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Pyroxasulfone with and without Sulfentrazone in Sunflower (*Helianthus annuus*)

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Pyroxasulfone (KIH-485) is a seedling growth-inhibiting herbicide developed by Kumiai America that has the potential to control weeds in sunflower. However, little is known about how this herbicide will interact with various soil types and environments when combined with sulfentrazone. The objective of this research was to evaluate sunflower injury and weed control with pyroxasulfone applied with and without sulfentrazone across the Great Plains sunflower production area. A multisite study was initiated in spring 2007 to evaluate sunflower response to pyroxasulfone applied PRE at 0, 167, 208, or 333 g ai ha^{-1}. In 2008, pyroxasulfone was applied alone and in tank mixture with sulfentrazone. In 2007, no sunflower injury was observed with any rate of pyroxasulfone at any location except Highmore, SD, where sunflower injury was 17%, 4 wk after treatment (WAT) with 333 g ha^{-1}. In 2008, sunflower injury ranged from 0 to 4% for all treatments. Adding sulfentrazone did not increase injury. Sunflower yield was only reduced in treatments in which weeds were not effectively controlled. These treatments included the untreated control and pyroxasulfone at 167 g ha^{-1}. Sunflower yield did not differ among the other treatments of pyroxasulfone or sulfentrazone applied alone or in combination. The addition of sulfentrazone to pyroxasulfone improved control of foxtail barley, prostrate pigweed, wild buckwheat, Palmer amaranth, and marshelder, but not large crabgrass or green foxtail. The combination of pyroxasulfone and sulfentrazone did not reduce control of any of the weeds evaluated.
Nomenclature: Pyroxasulfone (KIH-485); sulfentrazone; foxtail barley, *Hordeum jubatum* L. HORJU; green foxtail, *Setaria viridis* (L.) Beauv. SETVI; large crabgrass, *Digitaria sanguinalis* (L.) Scop. DIGSA; marshelder, *Iva xanthifolia* Nutt. IVAXA; Palmer amaranth, *Amaranthus palmeri* S. Wats. AMAPA; prostrate pigweed, *Amaranthus blitoides* S. Wats AMABL; wild buckwheat, *Polygonum convolvulus* L. POLCO; sunflower, *Helianthus annuus* L.
Key words: PRE herbicides, crop injury, environment, herbicides.

El pyroxasulfone (KIH-485) es un herbicida inhibidor del crecimiento de plántulas desarrollado por Kumiai América, que tiene el potencial para el control de maleza en cultivo del girasol. Sin embargo, se sabe poco acerca de cómo este herbicida interactúa con varios tipos de suelo y ambientes cuando se combina con sulfentrazone. El objetivo de esta investigación fue evaluar el daño al girasol y el control de maleza con pyroxasulfone aplicado con y sin sulfentrazone a lo largo del área de producción del girasol en los Great Plains, de Norteamérica. En la primavera de 2007 se inició un estudio en múltiples sitios para evaluar la respuesta de girasol a la aplicación PRE de pyroxasulfone a 0, 167, 208, o 333 g ia ha^{-1}. En 2008, se aplicó pyroxasulfone solo y en mezclas con sulfentrazone. En 2007, no se observó daño alguno al girasol a cualquier dosis de pyroxasulfone en ninguna de los sitios, excepto en Highmore, SD, donde el daño fue 17%, 4 semanas después del tratamiento (WAT) con 333 g ha^{-1}. En 2008, el daño al girasol varió de 0 a 4% para todos los tratamientos. La adición de sulfentrazone no incrementó el daño. El rendimiento del girasol se redujo solamente en los tratamientos donde la maleza no se controló con efectividad. Estos tratamientos incluyeron el testigo no tratado y pyroxasulfone a 167 g ha^{-1}. No hubo diferencia en el rendimiento del girasol entre los otros tratamientos de pyroxasulfone o sulfentrazone aplicado solo o en combinación. La adición de sulfentrazone a pyroxasulfone mejoró el control de *Hordeum jubatum, Amaranthus blitoides, Polygonum convolvulus, Amaranthus palmeri* e *Iva xanthifolia* pero no el de *Digitaria sanguinalis* o *Setaria viridis*. La combinación de pyroxasulfone y sulfentrazone no redujo el control de ninguna maleza evaluada.

Sunflower crops were planted on 1 million hectares in the United States during 2008 (Anonymous 2009a). A survey of sunflower growers conducted in 1999 indicated that 95% of the hectares received a herbicide application (Anonymous 2009b); 80% of this hectarage received PRE applications of ethalfluralin, pendimethalin, or trifluralin to control annual grasses and a limited number of small-seeded broadleaf weeds (Anonymous 2009b).

Competition from small-seeded broadleaf weeds such as kochia [*Kochia scoparia* (L.) Schrad.] or from grasses such as large crabgrass can cause significant yield loss to sunflower. Durgan et al. (1990) found that kochia decreased sunflower yield by 47% when 6 plants m^{-1} of row emerged within 1 wk after sunflower emergence, whereas Johnson (1971) found that a combination of large crabgrass and goosegrass [*Eleusine indica* (L.) Gaertn.], sicklepod (*Cassia obtusifolia* L.), tall morningglory [*Ipomea purpturea* (L.) Roth], ivyleaf morningglory [*I. hederacea* (L.) Jacq.], and redroot pigweed (*Amaranthus retroflexus* L.) decreased sunflower yield by 62% when the weeds competed with sunflower for the entire growing season.

Pyroxasulfone is a herbicide developed by Kumiai America. The mode of action of this herbicide is seedling growth

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inhibition. University faculty from many states have evaluated this herbicide in a variety of crops and found that it can provide excellent weed control. For example, King and Garcia (2008) reported that pyroxasulfone provided 88% or better control of kochia and velvetleaf (*Abutilon theophrasti* Medik.) 4 mo after planting, which was greater than metolachlor in furrow-irrigated corn (*Zea mays* L.). In glyphosate-resistant corn, pyroxasulfone applied with glyphosate controlled shattercane [*Sorghum bicolor* (L.) Moench ssp. *arundinaceum* (Desv.) de Wet & Harlan] 96%, but the combination of glyphosate with metolachlor, acetochlor, or pendimethalin only provided 88% or less control (King et al. 2007).

Other researchers have studied the application rate of pyroxasulfone. Knezevic et al. (2009) indicated that the proposed label rate of pyroxasulfone of 200 to 300 g ha^{-1} provided excellent control of green foxtail, field sandbur (*Cenchrus spinifex* Cav.), and large crabgrass. Geier et al. (2006) reported that pyroxasulfone at 250 g ha^{-1} provided 86% control of green foxtail, Palmer amaranth, and puncturevine (*Tribulus terrestris* L.). At 4 wk after treatment (WAT), pyroxasulfone applied at 208 g ha^{-1} or more provided at least 90% control of Texas panicum (*Panicum texanum*), Palmer amaranth, and velvetleaf (Gregory et al. 2005).

Research also has been conducted on the efficacy of pyroxasulfone for controlling weeds in sunflower. Zollinger and Ries (2007) reported that pyroxasulfone provided acceptable to excellent control of kochia, redroot pigweed, common ragweed (*Ambrosia artemisiifolia* L.), and green and yellow foxtail [*Setaria pumila* (Poir.) Roemer & J.A. Schultes] at three locations in North Dakota. These results suggest that pyroxasulfone would be an excellent addition to the list of herbicides registered for use in sunflower.

Sulfentrazone is a valuable tool for controlling weeds in sunflower, but it can injure the crop. Thompson et al. (2000) reported an average of 8% more injury from PRE applications of sulfentrazone after planting sunflower compared with sulfentrazone applied 2 wk before planting and also noted that sunflower injury was enhanced when sulfentrazone was applied in combination with pendimethalin. Wait and Johnson (2002) observed a similar increase in sunflower injury from sulfentrazone applied with pendimethalin. In their study, sulfentrazone alone injured sunflower 6% or less, whereas the combination of pendimethalin and sulfentrazone increased sunflower injury by 14%.

Pyroxasulfone has shown promise as a new herbicide to provide excellent weed control. However, researchers have not collected data on the response of sunflower to pyroxasulfone over multiple environments. In addition, the combination of sulfentrazone and pyroxasulfone could increase crop injury; research should be conducted to evaluate sunflower response to tank mixtures of pyroxasulfone with sulfentrazone. The objective of this study was to evaluate the effect of multiple rates of pyroxasulfone applied with and without sulfentrazone under various field conditions.

Materials and Methods

A multisite study was initiated in spring 2007 to evaluate the effect of pyroxasulfone on sunflower. Experiments were conducted at the Northwest Research-Extension Center at Colby, KS; Agricultural Research Center at Hays, KS; Southwest Research-Extension Center–Tribune Unit at Tribune, KS; Ashland Bottoms Research Unit at Manhattan, KS; North Central Research Extension Center at Minot, ND; Central Crops and Soils Research Station at Highmore, SD; and a farmer's field near Valley City, ND. Sunflower hybrids, planting rates and dates, soil types, soil pH, organic matter, and application information are presented in Table 1. Fertilizer was applied at each site in accordance with soil test levels and yield goals, and insecticides were used at each site as needed to prevent yield loss from insects. The standardized protocol used in 2007 was pyroxasulfone applied PRE at 167, 208, and 333 g ha^{-1} and an untreated control. All treatments were applied to plots ranging in size from 2 to 3 m wide and 6.7 to 7.6 m long. Sunflower injury was evaluated visually on a scale of 0 (no injury) to 100 (crop death). Grain weight and moisture content were recorded and yield was calculated at all sites, except Valley City, ND. Grain yield was adjusted to a standard moisture of 10%. All locations were set up as randomized complete block designs with three or four replications.

In 2008, experiments were conducted on fields adjacent to the locations used in 2007. Descriptions of experimental locations are listed in Table 2. General production practices were similar to those used in 2007. An expanded protocol, examining three rates of pyroxasulfone at 125, 167, and 250 g ha^{-1} (coarse-textured soils) or 167, 208, and 333 g ha^{-1} (medium-textured soils) applied alone and in combination with sulfentrazone at 105 and 140 g ha^{-1}, was used at each location. Treatments were applied at 120 to 187 L ha^{-1}. Plot layout, experimental design, and evaluation of sunflower injury were the similar to the procedures used in 2007. Weed control was assessed visually on a scale of 0 (no injury) to 100 (weed death). Grain weight, test weight, and moisture content were recorded at each location, except Tribune, KS, and Valley City, ND. Yield was calculated and adjusted to 10% moisture. Data were statistically analyzed with PROC GLM in SAS[1] and separated with Fisher's Protected LSD with $P \leq 0.05$.

Results and Discussion

Sunflower Response. In 2007, sunflower was not injured from PRE applications of pyroxasulfone at any of the locations, except Highmore, SD (data not shown). Organic matter ranged from 1.6 to 5.3%, and soil pH ranged from 5.5 to 8.3 across locations (Table 1). At Highmore, the mid-rate of pyroxasulfone (208 g ha^{-1}) injured sunflower 5% and the high rate of pyroxasulfone (333 g ha^{-1}) injured sunflower 17%, 4 WAT. This location received 18 mm of precipitation within 1 wk of planting and pyroxasulfone application. This rainfall event might have caused an increased accumulation of pyroxasulfone around the emerging sunflower shoot, resulting in sunflower injury. Another possible cause for sunflower injury might have been the result of pyroxasulfone coming into direct contact with the emerging sunflower cotyledons. Regardless of rate or location, sunflower yield was not affected by pyroxasulfone.

Table 1. Description of experiment locations and operations, 2007.[a]

	Kansas				North Dakota		South Dakota
	Colby	Hays	Tribune	Manhattan	Minot	Valley City	Highmore
Planting date	June 11	June 21	June 4	June 8	May 18	June 10	June 5
Sunflower hybrid	Triumph 645	Triumph 660 CL	Pioneer 63N81	Triumph 620 CL	Mycogen 8N386CL	Croplan CL520	Legend 218 NCL
Seeds ha^{-1}	42,250	44, 500	59,300	59,300	54,300	49,500	51,870
Appl. date	June 16	June 22	June 4	June 8	May 21	June 11	June 5
Soil type	Keith silt loam	Harney silt loam	Ulysses silt loam	Wymore silty clay loam	Williams loam	Barnes–Svea loam	Stickney–Java–Hoven complex
Soil texture	Medium	Medium	Coarse	Medium	Medium	Medium	Medium
Soil pH	6.1	7.6	8.3	6.2	5.9	5.5	5.9
Soil OM %	2.8	1.6	2.0	2.8	3.5	5.3	2.8

[a] Abbreviations: Appl., date of PRE herbicide application, OM, organic matter.

Table 2. Description of experiment locations and operations, 2008.[a]

	Kansas				North Dakota		South Dakota
	Colby	Hays	Tribune	Manhattan	Minot	Valley City	Highmore
Planting date	June 16	June 4	May 27	June 1	May 21	May 12	May 31
Sunflower hybrid	Triumph 645	Mycogen 8N386CL	Pioneer 63N82	Pioneer 63N82	Croplan 528	Pioneer 63N82	Legend 218 NCL
Seeds ha^{-1}	43,400	49,400	42,000	54,400	49,400	49,400	51,870
Appl. date	June 20	June 5	May 27	June 10	May 22	May 12	May 31
Soil type	Keith silt loam	Harney silt loam	Ulysses silt loam	Reading silt loam	Max–Williams Sandy loam	Barnes–Svea loam	Stickney–Java–Hoven complex
Soil texture	Medium	Medium	Coarse	Medium	Medium	Medium	Medium
Soil pH	6.5	6.5	7.9	5.8	7.5	7.1	6.3
Soil OM %	2.7	2.0	2.5	3.2	2.3	3.8	2.8

[a] Abbreviations: Appl., date of PRE herbicide application, OM, organic matter.

Table 3. Sunflower injury and yield and grass weed control from pyroxasulfone and sulfentrazone alone and in various combinations in 2008, 4 WAT.[a]

		Sunflower		DIGSA		SETVI	HORJU
Herbicide	Rate	Injury	Yield[b]	Manhattan	Hays	Brookings	Valley City
	g ha^{-1}	%	kg ha^{-1}	%			
Pyroxasulfone	167	0	1,940	95	58	75	40
	208	1	2,044	100	55	83	50
	333	1	2,054	100	67	90	75
Sulfentrazone	105	0	2,147	57	23	50	30
	140	1	2,049	67	55	65	47
Pyroxasulfone + sulfentrazone	167 + 105	0	2,128	100	50	86	67
	208 + 105	2	2,079	100	58	90	72
	333 + 105	3	2,265	100	53	92	50
	167 + 140	2	2,175	100	65	88	53
	208 + 140	2	2,038	100	65	88	72
	333 + 140	3	2,201	100	65	93	72
Untreated	—	0	1,763	0	0	0	0
LSD (P = 0.05)		NS	251	11	22	8	6

[a] Abbreviations: DIGSA, large crabgrass; HORJU, foxtail barley; SETVI, green foxtail; WAT, weeks after treatment.

[b] Yields were combined across the sites of Colby, Hays, Manhattan, Minot, and Highmore.

In 2008, five sunflower hybrids were planted at the seven different experimental locations with soil pH ranging from 5.8 to 7.9 and organic matter ranging from 2 to 3.8% (Table 2). Sunflower injury was $< 2\%$ for all rates of pyroxasulfone across the seven locations, 4 WAT (Table 3). Sulfentrazone also did not cause significant sunflower injury, and the combination of sulfentrazone and pyroxasulfone did not increase injury.

Sunflower yield was only lower in treatments that did not provide adequate weed control. These treatments included the lowest rate of pyroxasulfone and the untreated control (Table 3).

Grass Control. Large crabgrass control was inconsistent between Manhattan and Hays, KS. The lowest rate of pyroxasulfone (167 g ha^{-1}) provided 95% large crabgrass control at Manhattan, whereas large crabgrass control was only 58% at Hays (Table 3). Sulfentrazone at 105 g ha^{-1} provided 57 and 23% crabgrass control at Manhattan and Hays, respectively. Tank mixtures of these herbicides did not increase or decrease large crabgrass control. Differences in large crabgrass control between these locations could be attributed to the time of rainfall after herbicide application. The Manhattan location had 34 mm of rain within 1 d of application, whereas the first rainfall of > 3 mm was 13 d after herbicide application (12 mm) at Hays. The rain at Manhattan incorporated pyroxasulfone into the soil. At Brookings, the lowest rate of pyroxasulfone (167 g ha^{-1}) provided 75% control of green foxtail (Table 3). Increasing the rate of pyroxasulfone to 208 or 333 g ha^{-1} or tank mixing pyroxasulfone with sulfentrazone improved control of green foxtail. At Valley City, the tank mixture of 208 g ha^{-1} of pyroxasulfone and 105 g ha^{-1} of sulfentrazone provided 72% control of foxtail barley 4 WAT. Applied alone, these herbicides only provided 50 and 30% control of foxtail barley, respectively.

The combination of sulfentrazone and pyroxasulfone increased control of foxtail barley compared with either

Table 4. Broadleaf weed control from pyroxasulfone and sulfentrazone alone and in various combinations in 2008, 4 WAT.[a]

		AMABL	POLCO		AMAPA		IVAXA
Herbicide	Rate	Minot	Brookings	Minot	Manhattan	Tribune[b]	Valley City
	g ai ha^{-1}	%					
Pyroxasulfone	167	70	67	47	97	79	43
	208	73	68	58	97	87	53
	333	80	80	65	100	96	85
Sulfentrazone	105	79	63	93	87	99	27
	140	83	75	94	92	98	58
Pyroxasulfone + sulfentrazone	167 + 105	93	81	85	100	100	73
	208 + 105	95	83	91	100	100	77
	333 + 105	98	85	96	100	100	67
	167 + 140	98	85	97	100	100	65
	208 + 140	97	85	97	100	100	81
	333 + 140	97	85	92	100	100	89
Untreated	-	0	0	0	0	0	0
LSD (P = 0.05)		15	12	11	9	6	10

[a] Abbreviations: AMABL, prostrate pigweed; AMAPA, Palmer amaranth; IVAXA, marshelder; POLCO, wild buckwheat; WAT, weeks after treatment.

[b] At Tribune, pyroxasulfone of 125, 167, and 250 g ha^{-1} was applied.

herbicide alone, but not large crabgrass or green foxtail. Applying the herbicides together did not reduce control of any of the grass species evaluated.

Broadleaf Weed Control. Prostrate pigweed control ranged between 70 and 80% with pyroxasulfone applied alone at Minot (Table 4). Prostrate pigweed control with sulfentrazone was 79 and 83% with 105 and 140 g ha^{-1}, respectively. The addition of pyroxasulfone to sulfentrazone increased prostrate pigweed control by at least 10% compared with either herbicide applied alone.

At Brookings, pyroxasulfone rates of 208 g ha^{-1} or less provided 68% or less control of wild buckwheat (Table 4). However, when pyroxasulfone was applied at 208 g ha^{-1} in combination with sulfentrazone at 105 or 140 g ha^{-1} wild buckwheat control was 83 and 85%, respectively, a 15 to 20% increase in control over that observed from either herbicide applied alone. However, this improved control was not observed at Minot. In fact, control of wild buckwheat from sulfentrazone alone was $> 90\%$.

Palmer amaranth is an aggressive weed that has spread throughout most sunflower production fields in the Great Plains. A herbicide that can provide a high level of control of this weed would have an advantage in the marketplace. The combination of pyroxasulfone and sulfentrazone at the lowest tank mixture rate provided complete control of Palmer amaranth at Tribune and Manhattan (Table 4). Neither herbicide applied alone at the lowest application rate provided complete control of Palmer amaranth at either location.

At Valley City, pyroxasulfone applied at either the 167 or 208 g ha^{-1} rate with either the 105 or 140 g ha^{-1} rate of sulfentrazone enhanced marshelder control compared with the herbicides applied alone (Table 4). No difference in control was observed between the combination of pyroxasulfone and sulfentrazone applied at 333 and 140 g ai ha^{-1}, respectively, compared with pyroxasulfone applied at the 333 g ai ha^{-1} alone.

Pyroxasulfone and sulfentrazone applied together at the 167 and 105 g ai ha^{-1} rate provided higher levels of broadleaf weed control than either herbicide applied alone with the exception of wild buckwheat control at Minot, ND (Table 4). However, applying these two herbicides together did not reduce control compared with applying them separately.

These results indicate that pyroxasulfone has the potential to be a valuable tool in the future for growers to control annual grass and broadleaf weeds in sunflower when the herbicide is incorporated by rainfall or irrigation. Tank mixing pyroxasulfone with sulfentrazone broadens the spectrum of weeds controlled and improves the control of certain species. Sunflower has demonstrated excellent tolerance to pyroxasulfone, and the slight occasional injury did not reduce seed yield. This study was conducted over a wide range of soil and environmental conditions, which provides further support for the idea that pyroxasulfone has good potential for use in PRE weed control in sunflower. However, additional trials are needed to determine whether mixtures of pyroxasulfone and sulfentrazone or other herbicides will consistently provide improved broad-spectrum weed control compared with available herbicide treatments.

Sources of Materials

[1] SAS. 2002. Version 9.1. Cary, NC: SAS Institute.

[2] TeeJet nozzles, Spraying Systems Co., North Avenue, Wheaton, IL 60189.

Acknowledgment

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