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Effect of Carrier Volume on Grain Sorghum Response to Simulated Drift of Nicosulfuron

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Research was conducted in 2010 and 2012 to determine the effect of simulated drift of nicosulfuron on growth and yield of grain sorghum. Herbicide rates represented 25, 12.5, and 6.3% of the use rate of nicosulfuron at 52 g ai ha^{-1}. Nicosulfuron was applied in a constant carrier volume of 224 L ha^{-1} where herbicide concentration decreased with reduction in rate, and in carrier volumes of 56, 28, and 14 L ha^{-1} proportional to the 25, 12.5, and 6.3% herbicide rates, respectively. In 2010, grain sorghum injury and yield were greater when nicosulfuron was applied in constant compared to proportional carrier volume. Grain sorghum injury and plant height reduction increased with increasing nicosulfuron rate when averaged across carrier volume both years. In 2012, there was a greater reduction in grain sorghum yield from nicosulfuron applied in proportional carrier volume. These data indicate that simulated drift of nicosulfuron onto conventional grain sorghum causes significant height and yield reduction even at the lowest herbicide rate tested, and the effect of carrier volume may be influenced by seasonal rainfall.

Nomenclature: Nicosulfuron; grain sorghum, *Sorghum bicolor* (L.) Moench.
Key words: ALS, spray volume.

En 2010 y 2012, se realizó una investigación para determinar el efecto de la deriva simulada de nicosulfuron sobre el crecimiento y el rendimiento del sorgo para grano. Las dosis del herbicida representaron 25, 12.5, y 6.3% de la dosis de uso 52 g ai ha^{-1} de nicosulfuron. Nicosulfuron fue aplicado a un volumen constante de 224 L ha^{-1} donde la concentración del herbicida disminuyó con la reducción de la dosis, y en volúmenes de 56, 28, y 14 L ha^{-1} proporcionales a los 25, 12.5, y 6.3% de dosis del herbicida, respectivamente. En 2010, el daño en el sorgo para grano y el rendimiento fueron mayores cuando nicosulfuron fue aplicado a un volumen constante que con volúmenes proporcionales. El daño en el sorgo y la reducción en la altura de planta aumentaron con el incremento de la dosis de nicosulfuron cuando se promedió a lo largo de los diferentes volúmenes de aplicación en ambos años. En 2012, hubo una mayor reducción en el rendimiento del sorgo para grano producido por nicosulfuron aplicado en volúmenes proporcionales. Estos datos indican que la deriva simulada de nicosulfuron en sorgo para grano convencional causa reducciones significativas en la altura y el rendimiento del cultivo inclusive a la dosis más baja evaluada, y el efecto del volumen de aplicación podría ser influenciado por la lluvia.

Grain sorghum is an important crop in Texas, with over 1.2 million ha planted in the state in 2013 (NASS 2013). Grain sorghum is a drought-tolerant crop that can be grown in regions that are generally too hot and dry to support other crops (Bennet et al. 1990; Stahlman and Wicks 2000).

Weeds compete with grain sorghum for water, nutrients, and light, thereby reducing crop yield and grain quality (Grichar 2005). Early-season weed competition beyond 2 wk after grain sorghum emergence can reduce yield, depending on the weed species and environmental conditions (Burnside and Wicks 1969; Feltner et al. 1969; Smith et al. 1990). Control of grass weeds in grain sorghum has been difficult because of the absence of selective POST herbicides. The control of annual and perennial grasses in grain sorghum has been limited to PRE herbicides and cultivation. However, because grain sorghum is grown under predominantly dry conditions, the efficacy of PRE herbicides can be reduced.

The development of herbicide-resistant crops has provided novel weed management options to growers (Burnside 1992; Wyse 1992). Recent advances in grain sorghum breeding have resulted in hybrids that are resistant to several acetolactate synthase (ALS) –inhibiting herbicides (Hennigh et al. 2010). ALS-inhibiting herbicides are widely used in many crop and noncrop areas. There are more than 50 commercial herbicides that target the ALS enzyme (Senseman 2007). The ALS enzyme is

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required to produce the branched-chain amino acids valine, leucine, and isoleucine (Durner et al. 1990).

Nicosulfuron is a POST sulfonylurea herbicide labeled for use in corn (*Zea mays* L.) (Anonymous 2013). Nicosulfuron controls many difficult-to-control grass weeds and some broadleaf weeds at rates of 17.5 to 70 g ai ha^{-1} (Senseman 2007). A single application of nicosulfuron controlled over 90% of quackgrass [*Elythigia repens* (L.) Gould] 5 wk after treatment (WAT) and provided $>$ 80% control 1 yr later (Bhowmik et al. 1992). When applied in corn, nicosulfuron controlled giant foxtail (*Setaria faberi* Herrm.) 98 to 100% in 2 yr at two locations (Dobbels and Kapusta 1993). Shattercane [*Sorghum bicolor* (L.) Moench ssp. bicolor] was controlled $>$ 90% when nicosulfuron was applied at 30 g ha^{-1} (Rosales-Robles 1993). Prostko et al. (2006) reported that nicosulfuron controlled Texas panicum (*Panicum texanum* Buckl.) 80% when applied at 40 g ha^{-1}.

One of the major concerns of herbicide-resistant crops is the potential for off-target herbicide movement to sensitive crops (Ellis et al. 2002). Wolf et al. (1992) reported that particle drift from nonshielded sprayers ranged from 2 to 16%, depending on the nozzle size and wind velocity. ALS-resistant grain sorghum will improve growers' ability to combat grass weeds. However, many grain sorghum production areas in Texas will likely experience conventional and herbicide-resistant grain sorghum varieties growing in close proximity. Previous research on simulated drift of herbicides has shown differences in injury and yield because of changes in carrier volumes (Ellis et al. 2002; Roider et al. 2008). Previous research has been conducted to evaluate simulated herbicide drift to grain sorghum from glufosinate, glyphosate, imazethapyr, and sethoxydim (Al-Khatib et al. 2003). Additionally, Ghosheh et al. (2002) reported grain sorghum injury and yield reduction 33 to 94% from pyrithiobac applied in constant carrier volume. However, the effect of simulated nicosulfuron drift on grain sorghum has not been previously reported. Therefore, the objective of this study was to determine the effect of simulated drift of nicosulfuron on grain sorghum as influenced by carrier volume.

Materials and Methods

Field studies were conducted in 2010 and 2012 in Bee County, Texas (28.33743°N, 97.70439°W). Soil was a Monteola clay (fine, smectitic, hyperthermic Typic Haplusterts) with pH of 8.2 and 1.2% organic matter. 'Pioneer 83G19′ grain sorghum was planted on April 1, 2010, and March 16, 2012, at 15,000 seeds ha^{-1}. The experimental area was tilled before planting. The fertilizer program was 34 kg ha^{-1} of 32–0–0 side-dressed 3 wk after planting. Plots were maintained relatively weed free by a PRE application of dimethenamid plus atrazine (0.63 + 1.12 kg ai ha^{-1}) on the day of planting and by mechanical cultivation as necessary. Plots consisted of four 91.4-cm rows 6.1 m long. Herbicide treatments were applied at the four-leaf stage on May 1, 2010, and April 13, 2012.

The study design was a randomized complete block with a factorial arrangement of treatments and three replications. Factors included nicosulfuron rate and carrier volume. Nicosulfuron (Accent, E.I. Du Pont de Nemours and Co., Wilmington, DE 19898) rates were 13, 6.5, and 3.3 g ha^{-1} and represented 25, 12.5, and 6.3% of the use rate of 52 g ha^{-1}, respectively. Nicosulfuron rates were applied in a constant carrier volume of 224 L ha^{-1} and in proportional carrier volumes of 56 L ha^{-1} for the 25% rate, 28 L ha^{-1} for the 12.5% rate, and 14 L ha^{-1} for the 6.3% rate. A nontreated control was included for comparison. Herbicide treatments included a nonionic surfactant at 0.25% (v/v) (Induce, Helena Chemical Company, Collierville, TN 38017).

Herbicide treatments were applied with the use of a tractor-mounted CO_2-propelled sprayer, with a spray pressure of 186 kPa. A TurboDrop 005 Venturi air aspirator (Greenleaf Technologies, Covington, LA 70434) with a TurboTeejet 11001 nozzle (Teejet Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189) for exit pattern was used for all treatments, and tractor speed was adjusted to obtain desired carrier volumes.

Visual estimates of plant injury and plant height data were collected 14 and 28 d after treatment (DAT). Plant injury was estimated visually using a scale of 0 to 100 with 0 = no injury and 100 = plant death, whereas plant height was determined by measuring three plants per plot. Grain sorghum height was based on the measurement from the soil to the last fully developed collar. After grain sorghum reached harvest maturity, the two center rows of each plot were hand-harvested and yield was adjusted to 13% moisture. Plant height and yield

Table 1. Monthly rainfall received at nicosulfuron simulated drift study location during growing seasons in Bee County, TX in 2010 and 2012.

Month	2010	2012
	cm	
March	5.3	6.5
April	11.6	2.1
May	5.9	5.6
June	10.1	1.5
July	12.1	0.2

data are expressed as percentage reduction compared with the nontreated control. Arcsine transformation of percentage data did not affect the results; therefore, nontransformed data were used in the analysis. Data were subjected to ANOVA with the use of the PROC GLM procedure of SAS (version 9.3, SAS, Cary, NC) and means were separated with the use of Fisher's protected LSD at $P < 0.05$. Year-by-treatment interactions were observed; therefore, data are presented by year. Tables were constructed based on appropriate interactions.

Results and Discussion

Seasonal rains in 2010 were much greater compared to 2012 (Table 1); therefore, grain sorghum likely recovered from herbicide injury faster in 2010 with the added moisture. Injury from nicosulfuron appeared within 7 to 10 DAT as chlorosis of leaf foliage and growth inhibition. Nicosulfuron rate affected grain sorghum injury, height, and yield. Averaged across carrier volumes, grain sorghum injury ranged from 19 to 67% and increased with herbicide rate both years (Table 2). In both years, grain sorghum height reduction worsened with increasing rate. In 2010, grain sorghum seemed to recover from herbicide injury, possibly because of adequate rainfall (Table 1). Grain sorghum height in 2012 was reduced 45 and 66% at 14 and 28 DAT, respectively, which was greater than when nicosulfuron was applied at 3.3 g ha^{-1}. Injury and height reduction generally progressed in 2012 as moisture conditions became more limiting (Table 1). In 2010, grain sorghum yield was reduced 100% following nicosulfuron at 13 g ha^{-1} when averaged across carrier volumes compared to yield reductions of 57 and 35% following nicosulfuron at 6.5 and 3.3 g ha^{-1}, respectively. Increasing nicosulfuron rate when averaged across carrier volume generally resulted in greater injury, height, and yield reduction. These results are consistent with grain sorghum injury, height, and yield reduction from pyrithiobac simulated drift that generally increased with herbicide rate (Ghosheh et al. 2002). Additionally, Al-Khatib et al. (2003) reported that grain sorghum visible injury increased and yield generally decreased with increasing drift rates of imazethapyr and glyphosate.

Carrier volume affected grain sorghum injury and yield; height was not affected. Averaged across nicosulfuron rate, in 2010 grain sorghum injury was greater when applied in constant carrier volume (Table 3). In 2010, grain sorghum yield was reduced 73% when applied in the constant carrier volume of 224 L ha^{-1} compared to a yield reduction of 55% when applied in the proportional carrier volume averaged across 56, 28, and 14 L ha^{-1}. These data are in contrast to those previously reported for 2,4-D on cotton (*Gossypium hirsutum*

Table 2. Injury estimates, plant height, and yield reduction as influenced by simulated drift rates of nicosulfuron averaged across carrier volume.

	2010					2012			
Rate[a]	Injury 14 DAT	Injury 28 DAT	Height[b] 14 DAT	Height 28 DAT	Yield[b]	Injury 14 DAT	Injury 28 DAT	Height 14 DAT	Height 28 DAT
g ai ha^{-1}	%		% reduction			%		% reduction	
13	67	47	57	72	100	34	47	45	66
6.5	56	39	51	42	57	27	39	42	62
3.3	41	30	37	28	35	19	30	35	44
LSD	15	5	17	23	19	5	5	5	7

[a] Rates correspond to 25, 12.5, and 6.3% of the labeled rate of 52 g ai ha^{-1} nicosulfuron (13, 6.5, and 3.3 g ai ha^{-1}, respectively).

[b] Data expressed as a percent reduction compared with the nontreated control.

Table 3. Injury estimates and sorghum yield as influenced by simulated drift rates of nicosulfuron averaged across herbicide rate.

Carrier volume[a]	2010 Injury 14 DAT	2010 Injury 28 DAT	2012 Yield[b]	2012 Injury 28 DAT
	——%——		% reduction	—%—
Constant	62	51	73	36
Proportional	47	36	55	41
LSD	12	4	16	4

[a] Carrier volumes represent 224 L ha^{-1} for constant and an average for 56, 28, and 14 L ha^{-1} adjusted proportionally to herbicide rate of 25, 12.5, and 6.3%, respectively, of the labeled rate of 52 g ai ha^{-1} nicosulfuron.

[b] Data expressed as a percent reduction compared with the nontreated control.

Table 4. Grain sorghum yield in 2012 as influenced by simulated drift rates of nicosulfuron applied at constant and proportional carrier volumes.

Carrier volume[a]	Rate[b]	Yield[c]
	——% reduction——	
Constant	13	100
	6.5	84
	3.3	70
Proportional	13	100
	6.5	98
	3.3	80
LSD		7

[a] Carrier volume represents 224 L ha^{-1} for constant and an average for 56, 28, and 14 L ha^{-1} adjusted proportionally to herbicide rate of 25, 12.5 and 6.3%, respectively, of the labeled rate of 52 g ai ha^{-1} nicosulfuron.

[b] Rates correspond to 25, 12.5, and 6.3% of the labeled rate of 52 g ha^{-1} nicosulfuron (13, 6.5, and 3.3 g ha^{-1}, respectively).

[c] Data expressed as a percent reduction compared with the nontreated control.

L.) and for glyphosate on sweet corn (*Zea mays* L.) (Banks and Schroeder 2002) and for glyphosate on corn (Ellis et al. 2002) and for glyphosate on wheat (*Triticum aestivum* L.) (Roider et al. 2008). A possible explanation for this is the number of droplets deposited on the grain sorghum leaves. Bradford and Messersmith (2002) reported nicosulfuron applied with the same total amount of adjuvant at lower concentrations was more phytotoxic in four drops than in one drop. The proportional spray volume in this study likely resulted in fewer droplets deposited on grain sorghum leaves, thus causing less yield reduction.

A significant nicosulfuron rate by carrier volume interaction was observed for grain sorghum yield in 2012. For nicosulfuron at 13 g ha^{-1}, grain sorghum yield was reduced 100% when applied in both constant and proportional carrier volumes (Table 4). For nicosulfuron at 6.5 g ha^{-1}, yield was reduced 84% in constant carrier volume compared to 98% in proportional carrier volume. Nicosulfuron applied at 3.3 g ha^{-1} reduced yield 70% when applied in constant carrier volume, but reduction was 80% when the same rate was applied in proportional carrier volume. Regardless of carrier volume, the 13 g ha^{-1} nicosulfuron rate caused 100% yield reduction in both years. These results showing greater yield reduction in 2012 are likely attributable to reduced rainfall during the growing season (Table 1), perhaps due to decreased herbicide metabolism as the plants adjusted to drier conditions. The increased yield reduction from the proportional carrier volumes agree with results reported for glyphosate (Banks and Schroeder 2002; Ellis et al. 2002; Roider et al. 2008) but disagrees with 2010 results. A possible explanation could be increased epicuticular wax loads on grain sorghum plants in 2012. Epicuticular wax content in grain sorghum was found to increase under hot, dry conditions (Jordan et al. 1983). If epicuticular wax content was higher in 2012, it is possible that the more concentrated droplets from proportional carrier volumes resulted in greater herbicide uptake compared to less concentrated droplets from constant volume.

Based on these data, nicosulfuron drift onto conventional grain sorghum causes significant height and yield reduction even at the lowest herbicide rate. The proportional carrier volume resulted in greater yield reduction from lower rates under drier conditions, and the constant volume caused more yield reduction in a wetter year. If nicosulfuron drift occurred from ALS-resistant grain sorghum to conventional grain sorghum, significant yield losses could occur. Appropriate drift minimization measures should be utilized when nicosulfuron is applied to ALS-resistant grain sorghum in close proximity to conventional grain sorghum. Based on this research, nicosulfuron drift onto conventional grain sorghum can be expected to cause significant yield loss, and the effect of carrier volume may be affected by seasonal rainfall.

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