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Response of Aryloxyphenoxypropionate-Resistant Grain Sorghum to Quizalofop at Various Rates and Application Timings

M. Joy M. Abit, Kassim Al-Khatib, Phillip W. Stahlman, and Patrick W. Geier*

Conventional grain sorghum is highly susceptible to POST grass control herbicides. Development of aryloxyphenoxypropionate-resistant grain sorghum could provide additional opportunities for POST herbicide grass control in grain sorghum. Field experiments were conducted at Hays and Manhattan, KS, to determine the effect of quizalofop rate and crop growth stage on injury and yield of aryloxyphenoxypropionate-resistant grain sorghum. Quizalofop was applied at 62, 124, 186, and 248 g ai ha^{-1} at sorghum heights of 8 to 10, 15 to 25, and 30 to 38 cm, which corresponded to early POST (EPOST), mid-POST (MPOST), and late POST (LPOST) application timings, respectively. Grain sorghum injury ranged from 0 to 68% at 1 wk after treatment (WAT); by 4 WAT, plants generally recovered from injury. The EPOST and MPOST applications caused 9 to 68% and 2 to 48% injury, respectively, whereas injury from LPOST was 0 to 16%, depending on rate. Crop injury from quizalofop was more prominent at rates higher than the proposed use rate in grain sorghum of 62 g ha^{-1}. Grain yields of quizalofop treatments were similar with the non-treated treatments and that application of quizalofop at different timings did not reduce yield except when applied MPOST at the Manhattan site.

Nomenclature: Quizalofop; sorghum, *Sorghum bicolor* (L.) Moench. SORBI.

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Keywords: ACCase-inhibiting herbicides, growth stages, application timing, herbicide rate, crop response.

In terms of acreage, grain sorghum is the third largest cereal crop grown in the United States (Anonymous 2010). Sorghum (*Sorghum* bicolor (L.) Moench) is grown mainly in dry, warm conditions, and encounters several weeds that grow faster than the crop and typically dominate resource utilization. The most common weed control problems in grain sorghum include grasses such as *Setaria*, *Eichinochloa, Digitaria, Panicum,* and *Sorghum* species (Robinson et al. 1964; Smith et al. 1990; Stahlman and Wicks; 2000). Norris (1980) reported that the presence of one barnyardgrass (*Eichinochloa crus-galli*) plant per meter of crop row reduced grain sorghum yields by nearly 10%, whereas 175 plants per meter-crop row reduced yield by 52%. Unless good weed control is achieved, substantial yield loss will occur.

Crop rotation and tillage are often used to control grass weeds infesting grain sorghum. However, herbicides are still the major component of any sorghum weed control program (Brown et al. 2004). The main option for grass weed control in grain sorghum is PRE herbicides such as *S*-metolachlor, alachlor, and dimethenamid. However, grain sorghum is typically grown in dry conditions, and lack of soil moisture to activate PRE applications may decrease herbicide performances. Controlling grass weeds that escape PRE control or germinate after grain sorghum has emerged is difficult because options for POST grass control are very limited. Currently, there are no POST herbicides that provide broad spectrum grass control for grain sorghum.

Acetyl coenzyme A carboxylase (ACCase)-inhibiting herbicides are commonly used to control grass weeds in many crops including soybean (*Glycine max*). The selectivity of these herbicides is based on their effects at the target site – the plastidic ACCase that catalyzes the first committed step in de novo fatty acid biosynthesis (Burton 1997; Gronwald 1994). These herbicides block fatty acid biosynthesis, which consequently alters the integrity of the cell membrane causing metabolite leakage and plant death (Devine and Shimaburuko, 1994).

ACCase herbicides encompass three chemical families: phenylpyrazoline (DEN), cyclohexanediones (CHD), and aryloxyphenoxypropionates (APP). APP herbicides, such as quizalofop, are used as POST treatments to control grass weeds in soybeans, sunflower, cotton, and canola. Foliar-applied quizalofop effectively controlled wild oats (*Avena fatua*), green foxtail (*Setaria viridis*), yellow foxtail (*Seteria glauca*), barnyardgrass, and volunteer cereals (Parsells 1985). Unfortunately, POST application of quizalofop is not an option in conventional grain sorghum production because of the crop's high susceptibility to this herbicide. Recently, new options for POST weed control in grain sorghum have been developed by transferring a major ACCase resistance gene from a feral sorghum relative to elite grain sorghum (Tuinstra and Al-Khatib 2007). Resistance was caused by a tryptophan-to-cysteine mutation at location 2027 (Kershner et al. 2009). This mutation is known to provide resistance to APP but not CHD herbicides. Therefore, quizalofop has been selected to be registered for use on APP-resistant sorghum because of its high efficacy on weeds that are common in sorghum fields (http://ir4.rutgers.edu/FoodUse/food_Use2.cfm?PRnum=10092).

The advent of this technology would allow more effective POST grass weed control in grain sorghum production; however, climatic variability along with crop and weed growth stages often require producers to be flexible in their herbicide options for weed control, which could include altering the time or rate of quizalofop application (Carter et al. 2007). Using the correct herbicide rate and application timing is very important to maximize weed control and minimize injury potential to crops. Although information is available on the effect of quizalofop application rates and timing on weed control, much less information is available on crop response. Therefore, the objective of this research was to determine the influence of quizalofop rate and application timing on APP-resistant grain sorghum response and grain yield.

Materials and Methods

Field experiments were conducted at the Kansas State University Ashland Bottom Research Field at Manhattan, KS (lat:39.12, long:-96.64) and Agricultural Research Center at Hays, KS (lat:38.85, long:-99.34) in 2009. Agronomic practices for grain sorghum production followed the Kansas State University Agricultural Experiment Station and Cooperative Extension Services recommendations (Regehr 1998). The soil at the Manhattan site was a Reading silt loam (fine-silty, mixed, superactive, mesic Pachic Argiudolls) with 3.7% organic matter and pH 6.3. The soil at the Hays site was a Crete silty clay loam (fine, smectitic, mesic Pachic Argiustolls) with 2.3% organic matter and pH 6.5.

A genetic line of APP-resistant grain sorghum developed at Kansas State University was planted approximately 3 cm deep at 170,000 seeds ha^{-1} in rows spaced 76 cm apart. Plots were 3.1 m wide to accommodate four rows and 9.1 m long. Experimental plots were maintained weed free with a PRE application of *S*-metolachlor and atrazine at 1,410 and 1,120 g ai ha^{-1}, respectively, and hand hoeing as needed. Quizalofop was applied POST at 62, 124, 186, and 248 g ai ha^{-1}. The 62 g h^{-1} a rate of quizalofop is the proposed field use rate for control of grass weeds (http://ir4.rutgers.edu/FoodUse/food_Use2.cfm?PRnum=10092). All spray mixtures included 1% crop oil concentrate[1]. A non-treated control was included for comparison. Treatments were applied when grain sorghum was 8 to 10, 15 to 25, and 30 to 38 cm in height, which correspond to early POST (EPOST), mid POST (MPOST), and late POST (LPOST) application timings, respectively. Quizalofop was applied with either a tractor-mounted sprayer or CO_2 pressurized backpack equipped with TT110015[2] nozzles calibrated to deliver 120 L ha^{-1} at 207 kPa or 140 L ha^{-1} at 221 kPa, respectively.

Grain sorghum injury was visually rated at 1, 2, and 4 wk after treatment (WAT). Injury ratings were based on a scale of 0 (no injury) to 100% (plant death). Days to half bloom at flowering was recorded. Sorghum grain was mechanically harvested from the two middle rows of each plot and weighed, and grain yield was adjusted to 14% moisture content.

The experimental design was a randomized complete block with a 3 × 5 factorial arrangement. Treatments were replicated four times. Data were checked for normality and homogeneity of variance. Sorghum injury and days to half bloom data at each rating time were subjected to regression analysis using Sigma Plot 11^3. The appropriate model was selected on the basis of the nature of response, and models that provided the best description of the data are presented. A lack of fit test of each model was performed by partitioning sums of squares into lack of fit error and pure experimental error (Draper and Smith 1981). Models were considered appropriate if an F-test value for lack of fit sums of squares was not significant at $\alpha = 0.05$.

The relationship between visual crop injury and herbicide rate was described using the three-parameter, sigmoidal logistic function, as adapted from Seefeldt et al. (1995):

$$Y = [(A/X - 1) \times (ID_{50})^B]^{1/B} \qquad \text{[Eq. 1]}$$

where Y represents the crop visual injury compared with the nontreated control, A represents the maximum value of Y, X represents the herbicide dose, ID_{50} is the application rate required to cause 50% injury to the crop, and B is the slope at ID_{50}. Herbicide rates needed to cause injury by 15% (ID_{15}) were determined from regression equations. ID_{15} was selected because this is greatest acceptable injury for sorghum.

The relationship between days to half bloom and herbicide rate was described using the polynomial linear model. Slope of the regression were tested for significance using an F test:

$$\text{F stat} = \frac{\left[\dfrac{\text{Regression SS (combined)} - \Sigma\ \text{Regression SS 1\& 2}}{\text{DF (combined)} - \Sigma\text{DF (1 \& 2)}}\right]}{\left[\dfrac{\text{Regression SS 1 \& 2}}{\Sigma\text{DF (1 \& 2)}}\right]}$$

If the $F_{computed}$ is greater than the $F_{tabular}$ then they are different at $P \leq 0.05$.

Yield data were subjected to ANOVA using PROC MIXED in SAS[4] with location, quizalofop rate, application timing, and all possible interactions as fixed effects and blocks as random effects. Orthogonal contrasts among application timings were performed using PROC GLM in SAS.

Results and Discussion

Data were averaged across locations because no location by treatment interactions occurred for visual injury and days to half bloom. Data for sorghum injury at 4 WAT was not reported because no injury was observed in all treatments except in the highest rate at EPOST timing.

Quizalofop caused injury symptoms to grain sorghum including chlorosis, necrosis, leaf distortion, stunting and slight purple leaf coloring; the latter was attributed to anthocyanin accumulation (Ishikawa et al. 1985; Swisher and Corbin 1982). Visual injury was first observed 5 to 7 d after treatment as irregular chlorotic areas on treated tissue that became progressively necrotic. Leaf distortion and subsequent stunting of the plant were observed 7 to 10 d after treatment. Symptom intensity differed depending on herbicide rate and timing. At lower rates, initial injury symptoms were leaf chlorosis and slight leaf distortion. At the highest rate, especially when quizalofop was applied at EPOST, initial injury symptoms were severe chlorosis, stunting, and epinasty. Young leaves were the first to show symptoms, followed by other older leaves; however, all injury symptoms disappeared by the end of the growing season.

Quizalofop at all rates injured grain sorghum at each application timing. Injury severity increased with increasing quizalofop rate, especially at the two earlier application timings. Quizalofop caused more injury at the EPOST and MPOST than at the LPOST timing 1 WAT (Figure 1). These results are not surprising because young, rapidly growing plants would be expected to absorb more herbicide than the mature plant (Devine 1989; Wanamarta and Penner 1989). At 1 WAT, injury from EPOST application timing ranged from 9% when quizalofop was applied at 62 g ha^{-1} to 68% at the 248 g ha^{-1} rate. Injury ratings 2 WAT ranged from 4 to 58% when quizalofop was applied at 62 to 248 g ha^{-1}, respectively. At 4 WAT, plants generally recovered and produced normal shoots, except plants treated at 248 g ha^{-1} that showed less than 17% injury (data not shown). At MPOST quizalofop applied at 62 to 248 g ha^{-1} injured sorghum 2 to 48% at 1 WAT. However, by 2 WAT, injury dissipated except at the highest rate (12%). Sorghum injury was slight when quizalofop was applied at LPOST. At 1 WAT, injury ranged from 3 to 16%. By 2 WAT, symptoms faded and new shoots appeared normal.

Although there were differences in the level of crop response when quizalofop was applied at different timings, computed ID_{15} (quizalofop rate that would cause 15% injury to sorghum), shows that the suggested use rate of quizalofop at 62 g ha^{-1} would cause less than 15% injury 1 WAT to sorghum if applied at EPOST timing (Table 1). Furthermore, 101 and 232 g ha^{-1} are required to cause 15% injury when quizalofop is applied at MPOST and LPOST, respectively.

Sorghum flowering dates differed among application timings (Figure 2). A day delay in flowering was observed when plants were treated at EPOST when quizalofop was applied at186 and 248 g ha^{-1}. Moreover, there was a delay in flowering when quizalofop was applied at MPOST and LPOST, especially at the higher rates. Sorghum plants treated with 186 and 248 g ha^{-1} quizalofop at MPOST had a 4-d delay in flowering, whereas plants treated with 124, 186, and 248 g ha^{-1} quizalofop at LPOST had 5-, 6-, and 10-d delays in flowering, respectively. The flowering delay at the LPOST herbicide application timing may be due to the lack of time for recovery before the plant initiates its reproductive phase (Smith et al. 2006).

Significant interactions among application rates and timing by application rates were not detected; therefore, data for these parameters were pooled over rates. Although quizalofop caused significant injury, grain sorghum has shown the ability to recover from severe injury without sustaining yield reductions. Grain yield in quizalofop-treated and non-treated plots was 2,640 and 2,530 kg ha^{-1}, respectively, at Hays and 1,630 and 1,820 kg ha^{-1}, respectively, at Manhattan. Greater grain yield were observed at Hays compared to Manhattan due to rain-delayed harvest, which reduced test weights (data not shown). Contrast comparison (averaged over rates) between EPOST and MPOST, and MPOST and LPOST timings at Manhattan site were significant (Table 2) due to 17 and 19 % greater grain yield for the LPOST and EPOST timings, respectively.

This study demonstrate that application of quizalofop to APP-resistant sorghum at MPOST timing caused visual injury that could result in grain yield, however the injury symptoms at EPOST and LPOST timing did not cause any sorghum yield reductions. Under field conditions, herbicides are typically applied after the three- to five-leaf stage (MPOST timing) because weeds are usually just emerging at this time (Hennigh et al. 2010). Although weed size should be the primary criteria for herbicide application timing, when producers have some flexibility concerning weed size, LPOST quizalofop applications may be preferred over MPOST when the APP-resistant sorghum shows good tolerance. Although quizalofop can result in crop injury and yield its use must be considered along with the competitive effects that the unchecked weeds will have. Lastly, there is a high level of resistance to quizalofop in this grain sorghum genetic line; hence, it could provide greater flexibility in managing weeds in terms of application timing and rate.

Sources of Materials

[1] Prime Oil, Terra International Inc., P. O. Box 6000, Sioux City, IA 51102-6000.

[2] Teejet, Spraying Systems Co., P. O. Box 7900, Wheaton, IL 60189-7900.

[3] Systat Software, Inc. 501 Canal Blvd, Suite E, Point Richmond, CA 94804-2028.

[4] SAS version 9.1, SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513.

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Literature Cited

Anonymous. 2010. U.S. Grain Council. http://www.grains.org/sorghum. Accessed October 25, 2010.

Brown, D. W., K. Al-Khatib, D. L. Regehr, P. W. Stahlman, and T. M. Loughin. 2004. Safening grain sorghum injury from metsulfuron with growth regulator herbicides. Weed Sci. 52:319-325.

Burton, J. D. 1997. Acetyl-coenzyme A carboxylase inhibitors. Pages 187-205 *in* R. M. Roe, J. D. Burton, and R. J. Kuhn, eds. Herbicide Activity: Toxicology, Biochemistry and Molecular Biology. Amsterdam: IOS Press.

Carter, A. H., J. Hansen, T. Koehler, D. C. Thill, and R. S. Zemetra. 2007. The effect of imazamox application timing and rate on imazamox resistant wheat cultivars in the Pacific Northwest. Weed Technol. 21:895-899.

Devine, M. D. 1989. Phloem translocation of herbicides. Rev. Weed Sci. 4:191-213.

Devine, M. D. and R. H. Shimaburuko. 1994. Resistance to acetyl coenzyme A carboxylase inhibiting herbicides. Pages 141-169 *in* S. B. Powles and J. A. M. Holtun, eds. Herbicide Resistance in Plants. Boca Raton, FL: CRC Press.

Draper, N.R. and H. Smith. 1981. Applied Regression Analysis. New York: J. Wiley. Pp. 458-517.

Gronwald, J. W. 1994. Herbicides inhibiting acetyl-CoA carboxylase. Biochem. Soc. Trans. 22:616-621.

Hennigh, D. S., K. Al-Khatib, and M. R. Tuinstra. 2010. Response of acetolactate synthase-resistant grain sorghum to nicosulfuron plus rimsulfuron. Weed Technol. 24:411-415.

Ishikawa, H., S. Tamada, H. Hosaka, T. Kawana, S. Okunuki, and K. Kohara. 1985. Herbicide properties of sethoxydim for the control of gramineous weeds. J. Pestic. Sci. 10:187-193.

Kershner, K. S., K. Al-Khatib, and M. R. Tuinstra. 2009. Resistance to acetyl-coenzyme A carboxylase-inhibiting herbicides in grain sorghum. Crop Sci. Soc. Am. Proc. 54:167-17.

Norris, R. F. 1980. Barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] competition and seed production. Proc. Weed Sci. Soc. Am. 20:5.

Parsells, A. J. 1985. Assure – A new postgrass herbicide from Dupont. Weeds Today. 16:9-10.

Regehr, D. L. 1998. Grain Sorghum Handbook: Weed Control. Manhattan, KS: Kansas State University Agricultural Experiment Station and Cooperative Extension Service. 32p.

Robinson, R. G., W. W. Nelson, R. L. Thompson, and J. R. Thompson. 1964. Herbicides and mixtures for annual weed control in grain sorghum. Weeds. 12:77-79.

Smith, K., L. Espinoza, and D. Oliver. 2006. Development of effective weed control programs with crop safety *in* 2006 Research Summary Arkansas Corn and Sorghum Board. http://www.corn-sorghum.org/research_results/2006pdf/08 Development of Effective Weed Control Programs with Crop Safety.pdf. Accessed January 23, 2010.

Smith, B. S., D. S. Murray, J. D. Green, W. M. Wanyahaya, and D. L. Weeks. 1990. Interference of three annual grasses with grain sorghum (*Sorghum bicolor*). Weed Technol. 4:245-249.

Stahlman, P. W. and G. A. Wicks. 2000. Weeds and their control in grain sorghum. Pages 535-582 *in* C. W. Smith, ed. Sorghum: Origin, History, Technology, and Production. New York.: Wiley.

Swisher, B. A. and F. T. Corbin. 1982. Behavior of BAS-9052OH in soybean and johnsongrass plant and cell cultures. Weed Sci. 30:640-650.

Tuinstra, M. R. and K. Al-Khatib. 2007. New herbicide tolerance strains in sorghum. In Proceedings of the 2007 Corn, Sorghum, and Soybean Seed Research Conf. and Seed Expo. Chicago, IL: Am. Seed Trade Assoc.

Table 1. Regression parameters (see Equation 1) and quizalofop rate that provided 15% injury (ID_{15}) to APP- resistant grain sorghum. Values in parentheses are standard errors showing variation around the mean of eight replicates.

	1 WAT[a]				2 WAT			
Timing	A[b]	b[c]	ID_{50}[d]	computed[e] ID_{15}	A	b	ID_{50}	computed ID_{15}
				g ha^{-1}				g ha^{-1}
	68.0	37.2	124.6			35.6	144.9	
	(5)	(8)	(10)			(3)	(5)	
	59.5	62.6	169.4		60.2 (2)	53.3	218.9	
EPOST	(24)	(30)	(63)	78	18.7 (5)	(11)	(34)	106
MPOST	19.0	49.5	167.0	101	1.3	34.4	162.1	294
LPOST	(2)	(8)	(14)	232	(0.12)	(7)	(10)	*

* cannot be estimated

[a] WAT = weeks after treatment

[b] A = maximum injury

[c] b = slope

[d] ID_{50} = application rate required to cause 50% injury

[e] Computed ID_{15} = application rate required to cause 15% injury determined from regression equations

Table 2. Yield of quizalofop-treated APP-resistant grain sorghum as influenced by quizalofop application timing at Hays and Manhattan, KS.

Timing	Yield	
	Hays	Manhattan
	kg ha^{-1}	
EPOST	2751	1757
MPOST	2555	1429
LPOST	2438	1729
CV	12	10
Contrasts[a]		
EPOST vs MPOST	NS	*[b]
EPOST vs LPOST	NS	NS
MPOST vs LPOST	NS	*

[a] Contrasts are averaged over quizalofop rates

[b] Level of significance represented by * = < 0.05

Figure 1. Quizalofop injury to APP-resistant grain sorghum as affected by quizalofop rate and timing 1 and 2 wk after treatment (WAT).

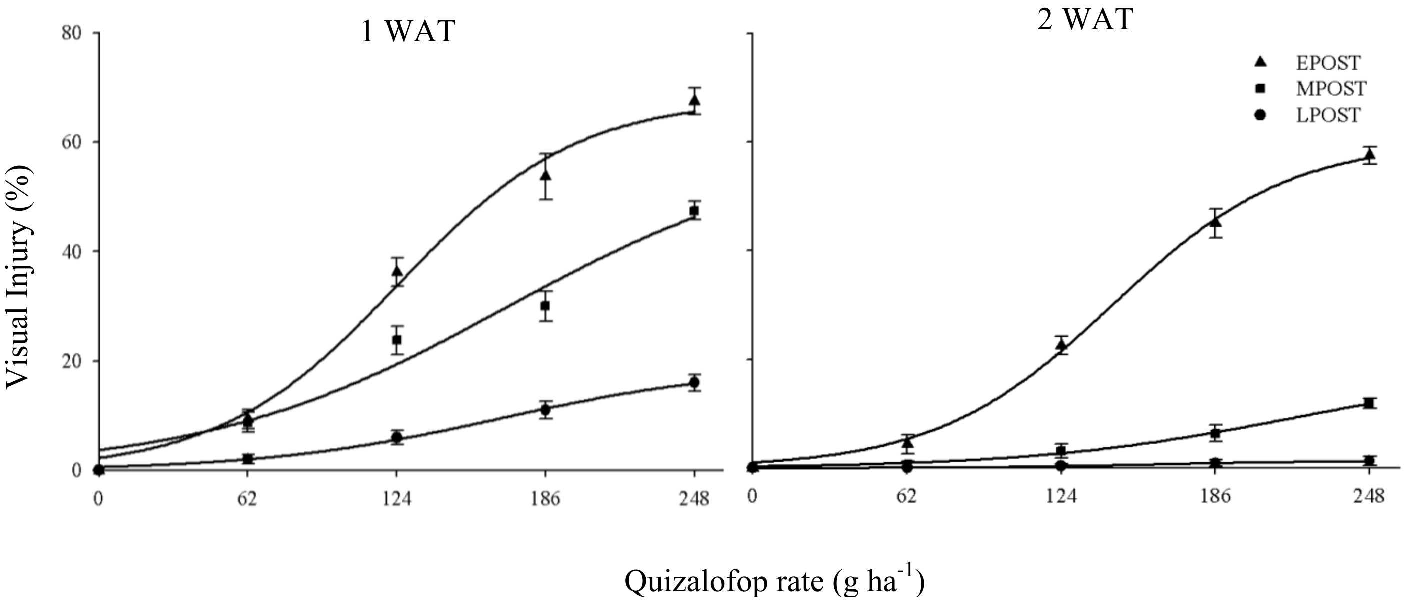

Figure 2. The effect of quizalofop rate and timing to days to half bloom of APP-resistant grain sorghum.