glufosinate-resistant grain sorghum varieties have not yet been developed, therefore all varieties are sensitive. In 2015, 341,000 ha of cotton and soybean combined were treated with glufosinate (USDA-NASS 2016). Glufosinate being sprayed on fields neighboring grain sorghum in 2015 often resulted in off-target movement and visible injury to grain sorghum (T. Barber, personal communication).

Nicosulfuron was applied in corn to control numerous weedy grass species prior to the introduction of glyphosate-resistant (GR) corn. It is an acetolactate synthase (ALS)-inhibiting (WSSA Group 2) herbicide. This site of action was arguably one of the most widely used in agriculture prior to the introduction of GR crops (Tranel and Wright 2002). The ALS enzyme is the first in the biosynthetic pathway of branched chain amino acids leucine, isoleucine, and valine (Ray 1984). By inhibiting this pathway, susceptible plants can be starved of branched chain amino acids, leading to mortality.

Previous research has been conducted using corn and grain sorghum to show the effect of low rates of glufosinate, glyphosate, imazethapyr, and sethoxydim (Al-Khatib et al. 2003). However, this research examined these herbicides only when they were applied to susceptible crops at the 3- to 4-leaf growth stage. During this research, it was observed that symptoms from imazethapyr were similar to those reported for nicosulfuron (Al-Khatib and Peterson 1999; Al-Khatib and Tamhane 1999). However, because both herbicides inhibit ALS, these results were not surprising (Beyer et al. 1988; Stidham and Singh 1991). Response of grain sorghum to 1/10× the labeled rate glufosinate applied at the V6 and flagleaf growth stages did not result in yield loss when pooled together (Hale et al. 2019). However, this research did not report grain sorghum yield following glufosinate application at the individual growth stages. The objective of this field test was to evaluate the tolerance of grain sorghum to low rates of glufosinate and nicosulfuron at varying growth stages to determine the most sensitive period for severe injury and/or yield loss to occur.

Materials and Methods

Research was conducted at the Lon Mann Cotton Research Station (LMCRS) near Marianna, AR, and the Agricultural Research and Extension Center in Fayetteville, AR, in 2016 and 2017; the Northeast Research and Extension Center in Keiser, AR in 2016; and the Pine Tree Research Station near Colt, AR in 2016 to evaluate response of grain sorghum to low rates of nicosulfuron and glufosinate. Soil texture near Colt, AR, was a Herbert silt loam (fine-salty, mixed, active, thermic Aeric Epiaqualf) with 16% sand, 67% silt, 17% clay, pH 7.1, and 2.2% organic matter (OM). The Keiser, AR, site was a Sharkey clay (very fine, montmorillonitic, nonacid, thermic, Vertic Haplaquept) with 22% sand, 25% silt, 53% clay, pH 6.7, and 1.7% OM. Near Marianna, AR, the soil texture was a Calloway silt loam (fine-silty, mixed, active, thermic Aquic Fraglossudalfs) with 2% sand, 82.3% silt, 15.6% clay, pH 5.5, and 2.2% OM. The soil texture at the Fayetteville, AR, site was a Captina silt loam (fine-silty, siliceous, active, mesic Typic Fragiudults) with 22% sand, 64% silt, 14% clay, pH 5.8, and 1.8% OM. A Dekalb® (Monsanto Company, St. Louis, MO) grain sorghum hybrid, DKS 53-67, was planted at 217,000 seeds ha^{-1} at all locations. DKS 56-67 was chosen because it is a nontraited hybrid that confers no tolerance to either glufosinate or nicosulfuron. Plots were four rows wide at all locations. This field test was arranged as a three-factor factorial including herbicide, rate, and timing of application. The herbicide factor was either glufosinate or nicosulfuron. A proportional rate of 656 g ai ha^{-1} of glufosinate and 35 g ai ha^{-1} of nicosulfuron at 1/10×, 1/50×, and 1/250× was applied. Growth stages of V3, V8, flagleaf, heading, and soft dough grain sorghum were chosen to determine at which stage of growth the highest sensitivity exists. All applications were made using an air-pressurized four-nozzle spray boom equipped with TeeJet® Air Induction XR 110015 nozzles, traveling at 4.8 km h^{-1} and calibrated to deliver 140 L ha^{-1} (TeeJet® Technologies, Wheaton, IL). At RRS and LMCRS plots were 9 m long, and at NREC and AAREC they were 6 m long. To maintain weed-free plots, an application of atrazine (Aatrex, Syngenta Crop Protection, LLC, Greensboro, NC) at 1,120 g ha^{-1} and *S*-metolachlor (Dual II Magnum, Syngenta Crop Protection, LLC) at 1,070 g ha^{-1} were applied at planting. Any escapes from this application were controlled by a single postemergence application of the same mix, applied 4 wk after initial application. Further escapes were removed by hand for the remainder of the field test. Fertilizer and pest management decisions were based on University of Arkansas extension recommendations (Espinoza 2015; McLeod and Greene 2015).

In 2016, visible crop injury was rated at 2 and 4 wk after application (WAA) and grain yield was collected at crop maturity. In 2017, visible crop injury was rated at 2 and 4 WAA, along with crop canopy heights (cm), days to 50% heading, and yield at crop maturity. Visible crop injury relative to nontreated checks was rated on a scale of 0% to 100%, with 0% being no injury and 100% being complete plant mortality. In each plot, five random grain sorghum plants were measured in centimeters, then averaged together

Table 1. Analysis of variance for grain sorghum injury, canopy heights, and grain yield from low rates of postemergence-applied glufosinate and nicosulfuron applications from 2016 and 2017.[a,b]

Variable[c]	Source	DF[a]	*F*-ratio	P-value[d]
Visible injury 2 WAA (%)	Herbicide	1	11.5877	0.0008*
	Rate	2	177.1027	<0.0001*
	Herbicide*Rate	2	5.9441	0.003*
	Timing	4	14.0215	<0.0001*
	Herbicide*Timing	4	18.802	<0.0001*
	Rate*Timing	8	6.0009	<0.0001*
	Herbicide*Rate*Timing	8	6.1219	<0.0001*
Canopy heights 2 WAA (cm)	Herbicide	1	1.3823	0.2411*
	Rate	2	61.5916	<0.0001*
	Herbicide*Rate	2	0.3755	0.6874
	Timing	4	13.2156	<0.0001*
	Herbicide*Timing	4	2.7439	0.0295*
	Rate*Timing	8	2.5698	0.0108*
	Herbicide*Rate*Timing	8	3.9713	0.0002*
Visible injury 4 WAA (%)	Herbicide	1	84.3457	<0.0001*
	Timing	4	50.4465	<0.0001*
	Herbicide*Timing	4	50.2725	<0.0001*
Canopy heights 4 WAA (cm)	Herbicide	1	7.9254	0.0053*
	Rate	2	1.5439	0.216
	Herbicide*Rate	2	0.4728	0.6239
	Timing	4	0.9848	0.4168
	Herbicide*Timing	4	0.9178	0.4545
	Rate*Timing	8	0.9592	0.469
	Herbicide*Rate*Timing	8	0.4273	0.9039
Relative yield (%)	Herbicide	1	18.8745	<0.0001*
	Rate	2	66.5464	<0.0001*
	Herbicide*Rate	2	33.7638	<0.0001*
	Timing	4	18.0419	<0.0001*
	Herbicide*Timing	4	19.1681	<0.0001*
	Rate*Timing	8	11.8419	<0.0001*
	Herbicide*Rate*Timing	8	10.0001	<0.0001*

[a]Injury experiments for 2016 conducted near Colt, AR; in Keiser, AR; near Marianna, AR; and in Fayetteville, AR.
[b]Injury experiments for 2017 conducted near Marianna, AR, and in Fayetteville, AR.
[c]Abbreviations: DF, degrees of freedom; WAA, weeks after application.
[d]*Denotes significance.

Table 2. Visible injury to grain sorghum at various growth stages and herbicide rates 2 WAA.[a,b,c]

Herbicide	Rate	Injury 2 WAA[d]				
		V3	V8	Flagleaf	Heading	Soft dough
		% of nontreated				
Glufosinate[e]	1/10	32 c	22 de	36 c	23 d	14 fgh
	1/50	9 hij	5 jklm	12 ghi	8 ijk	8 ijk
	1/250	3 klm	1 m	2 lm	3 klm	1 m
Nicosulfuron[f]	1/10	51 b	65 a	21 de	17 efg	19 def
	1/50	14 fgh	36 c	4 klm	4 klm	4 klm
	1/250	3 klm	1 m	0 m	0 m	0 m

[a]Injury experiments for 2016 conducted near Colt, AR; in Keiser, AR; near Marianna, AR; and in Fayetteville, AR.
[b]Injury experiments for 2017 conducted near Marianna, AR, and in Fayetteville, AR.
[c]Abbreviations: WAA, weeks after application.
[d]Means followed by the same letter are not different ($\alpha = 0.05$).
[e]Glufosinate rates are proportional to 656 g ai ha^{-1}.
[f]Nicosulfuron rates are proportional to 35 g ai ha^{-1}.

and divided by the average of the nontreated plots and recorded as relative crop canopy heights. The center two rows at each location were harvested using a small-plot research combine and recorded as kilograms per hectare after moistures were adjusted to 14%. Reductions or increases in relative yield were calculated by dividing yield of plots by the average yield of nontreated plots.

All data collected were subjected to ANOVA using JMP software (JMP PRO 13, SAS Institute Inc., Cary, NC), with significant means separated using Fisher's protected LSD ($\alpha = 0.05$). Herbicide, rate, and timing of application were included as fixed effects, with location and year being random effects. The nontreated in each replication was excluded from the analysis because they were included only for relative comparisons.

Results and Discussion

A three-way interaction for factors herbicide, rate, and timing was observed for visible injury ($P < 0.0001$) and canopy heights ($P = 0.0002$) at 2 WAA (Table 1). Response of grain sorghum differed between herbicide, with nicosulfuron generally causing more visible injury than glufosinate. However, increasing herbicide rate resulted in an increase of visible injury for both herbicides (Table 2). At 2 WAA, injury from glufosinate at the 1/10× rate ranged from 14% to 36% across all growth stages. The greatest visible injury (32%–36%) from glufosinate was observed following applications to V3 and flagleaf stages (Table 2). Grain sorghum injury from glufosinate was <12% for the 1/50× and 1/250× rates regardless of growth stage.

The greatest visible injury (65%) observed at 2 WAA resulted from applications of nicosulfuron at the 1/10× rate applied to V8 sorghum. At this rate and crop stage, along with the flagleaf stage (21%), growth was halted and death of the shoot occurred. Visible injury from glufosinate was high at this growth stage (≤36%) but did not result in death of the growing point. Hale et al. (2019) reported less visible injury to grain sorghum following glufosinate application at the V6 growth stage when compared to those of the flagleaf growth stage. This was similar to these results at the V8 growth stage. Increased injury at the flagleaf growth stage could be a result of grain sorghum using sugars and energy toward the metabolism of herbicides and not to the development seed producing blooms (Saeed et al. 1986). Results from nicosulfuron injury were similar to symptoms of imazethapyr reported in other research (Al-Khatib et al. 2003). Injury from nicosulfuron was greater than that by glufosinate at the 1/50× rate, ranging from 14% to 36%, with the highest occurring from applications to the V8 growth stage. All other injury was ≤4% at this rate. Visible injury to grain sorghum caused by the 1/250× rate of glufosinate and nicosulfuron was minimal, not exceeding 6% no matter the growth stage of sorghum at the time of application (Table 2).

Glufosinate at the 1/10× rate resulted in height reductions at all growth stages 2 WAA, except for V8 (Table 3). Height reductions were found with the 1/10× rate of nicosulfuron at V3 (21%) and flagleaf (31%) growth stages. Generally, no reduction in height occurred with applications at the 1/50× or 1/250× rate of either herbicide, except for 1/50× rate of glufosinate applied at V3 (9%) and a 1/50× rate of nicosulfuron applied at flagleaf (8%; Table 3).

As reported by Hale et al. (2019), visible injury decreased by 4 WAA, so only plots where the 1/10× rate was applied were included in the statistical analysis, because visible injury from glufosinate or nicosulfuron at the 1/50× or 1/250× rate did not exceed 4%. A two-way interaction of herbicide and timing ($P < 0.0001$) was observed (Table 1). Glufosinate applied at the 1/10× rate to flagleaf sorghum resulted in 19% injury. At 4 WAA, the least amount of visible injury (3%) was observed when glufosinate at the 1/10× rate was applied to soft dough sorghum (Table 4). The greatest injury (78%) was recorded with the 1/10× rate of nicosulfuron applied to V8 sorghum, which was significantly higher than injury (22%) with the same rate at flagleaf (Table 4). By 4 WAA there was a difference in canopy height found in the main effect of herbicide ($P = 0.0053$; Table 1). Plots where glufosinate was applied were taller than plots applied with nicosulfuron (data not shown).

No delay in heading was observed in plots applied with glufosinate. However, plots applied with the 1/10× rate of nicosulfuron to V8 and flagleaf sorghum often did not mature into a headed plant (data not shown). Al-Khatib and others (2003) found similar effects from low rates of imazethapyr. The number of seeds per head of grain sorghum can be greatly affected if plants are using sugars and energy toward the metabolism of herbicides (Saeed et al. 1986). A three-way interaction of herbicide, rate, and timing was found for the response variable relative yield ($P < 0.0001$; Table 1). Injury caused by glufosinate applications only resulted in a yield reduction of greater than 10% when applied at the 1/10× rate to flagleaf sorghum (Table 5). At the 1/10× rate of glufosinate on flagleaf grain sorghum, a 16% yield reduction occurred; however, this reduction did not differ from that of the 1/10× rate of

Table 3. Relative plant heights from grain sorghum in 2017 at various growth stages, 2 WAA of nicosulfuron and glufosinate at low rates in near Marianna, AR and Fayetteville, AR.[a]

Herbicide	Rate	Heights 2 WAA[b]				
		V3	V8	Flagleaf	Heading	Soft dough
		% of nontreated				
Glufosinate[c]	1/10	80 j	93 efghi	86 ij	88 hi	85 ij
	1/50	91 ghi	99 bdefg	93 efghi	94 defghi	99 bcdefg
	1/250	97 bcdefg	101 abcd	94 defghi	103 abc	109 a
Nicosulfuron[d]	1/10	79 j	95 cdefgh	69 k	96 bcdefg	97 bcdefg
	1/50	100 bcde	99 bcdefg	92 fghi	101 abcd	104 ab
	1/250	102 abcd	102 abcd	99 bcdefg	104 ab	100 bcde

[a]Abbreviations: WAA, weeks after application.
[b]Means followed by the same letter are not different ($\alpha = 0.05$).
[c]Glufosinate rates are proportional to 656 g ai ha^{-1}.
[d]Nicosulfuron rates are proportional to 35 g ai ha^{-1}.

Table 4. Visible injury to grain sorghum at various growth stages and herbicide rates 4 WAA.[a,b,c]

Herbicide	Rate	Injury 4 WAA[d e]				
		V3	V8	Flagleaf	Heading	Soft dough
		% of nontreaed				
Glufosinate[f]	1/10	12 c	10 cd	19 b	13 c	3 e
	1/50	0	0	3	2	1
	1/250	0	0	1	1	0
Nicosulfuron[g]	1/10	10 cd	78 a	22 b	10 cd	5 de
	1/50	4	3	2	0	0
	1/250	0	0	0	0	0

[a]Injury experiments for 2016 conducted near Colt, AR; in Keiser, AR; near Marianna, A;, and in Fayetteville, AR.
[b]Injury experiments for 2017 conducted near Marianna, AR, and in Fayetteville, AR.
[c]Abbreviations: WAA, weeks after application.
[d]Means followed by the same letter are not different ($\alpha = 0.05$).
[e]Rate was not included in statistical analysis due to low levels of visible injury.
[f]Glufosinate rates are proportional to 656 g ai ha^{-1}.
[g]Nicosulfuron rates are proportional to 35 g ai ha^{-1}.

Table 5. Relative yield of grain sorghum after applications of low rates of nicosulfuron and glufosinate.[a,b]

Herbicide	Rate	Relative yield[c d]				
		V3	V8	Flagleaf	Heading	Soft dough
		% of nontreated				
Glufosinate[e]	1/10	94 bcdef	96 abcdef	81 g	91 cdefg	89 defg
	1/50	96 abcdef	96 abcdef	100 abcde	95 abcdef	95 abcdef
	1/250	103 ab	96 abcdef	103 ab	100 abc	92 cdef
Nicosulfuron[f]	1/10	97 abcdef	1 i	1 i	56 h	110 a
	1/50	106 abc	81 fg	83 efg	108 ab	97 abcdef
	1/250	95 abcdef	103 abcde	95 abcdef	110 a	105 abcd

[a]Injury experiments for 2016 conducted near Colt, AR; in Keiser, AR; near Marianna, AR; and in Fayetteville, AR.
[b]Injury experiments for 2017 conducted near Marianna, AR and in Fayetteville, AR.
[c]Means followed by the same letter are not different ($\alpha = 0.05$).
[d]Yield relative to the nontreated check average of 8,174 kg ha^{-1}.
[e]Glufosinate rates are proportional to 656 g ai ha^{-1}.
[f]Nicosulfuron rates are proportional to 35 g ai ha^{-1}.

glufosinate on heading and soft dough grain sorghum, which resulted in 6% and 8% reductions, respectively (Table 5). The greatest yield reduction of 96% was collected from plots where nicosulfuron was applied at a 1/10× rate to V8 and flagleaf grain sorghum. When nicosulfuron was applied to heading sorghum at the same 1/10× rate a 41% yield reduction was found. All other applications of nicosulfuron only resulted in a 16% or less reduction in yield (Table 5). Nicosulfuron at the 1/50× rate applied to V8 and flagleaf sorghum did cause a 14% and 16% yield reduction, respectively (Table 5). These results show that the V8 and flagleaf growth stages appear to be the most sensitive stages for yield loss to occur from off-target nicosulfuron or glufosinate herbicide movement and that grain sorghum is not sensitive to yield loss from low rates of glufosinate.

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