PYROXASULFONE TOLERANCE OF NAVY AND PINTO BEANS (*Phaseolis vulgaris* L.), DRY PEA (*Pisum sativum* L.), AND LENTIL (*Lens culinaris* Medik)

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By

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

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Date

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ABSTRACT

Hunt, Ryan Leigh; M.S.; Department of Plant Sciences; College of Agriculture, Food Systems, and Natural Resources; North Dakota State University; November 2010. Pyroxasulfone Tolerance of Navy and Pinto Beans (*Phaseolis vulgaris* L.), Dry Pea (*Pisum sativum* L.), and Lentil (*Lens culinaris* Medik). Major Professor: Dr. Richard K. Zollinger.

Field experiments were conducted to determine the tolerance of navy and pinto bean, dry pea, and lentil to pyroxasulfone. Additional field studies were conducted to evaluate the weed control efficacy of pyroxasulfone in preemergence and early-preplant applications. Greenhouse experiments were conducted to determine plant uptake of pyroxasulfone and the influence of activation timing on navy bean injury. Navy bean tolerance to pyroxasulfone varied by rate and experiment location. Navy bean injury occurred at 166 g ai ha^{-1} in 2008 and at 332 g ai ha^{-1} in 2009. A pyroxasulfone rate of 166 g ai ha^{-1} and greater resulted in decreased yield of navy bean. Pinto bean injury from pyroxasulfone varied by location. As pyroxasulfone rate increased, visual injury to pinto bean increased at Prosper in 2008; however, no pinto bean injury was observed at Prosper in 2009. Pinto bean injury was observed in all other environments at 332 g ai ha^{-1}. Pinto bean yield was not reduced. Dry pea tolerance was excellent in all environments tested; however, the lack of weed control in all environments was evidence that pyroxasulfone was not activated by precipitation received. Lentil tolerance was excellent in all environments tested, except for Minot 2009. Visual injury at Minot 2009 increased from 14 to 28 d after emergence, and then decreased to insignificant levels 56 d after emergence. Lentil yield was not affected at any environment; however, a lack of weed control in all environments, except for Minot 2009, was caused by inadequate precipitation to activate the herbicide. These studies suggest that navy bean may not have sufficient tolerance to pyroxasulfone for field use. More research should be performed on dry pea and lentil tolerance to determine the extent of tolerance in various environments.

Weed control experiments showed both the potential and inconsistency of pyroxasulfone. High weed control ratings in the 2008 EPP (early preplant) study, from 14 to 35 d after application, demonstrated the ability of pyroxasulfone to control weeds growing prior to herbicide activation. Yellow foxtail (*Setaria glauca* (L.)) and hairy nightshade (*Solanum sarrachoides* Sendt.) were controlled at 166 g ai ha^{-1}. Wild mustard (*Brassica Kaber* (DC.)), hairy nightshade, and redroot pigweed (*Amaranthus retroflexus*) were controlled 70 d after application at 166 g ai ha^{-1}. Redroot pigweed control at 125 g ai ha^{-1} was equivalent to acetochlor in the PRE (preemergence) 2008 study. Yellow foxtail control at an increased rate of 209 g ai ha^{-1} pyroxasulfone was equivalent to the yellow foxtail control of acetochlor in the PRE 2008 study. Pyroxasulfone consistently controlled all weeds better than S-metolachlor, except for yellow foxtail at a reduced rate. Pyroxasulfone at the suggested use rate of 166 g ai ha^{-1} controlled all weeds tested, except for marshelder, at the same level as acetochlor in the PRE studies. Rates of pyroxasulfone higher than 166 g ai ha^{-1} were needed to control weeds at the same level as acetochlor, as the growing season progressed.

Visual injury to navy bean with pyroxasulfone was found to be severe when moisture activated the herbicide at the ground-crack stage in greenhouse experiments. No injury occurred from herbicide activation at other timings. Soil with decreased organic matter showed less injury. The soil placement study confirmed that pyroxasulfone can be taken into a plant through both the roots and shoots; however, pyroxasulfone activity is greatest through root uptake.

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INTRODUCTION

For growers to reach maximum yields, an effective weed control program must be implemented. There are many ways to minimize weed competition with the crop being grown, whether it is done through the use of physical, cultural, biological, or chemical means. In many cases, chemical weed control is the primary method used to manage weeds. Chemical weed control is the most economical and is easiest to use. Herbicides that eliminate weed growth without reducing crop yield are required.

Pyroxasulfone is a preemergence herbicide with residual control of annual grass and many broadleaf weeds. Tolerance of corn (*Zea mays* (L.)) and soybean (*Glycine max* (L.) Merr.) to pyroxasulfone has been characterized thoroughly across the United States (Kumiai 2006); however, evaluation for potential use in other crops has not been thoroughly investigated. Sunflower (*Helianthus anuus* L.), safflower (*Carthamus tinctorius L.*), and wheat (*Triticum aestivum* L.) have shown excellent tolerance to pyroxasulfone in North Dakota (Zollinger et al. 2007). Dry edible bean (*Phaseolis vulgaris* L.), dry pea (*Pisum sativum* L.), and lentil (*Lens culinaris* Medik) are three important legume crops to North Dakota. Not only are these crops important in production value to North Dakota's agricultural industry, but they also play an important role in crop rotations with the ability to fix nitrogen in the soil (Saskatchewan Pulse Growers 2000). As with any crop, elimination of weeds in these three legume crops is very important. Prevention of weed growth is necessary to reach maximum yields, to prevent the production of weed seeds that enter the soil, and to prevent the spread of unwanted plant species to the surrounding areas (Hanson and Thill 2001).

North Dakota's dry edible bean producers harvested 229,000 hectares of dry edible beans in 2009, leading the United States in dry bean production (USDA-NASS 2009). Annually, the top two classes of dry edible beans grown in North Dakota are pinto and navy at approximately 72 and 17 percent of planted acres, respectively (Knodel et al. 2008).

Dry pea was planted on 198,000 hectares in North Dakota during the 2009 cropping season. Growers harvested 194,000 of the planted hectares. North Dakota dry pea production included 57% of the production in the United States, and was ranked number one in dry pea production among the 50 states (USDA-NASS 2009).

North Dakota growers increased lentil production in 2009 to 66,000 harvested hectares, from the 2008 level of 29,000 harvested hectares. North Dakota ranked number one in the value of production of lentils in the United States. North Dakota also comprised approximately 44% of the United States' total lentil production (USDA-NASS 2009).

Dry edible bean, dry pea, and lentil do not compete with weeds during the cropping season, particularly during the first month after emergence (McKay et al. 2003; Daniels 2007). These crops are poor competitors as a result of slow seedling growth and poor canopy closure (Daniels 2007). Weed species are difficult to control because there are far fewer herbicides registered for use than in major acreage crops such as corn, soybean, and wheat (*Triticum aestivum* L.) (Hanson and Thill 2001). Broadleaf and grass weed species that can reduce crop yield include, yellow foxtail (*Setaria glauca* (L.)), wild oat (*Avena fatua* L.), kochia (*Kochia scoparia* (L.)), common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus*), eastern black nightshade (*Solanum ptycanthum*

Dunal), common ragweed (*Ambrosia artemisiifolia* L.), and wild buckwheat (*Polygonum convolvulus* L.) (Daniels 2007; Knodel et al. 2008; Whitson et al. 1996).

This research has four main objectives: (1) Evaluate crop tolerance of navy and pinto dry edible beans, dry pea, and lentil to pyroxasulfone. (2) Evaluate the residual weed control of pyroxasulfone in no-tillage and conventional tillage systems. (3) Evaluate dry edible bean tolerance to pyroxasulfone as influenced by moisture. (4) Evaluate the amount of plant uptake of pyroxasulfone from root and shoot.

LITERATURE REVIEW

Pyroxasulfone Overview

Pyroxasulfone is a compound currently being developed by Kumiai Chemical Industry Co. Ltd. as a soil-applied herbicide for residual weed control of annual grass and some broadleaf weeds in corn and soybean (Porpiglia and Yamaji 2007). Pyroxasulfone is reported to be absorbed by both the roots and shoots (Porpiglia et al. 2005). Growth of both the apical meristem and coleoptile of the young seedling is inhibited in susceptible plants from pyroxasulfone (Geier et al. 2006; Sikkema et al. 2007).

The weed spectrum of pyroxasulfone has been characterized as similar to pre-emergence herbicides from the acetanilide family, specifically acetochlor, *S*-metolachlor, and dimethenamid-P (Porpiglia and Yamaji 2007). However, pyroxasulfone controls annual grasses and broadleaf weeds at lower rates than acetanilide herbicides (Geier et al. 2006; Dyer et al. 2004). Grass and broadleaf weeds that have been controlled in North Dakota by pyroxasulfone include, yellow foxtail, wild oat, kochia, common lambsquarter, redroot pigweed, eastern black nightshade, and russian thistle (*Salsola iberica* Sennen). Common ragweed, wild buckwheat, and marshelder (*Iva xanthifolia* Nutt.) were suppressed by pyroxasulfone. Common ragweed control was superior to control from labeled acetanilide herbicides (Zollinger and Ries 2007).

Soil applied herbicides require activation for weed control (Hager and Sprague 2001). Activation occurs when precipitation provides water to carry the herbicide into the root or shoot zone of the soil where the herbicide can be absorbed by the germinating plants (Hager and Sprague 2001; Zollinger 1997). Precipitation of 1.3 to 2.5 cm is typically required within 7 to 10 days of the herbicide application for activation, but this may vary depending on chemical properties of the herbicide and soil and surface residue conditions (Hager and Sprague 2001).

Pyroxasulfone is effective at much lower rates compared to acetanilide herbicides. Lower use rates may be perceived as more environmentally friendly by regulatory agencies due to total loading of pesticide into the environment. The water solubility is also much lower compared to acetanilide herbicides. Pyroxasulfone has a water solubility of 3.49 mg/L (Kumiai 2006) which is lower than the water solubility of acetochlor (223 mg/L), *S*-metolachlor (488 mg/L), and dimethenamid-p (1174 mg/L) (Vencill et al. 2002). Adsorption to soil and soil organic matter is the primary factor which affects the potential of an herbicide to be lost to leaching, in runoff water, or with sediment. Typically, weakly adsorbed herbicides are subject to leaching or runoff with water (Baker and Mickelson 1994). Unfortunately, the adsorption of pyroxasulfone is undisclosed (Kumiai 2006); however, in many situations solubility in water is correlated inversely to adsorption (Baker and Mickelson 1994). If this relationship holds for pyroxasulfone, adsorption to soil particles would be higher than the acetanilides, and potential for leaching into groundwater or exiting the site of application would be lower. Weed control from the soil residual of pyroxasulfone has not been significantly different from acetochlor, dimethenamid-P, or *S*-metolachlor (Porpiglia et al. 2005). Pyroxasulfone may potentially replace acetanilide herbicides due to a reduced rate of activie ingredient used, the probability of reduced water contamination, and comparable weed control to acetanilide herbicides.

Soil texture is also affects crop tolerance and weed control efficacy pyroxasulfone (Kumiai 2006). The clay soil fraction contains much more surface area per unit weight compared to silt and sand-sized particles, and therefore, results in the majority of binding sites for herbicide adsorption. Cation exchange capacity (CEC) is the measure of adsorptive sites in the soil and is related to clay and organic matter content (Hartzler 2002) as well as clay type. As CEC increases, the number of binding sites increases; requiring more herbicide to achieve equivalent weed control compared to rates of herbicide used in soil with a lower CEC. The use rate range of pyroxasulfone has been structured on the basis of soil texture. As the soil changes from coarse sandy loam to fine clay, the amount of active ingredient needed for weed control increases linearly (Kumiai 2006). The effective dose of pyroxasulfone to provide 90% weed control (ED_{90} values) for five weed species calculated on soils containing 1%, 2%, 3%, and 4% organic matter showed that as the organic matter increased, the ED_{90} values for all weed species increased as well (Knezevic et al. 2007).

Pyroxasulfone - Plant Interaction

The mechanism of action of pyroxasulfone is very-long-chain fatty acid elongase (VLCFAE) inhibition. After plant uptake pyroxasulfone decreases very-long-chain fatty acid (VLCFA) biosynthesis which results in the buildup of fatty acid precursors (Tanetani et al. 2009). Pyroxasulfone has minimal effect on seed germination; however, shoot elongation of germinating seeds is strongly inhibited.

Herbicides that inhibit the VLCFAE mechanism include herbicides from the chloroacetamide chemical family: alachlor, acetochlor, dimethanamid-P, and S-metolachlor (Böger et al. 2000; Menne 2005). The Herbicide Resistance Action Committee categorized these herbicides into the K3 group (Menne 2005). Herbicides in the mode of action K3 category prevent shoot elongation of germinating seeds (Böger et al. 2000). Tanetani et al. (2009) confirmed assumptions of the similarity in mechanism of action between pyroxasulfone and other chloroacetamide K3 herbicides' through an *in vivo* and *in vitro* examination of the effects of pyroxasulfone on very-long-chain fatty acid biosynthesis.

The chloroacetamide chemical family of herbicides was introduced in the 1950s. Despite widespread use around the world, almost no weed resistance to this herbicide class has been reported (Böger 2003; Böger et al. 2000). Typically, a susceptible weed will germinate and the seedling will be stunted with the first leaves emerging from the coleoptile deformed and stunted. Dicotyledons will have deformed and stunted cotyledons (Böger et al. 2003). Deal and Hess (1980) determined this occurred as a result of inhibition of both cell division and cell enlargement. Böger (2003) concluded that chloroacetamides inhibited the elongation of VLCFAs of greater than 18 C-atoms. The lack of VLCFAs is toxic to plants. Elongation steps catalyzed by VLCFAEs from C18:0 to C20:0, C20:0 to C22:0, and so on up to C26:0 to C28:0 were found to be inhibited by pyroxasulfone (Tanetani et al. 2009).

Pyroxasulfone - Field Crop Injury

Evaluation of pyroxasulfone as a soil-applied herbicide in dry edible bean, field pea, and lentil has not been thoroughly evaluated (Zollinger et al. 2007). Additional data is needed to determine crop tolerance and rate structures needed in each crop, especially in dry edible beans in where tolerance levels to herbicides often vary between market classes (Sikkema et al. 2007). Preliminary data suggests that of the four major market classes of dry edible beans grown in North Dakota, pinto has the highest tolerance to pyroxasulfone. Navy beans are less tolerant than pinto beans, but much more tolerant than both kidney beans and black beans. There have been studies that show field pea and lentil injury and other studies that indicate a high level tolerance. Field pea and lentil tolerance was excellent one season, but the following year crop injury for both species significantly increased due to more rainfall early in the growing season (Zollinger et al. 2007).

Pinto beans treated with pyroxasulfone applied preemergence at 210 and 420 g ai ha^{-1} showed visual injury of 6 and 21% respectively at 2 locations over a 2 year period. A third location during the same time period showed 55% visible injury when averaged across both rates. Navy beans treated with pyroxasulfone applied PRE at 210 and 420 g ai ha^{-1} showed visible injury of 8 and 27% respectively at 2 locations over a 2 year period. A third location during the same time period showed 65% visible injury when averaged across both rates (Sikkema et al. 2007). Multiple studies in which pyroxasulfone was applied PRE to dry beans resulted in visual injury, yield reduction, and plant height; however, dry bean seed moisture content was not affected (Sikkema et al. 2008; Soltani et al. 2009).

MATERIALS AND METHODS

Field Experiments

Navy and Pinto Bean Tolerance to Pyroxasulfone

Experiments were conducted in 2008 and 2009 to evaluate the tolerance of navy and pinto beans to pyroxasulfone near Prosper, Hatton, and Thompson, North Dakota. Plots at each location consisted of four rows of dry bean spaced 76 cm apart and 6 m long. Field preparation for seeding was conducted using a field cultivator. No additional fertilizer was added to the soil and beans were not inoculated prior to planting.

The cultivars 'Ensign' navy bean and 'Lariat' pinto bean were sown at all locations. Beans were sown in 2008 at Prosper on May 22, at Hatton on June 2, and at Thompson on May 23. Beans were sown in 2009 at Prosper on May 30, at Hatton on June 6, and at Thompson on June 10. Dry beans were sown at a depth of 5 cm. Seeding rate for navy bean was 44 plants/m^2 and pinto bean at 22 plants/m^2 with a John Deere Max-Emerge II row crop planter[1] in 76 cm rows.

Pyroxasulfone was applied preemergence at 84, 125, 166, and 332 g ai ha^{-1} immediately after seeding at Prosper and Thompson in 2008 and Thompson in 2009. Hatton 2008 was applied June 2, Prosper 2009 was applied May 30, and Hatton 2009 was applied June 6. A fifth treatment of dimethanamid-P was applied preemergence at 1100 g ai/ha. Treatments were applied to the center two rows of beans in each plot using a backpack sprayer and 2-m-wide boom with Turbo TeeJet 11002 flat-fan nozzles[2] delivering 160 L ha^{-1} at 280 kPa. Environmental conditions at pyroxasulfone application in

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[1] Deere & Company, One John Deer Place Moline, IL 61265.

[2] TeeJet Technologies Spraying Systems Co., P.O. Box 7900 Wheaton, IL 60189.

2008 are shown in Table 1. Environmental conditions at time of pyroxasulfone application in 2009 are shown in Table 2.

Table 1. Environmental data at pyroxasulfone application for dry bean tolerance experiments in 2008.

	Location		
Factor	Prosper	Hatton	Thompson
Application Timing	Preemergence	Preemergence	Preemergence
Date	May-22	June-4	May-23
Time	10:30am	12:30pm	2:40pm
Temperature (C°)			
Air	19	20	22
Soil	14	17	16
Relative Humidity (%)	28	50	26
Wind Speed (km h^{-1})	13	0	19
Wind direction	East		East
Cloud Cover (%)	0	100	30
Soil surface moisture	dry	moist	dry
Subsoil moisture	moist	moist	moist
First activating rainfall date	May-30	June-6	May-30
First activating rainfall (mm)	25	18	8.5

Plots were maintained weed free with cultivation and hand-weeding, as well as post-emergent herbicide. Bentazon at 560 g ai ha^{-1}, plus clethodim at 35 g ai ha^{-1}, plus methylated seed oil at 1.5 L ha^{-1} was applied across the entire experimental area.

Visible injury evaluations were made on a percentage scale 14, 28, and 56 d after emergence. The percent injury rating included stunting, chlorosis, necrosis, and overall injury, with 0 representing no noticeable injury and 100 representing a dead plant. Percent dry bean injury was estimated through a comparison of treated areas to untreated borders between plots. Stand counts were performed 28 d after emergence, and plant height was measured at 56 d after emergence.

Table 2. Environmental data at pyroxasulfone application for dry bean tolerance experiments in 2009.

Factor	Location Prosper	 Hatton	 Thompson
Application Timing	Preemergence	Preemergence	Preemergence
Date	June-1	June-10	June-10
Time	10:30am	1:30pm	9:50am
Temperature (C°)			
Air	17	17	16
Soil	14	14	10
Relative Humidity (%)	46	37	51
Wind Speed (km h^{-1})	4	3	9
Wind direction	South	North	Northwest
Cloud Cover (%)	95	80	25
Soil surface moisture	dry	dry	moist
Subsoil moisture	moist	moist	moist
First activating rainfall date	June-8	June-16	June-17
First activating rainfall (mm)	13	11.5	24

Soil samples were taken from 0-15 cm at each experiment location and analyzed by the NDSU Soil Testing Laboratory. Samples were analyzed for soil pH, soil organic matter, and mechanical analysis (Table 3).

Table 3. Soil properties for dry bean tolerance experiment locations

Location	Depth	pH	Organic Matter	Texture
2008	cm		%	
Prosper	0-15	7.2	3.1	Loam
Hatton	0-15	5.8	1.9	Sandy loam
Thompson	0-15	7.9	3.9	Silt loam
2009				
Prosper	0-15	7.1	4.2	Loam
Hatton	0-15	7.7	3.1	Sandy loam
Thompson	0-15	8.1	5.6	Silt loam

Dry bean plants from the center 2 rows of each plot were harvested at physiological maturity. Seed samples were dried, cleaned, and weighed to calculate yield. No yield was taken from Prosper in 2008 due to very wet field conditions that resulted in the inability to access the field.

Experiments for navy bean and pinto bean were each arranged in a randomized complete block design with four replicates as separate experiments. Four pyroxasulfone rates and one dimethanamid-P rate were randomized within each replicate (block). Environment and replicate were considered random effects. Herbicide treatment was a fixed effect. Data were subjected to analysis of variance, and treatment mean separation was performed using Fisher's protected LSD test with $\alpha = 0.05$.

Dry Pea Tolerance to Pyroxasulfone

Experiments were conducted in 2008 and 2009 to evaluate the tolerance of dry pea to pyroxasulfone near Carrington, Minot, and Williston, North Dakota. Plots at each were 3 m wide by 9 m long. The plot area was prepared using a light harrow. No additional fertilizer was added to the soil.

The cultivar 'Majorette' dry pea was sown at all locations. Peas were sown in 2008 at Carrington on April 30, at Minot on May 8, and at Williston on May 6. Peas were sown in 2009 at Carrington on May 15, at Minot on May 12, and at Williston on April 24. Peas were sown at a depth of 5 cm with a population of 86 plants m^{-2} in 19 cm rows.

Pyroxasulfone was applied preemergence at 84, 125, 166, and 332 g ai ha^{-1} immediately after seeding at Williston in 2008. At the Carrington site in 2008 pyroxasulfone was applied May 6 and at Minot in 2008 it was applied May 14. At the Carrington site in 2009 pyroxasulfone was applied May 18, at Minot in 2009 it was applied

May 14, and at Williston in 2009 it was applied May 6. A fifth treatment of sulfentrazone was applied preemergence at 105 g ai ha^{-1}. Treatments were applied to the center 2 m of each plot using a backpack sprayer and 2-m-wide boom with Turbo TeeJet 11002 flat-fan nozzles[2] delivering 160 L ha^{-1} at 280 kPa. Environmental conditions at pyroxasulfone application in 2008 are shown in Table 4. Environmental conditions at pyroxasulfone application in 2009 are shown in Table 5.

Table 4. Environmental data at pyroxasulfone application for field pea tolerance experiments in 2008.

	Location		
Factor	Carrington	Minot	Williston
Application Timing	Preemergence	Preemergence	Preemergence
Date	May-6	May-15	May-6
Time	9:30am	5:00pm	5:15pm
Temperature (C°)			
Air	17	15	18
Soil	9	14	15
Relative Humidity (%)	29	55	36
Wind Speed (km h^{-1})	16	13	8
Wind direction	Northeast	Southwest	Northeast
Cloud Cover (%)	50	98	75
Soil surface moisture	Dry	moist	dry
Subsoil moisture	Dry	wet	dry
First activating rainfall date	May-30	May-25	May-9
First activating rainfall (mm)	23	18	16

Plots were maintained weed free with hand-weeding, as well as post-emergence herbicides. Bentazon at 560 g ai ha^{-1}, plus clethodim at 35 g ai ha^{-1}, plus methylated seed oil at 1.5 L ha^{-1} was applied across the entire experimental area.

Visible injury evaluations were made on a percentage scale 14, 28, and 56 d after emergence. The percent injury rating included stunting, chlorosis, necrosis, and overall injury, with 0 representing no noticeable injury and 100 representing a dead plant. Percent pea injury was estimated through a comparison of treated areas to the untreated border between plots. Stand counts were conducted 28 d after emergence, and plant height was measured at 56 d after emergence. Injury ratings, stand count, and plant height were not conducted at Williston in 2008, where the plots were abandoned due to severe drought stress and minimal growth.

Table 5. Environmental data at pyroxasulfone application for field pea tolerance experiments in 2009.

	Location		
Factor	Carrington	Minot	Williston
Application Timing	Preemergence	Preemergence	Preemergence
Date	May-18	May-14	May-6
Time	1:00pm	3:10pm	1:30pm
Temperature (C°)			
Air	24	14	18
Soil	16	11	15
Relative Humidity (%)	38	47	20
Wind Speed (km h^{-1})	16	11	18
Wind direction	North	Southeast	West
Cloud Cover (%)	5	50	5
Soil surface moisture	Dry	moist	dry
Subsoil moisture	Moist	moist	moist
First activating rainfall date	May-25	May-25	June-7
First activating rainfall (mm)	20	25	16

Soil samples were taken from 0-15 cm at each experiment location and analyzed by the NDSU Soil Testing Laboratory. Samples were analyzed for soil pH, soil organic matter, and mechanical analysis (Table 6).

Field pea plants were harvested from the center 2 m of each plot at physiological maturity with a small plot combine. Samples were dried, cleaned, and weighed to calculate yields after harvest. No yield data was taken from Williston in 2008, due to severe drought conditions.

Table 6. Soil properties for field pea tolerance experiment locations

Location	Depth	pH	Organic Matter	Texture
2008	cm		%	
Carrington	0-15	5.0	3.7	Silt loam
Minot	0-15	4.9	4.6	Loam
Williston	0-15	4.7	3.0	Loam
2009				
Carrington	0-15	5.6	4.0	Silt loam
Minot	0-15	4.5	4.1	Silt loam
Williston	0-15	5.4	2.2	Silt loam

Experiments were conducted in a randomized complete block design with four replicates. Four pyroxasulfone rates and one sulfentrazone rate were randomized within the block of field pea. Environment and replicate were considered random effects. Herbicide treatment was a fixed effect. Data were subjected to analysis of variance, and treatment mean separation was performed using Fisher's protected LSD test with $\alpha = 0.05$.

Lentil Tolerance to Pyroxasulfone

Experiments were conducted in 2008 and 2009 to evaluate the tolerance of lentil to pyroxasulfone near Carrington, Minot, and Williston, North Dakota. Plots at each location were 3 m wide by 9 m long. The plot area was prepared using a light harrow. No additional fertilizer was added to the soil.

The cultivar 'Richlea' lentil was sown at all locations. Lentils were sown in 2008 at Carrington on April 30, at Minot on May 14, and at Williston on May 6. Lentils were sown in 2009 at Carrington on May 15, at Minot on May 18, and at Williston on May 4. Lentils were sown at a depth of 5 cm with a population of 130 plants m^{-2} in 19 cm rows.

Pyroxasulfone was applied preemergence at 84, 125, 166, and 332 g ai ha^{-1} immediately after seeding at Williston in 2008. At the Carrington site in 2008 it was applied May 6 and at Minot in 2008 it was applied May 15. At Carrington in 2009 pyroxasulfone was applied May 18, at Minot in 2009 it was applied May 22, and at Williston in 2009 it was applied May 6. A fifth treatment of pendimethalin was applied preemergence at 560 g ai ha^{-1}. Treatments were applied to the center 2 m each plot using a backpack sprayer and 2-m-wide boom with Turbo TeeJet 11002 flat-fan nozzles[2] delivering 160 L ha^{-1} at 280 kPa. Environmental conditions at pyroxasulfone application in 2008 are shown in Table 7. Environmental conditions at pyroxasulfone application in 2009 are shown in Table 8.

Table 7. Environmental data at pyroxasulfone application for lentil tolerance experiments in 2008.

	Location		
Factor	Carrington	Minot	Williston
Application Timing	Preemergence	Preemergence	Preemergence
Date	May-6	May-15	May-6
Time	9:50am	10:45am	4:45pm
Temperature (C°)			
Air	17	19	18
Soil	9	9	15
Relative Humidity (%)	29	40	36
Wind Speed (km h^{-1})	16	13	8
Wind direction	Northeast	Southwest	Northeast
Cloud Cover (%)	50	1	75
Soil surface moisture	Dry	dry	dry
Subsoil moisture	Dry	wet	dry
First activating rainfall date	May-30	May-25	May-9
First activating rainfall (mm)	23	18	16

Plots were maintained weed free with hand-weeding, as well as post-emergent herbicide. Clethodim at 35 g ai ha^{-1}, plus methylated seed oil at 1.5 L ha^{-1} was applied across the entire experimental area for grass control.

Visible injury evaluations were made on a percentage scale 14, 28, and 56 d after emergence. The percent injury rating included stunting, chlorosis, necrosis, and overall injury, with 0 representing no noticeable injury and 100 representing a dead plant. Percent lentil injury was estimated through a comparison of treated areas to untreated borders between plots. Stand counts were conducted 28 d after emergence, and plant height was measured at 56 d after emergence. Injury ratings, stand count, and plant height were not conducted at Williston in 2008 where the plots were abandoned due to severe drought stress and minimal growth.

Table 8. Environmental data at pyroxasulfone application for lentil tolerance experiments in 2009.

	Location		
Factor	Carrington	Minot	Williston
Application Timing	Preemergence	Preemergence	Preemergence
Date	May-18	May-22	May-6
Time	12:40pm	12:00pm	2:00pm
Temperature (C°)			
Air	24	19	18
Soil	16	13	15
Relative Humidity (%)	38	22	20
Wind Speed (km h^{-1})	16	18	18
Wind direction	North	North	West
Cloud Cover (%)	5	10	5
Soil surface moisture	Dry	dry	dry
Subsoil moisture	Moist	moist	moist
First activating rainfall date	May-25	May-25	June-7
First activating rainfall (mm)	20	25	16

Soil samples were taken from 0-15 cm at each experiment location and analyzed by the NDSU Soil Testing Laboratory. Samples were analyzed for soil pH, soil organic matter, and mechanical analysis (Table 9).

Lentil plants were harvested from the center 2 m of each plot at physiological maturity with a small plot combine. Samples were dried, cleaned, and weighed to calculate yields after harvest. No yield data was taken from Williston in 2008, due to severe drought conditions resulting in minimal crop growth.

Table 9. Soil properties for lentil tolerance experiment locations

Location	Depth	pH	Organic Matter	Texture
2008	cm		%	
Carrington	0-15	5.0	3.7	Silt loam
Minot	0-15	4.7	2.4	Sandy loam
Williston	0-15	4.7	3.0	Loam
2009				
Carrington	0-15	6.2	3.6	Silt loam
Minot	0-15	3.8	4.8	Loam
Williston	0-15	5.3	2.4	Silt loam

Experiments were conducted in a randomized complete block design with four replicates and five treatments. Treatments were four pyroxasulfone rates and one sulfentrazone rate. Environment and replicate were considered random effects. Herbicide treatment was a fixed effect. Data were subjected to analysis of variance, and treatment mean separation was performed using Fisher's protected LSD test with $\alpha = 0.05$.

Pyroxasulfone Weed Control

Two experiments were conducted in 2008 and 2009 at Prosper, North Dakota to evaluate weed control efficacy of pyroxasulfone applied EPP with no-tillage and applied

PRE with conventional tillage. Plot size was 3 m wide by 9 m long, with four replicates. Experiments were established without a crop. No tillage was performed in the spring prior to the application of the EPP treatments. Conventional tillage was performed prior to application of the PRE treatments.

Pyroxasulfone was applied at 0, 125, 166, 209, and 332 g ai ha^{-1} in the EPP studies. Two additional treatments included S-metolachlor at 1430 g ai ha^{-1} and acetochlor at 2200 g ai ha^{-1}. All treatments were applied with the addition of 870 g ae ha^{-1} of a .84 kg ae glyphosate. EPP treatments were applied on May 8 in 2008 and May 19 in 2009. Treatments were applied to the center 2 m of each plot using a backpack sprayer and a 2-m-wide boom with Turbo TeeJet 11002 flat-fan nozzles^2 delivering 160 L ha^{-1} at 280 kPa. Environmental measurements at time of application can be found in Table 10.

Pyroxasulfone was applied at 0, 83, 125, 166, and 209 g ai ha^{-1} in the PRE studies. Two additional treatments included S-metolachlor at 1430 g ai ha^{-1} and acetochlor at 1489 g ai ha^{-1}. All treatments were applied with the addition of 870 g ae ha^{-1} of a .84 kg ae glyphosate. PRE treatments were applied on June 17 in 2008 and May 28 in 2009. Treatments were applied to the center 2 m of each plot using a backpack sprayer and a 2-m-wide boom with Turbo TeeJet 11002 flat-fan nozzles^2 delivering 160 L ha^{-1} at 280 kPa. Environmental data at time of application can be found in Table 10.

Soil samples were taken from 0-15 cm at each experiment location and analyzed by the NDSU Soil Testing Laboratory. Samples were analyzed for soil pH, soil organic matter, and mechanical analysis. Soil test results showed a pH of 7.5 and organic matter content of 4.4% for the location in 2008 and a pH of 7.8 and organic matter content of

4.7% for the location in 2009. Mechanical analysis determined the soil to be a silty loam in 2008 and 2009.

Table 10. Environmental data at pyroxasulfone application in EPP and PRE experiments.

	Year			
Factor	2008		2009	
Application Timing	EPP	PRE	EPP	PRE
Date	May-8	June-17	May-19	May-28
Time	2:30pm	2:00pm	1:30pm	12:45pm
Temperature (C°)				
Air	12	27	17	24
Soil	7	25	9	12
Relative Humidity (%)	30	28	52	39
Wind Speed (km h^{-1})	5	5	11	11
Wind direction	South	Northwest	Southeast	North
Cloud Cover (%)	100	10	90	10
Soil surface moisture	dry	moist	wet	dry
Subsoil moisture	moist	wet	wet	moist
First activating rainfall date	May-30	June-28	June-8	June-8
First activating rainfall (mm)	26	28	13	13

Visual evaluations for weed control were conducted for each species present on a 0 to 99 scale, with 0 being no phytotoxicity and 99 being complete plant death. Evaluations were performed 14, 35, and 70 days after application (DAA) in the 2008 EPP experiment and 28 DAA in the 2008 PRE experiment. Weed species evaluated included yellow foxtail, wild mustard, marshelder, common lambsquarters, hairy nightshade, and common ragweed. Redroot pigweed was also evaluated for the PRE experiment and at 70 DAA for the EPP experiment. Weed control evaluation of the 2009 EPP experiment was conducted 42 DAA. Weed control evaluation of the 2009 PRE experiment was conducted 28 and 42 DAA. Weed species growing in the plot area included yellow foxtail, common lambsquarters, redroot pigweed, and wild buckwheat.

Experiments were conducted in a complete randomized block design with seven treatments and four replicates. The treatments consisted of five pyroxasulfone rates, one S-metolachlor rate, and one acetochlor rate. Environment and replicate were considered random effects. Herbicide treatment was considered a fixed effect. Data were subjected to analysis of variance, and treatment mean separation was performed using Fisher's protected LSD test with $\alpha = 0.05$.

Greenhouse Experiments

Pyroxasulfone Activation Timing

Navy bean tolerance to pyroxasulfone was evaluated based on the growth stage of the navy bean at the time of herbicide activation in a low and high organic matter soil of the same texture. Soil collected near Hatton, North Dakota had a pH of 6.8 and an organic matter content of 2%. Soil collected near Valley City, North Dakota had a pH of 7.5 and an organic matter content of 5.8%. Mechanical analysis of soils resulted in sand, silt and clay content consistent with a sandy loam texture for each soil. The soil was placed into 10 cm by 15 cm by 5 cm plastic pots. 'Ensign' navy beans were sown at 5 cm deep. Three plants per pot were allowed to grow. Pyroxasulfone was applied at 0, 84, 166, and 250 g ai/ha. Dimethenamid-P was applied at 1100 g ai/ha. Treatments were applied in a cabinet-type sprayer that delivered 80 L ha^{-1} at 289 kPa from an 8001 flat-fan tip nozzle[2] traveling at 5 km h^{-1}. Soil was kept moist through sub-irrigation of the pots.

Treatments were activated at three water timing events; with a fourth timing that did not receive a water event to activate the herbicide. Activation occurred immediately following PRE applications, the ground crack stage of the navy beans, and the unifoliate stage of the navy beans. To activate the herbicide treatments, 25 mm of water was irrigated onto the soil of each pot. Visual evaluations were conducted 7 and 14 DAT. Evaluations were performed on a percentage scale with 0 equals no visible injury and 100 equals complete plant death. Plant material above ground was harvested 30 DAP, dried, and weighed.

The experimental design was a randomized complete block with four replicates, and each experiment was repeated. The treatment design was a factorial arrangement of water timing and rates of pyroxasulfone plus four additional dimethenamid-P treatments. Environments were considered random effects, while herbicide, activation timing, and soil were considered fixed effects. Data were subjected to analysis of variance, and treatment mean separation was performed using Fisher's protected LSD test with $\alpha = 0.05$. Data were combined from repeated experiments when error means squares, over environments, were homogenous.

Pyroxasulfone Soil Placement

Pyroxasulfone uptake by root or shoot absorption by a susceptible plant was investigated in soil collected near Hatton, North Dakota with a pH of 6.8 and organic matter of 2%. Mechanical analysis resulted in a sand, silt and clay content consistent to that of a sandy loam. The soil was placed into 10 cm by 15 cm by 5 cm plastic pots. 'Ensign' navy beans were sown at 5 cm deep and the population was thinned to 3 plants per pot.

Pyroxasulfone was applied at 250 g ai ha^{-1} to 200 g of soil using a cabinet-type sprayer that delivered 80 L ha^{-1} at 289 kPa from an 8001 flat-fan tip nozzle[2] traveling at 5 km h^{-1}. The treated soil was mixed and added as the bottom, middle, or top layer in a pot. A fourth treatment of no herbicide was included. 'Ensign' navy beans were sown into the middle layer of treated or untreated soil. Sub-irrigation was used to maintain sufficient water availability without herbicide movement in the soil column. Visual evaluations were performed 10 and 20 DAP. Evaluations were conducted on a percentage scale where 0 equals no visible injury and 100 equals complete plant death. Plant material above ground was harvested 30 DAP, dried, and weighed.

The experimental design was a complete randomized block with four replicates, and each experiment was repeated. Environments were considered random effects, while herbicide placement was considered a fixed effect. Data were subjected to analysis of variance, and treatment mean separation was performed using Fisher's protected LSD test with $\alpha = 0.05$. Data were combined from repeated experiments when error means squares over environments were homogenous.

RESULTS AND DISCUSSION

Field Experiments

Navy Bean Tolerance to Pyroxasulfone

Environment, pyroxasulfone rate, and evaluation timing all influenced navy bean tolerance to pyroxasulfone. Pyroxasulfone rate by evaluation timing and pyroxasulfone rate by environment interactions are discussed (ANOVA not shown). Data for pyroxasulfone rate by environment were averaged across three evaluation timings.

Pyroxasulfone rates used in this experiment were 84, 125, 166 and 332 g ai ha^{-1} and represent a one-half, three-fourths, full, and double rate (Kumiai 2006). Dimethanamid-P was used as the standard and applied at the rate of 1100 g ai ha^{-1} which is the recommended rate for the soil type (Zollinger et al. 2010).

Navy bean injury from pyroxasulfone at all locations consisted of stunting, leaf and cotyledon necrosis, and leaf chlorosis. Pyroxasulfone rate by environment was a significant interaction. Navy bean injury at Prosper 2008 was more severe at all pyroxasulfone rates than the other five environments. Navy bean injury from 166 and 332 g ai ha^{-1} pyroxasulfone was more severe at the 2008 environments as compared to the same location in 2009. Navy beans at Hatton 2008 and Prosper 2008 showed significant injury at 125 g ai ha^{-1}, this injury significantly increased as pyroxasulfone rate increased. Navy bean injury from pyroxasulfone was significant only at 332 g ai ha^{1} at all environments in 2009 (Table 11). Injury that was more severe in 2008 environments compared to the 2009 environments at the same location was due to differing herbicide activating rainfall events occurring at emergence, which is consistent with results found by Bellinder (2008). The greater injury observed at Prosper 2008 may also have been due to standing water damage early in the growth stage of the navy beans.

Pyroxasulfone rate by evaluation timing resulted in higher navy bean tolerance 56 d after emergence compared to 14 d after emergence at 166 g ai ha^{-1} and 332 g ai ha^{-1}. Injury to navy beans was significant at 166 g ai ha^{-1} and 332 g ai ha^{-1} at 14 and 28 d after emergence. Only navy beans treated with 332 g ai ha^{-1} showed significant injury at 56 d after emergence when data was averaged across locations (Table 12). Navy bean injury decreased over time likely due to improved plant vigor and breakdown of pyroxasulfone in the soil. These results are consistent with those of Sikkema et al. (2008).

Table 11. Herbicide effect on navy bean injury across all evaluation dates.

		Environment						
Treatment		H08[a]	H09[b]	T08[c]	T09[d]	P08[e]	P09[f]	Combined
	g ai ha^{-1}	% injury						
Pyroxasulfone	84	0	0	1	0	9	0	2
Pyroxasulfone	125	6	1	1	1	20	0	5
Pyroxasulfone	166	15	3	8	2	46	0	12
Pyroxasulfone	332	25	18	30	24	96	10	34
Dimethanamid-P	1100	0	0	0	0	0	0	0
LSD (0.05)		4						15

[a] H08, Hatton 2008
[b] H09, Hatton 2009
[c] T08, Thompson 2008
[d] T09, Thompson 2009
[e] P08, Prosper 2008
[f] P09, Prosper 2009

Table 12. Herbicide effect on navy bean injury over time in 2008 and 2009 averaged across locations.

		Days after emergence		
Treatment		14	28	56
	g ai ha^{-1}	% injury		
Pyroxasulfone	84	3	1	0
Pyroxasulfone	125	7	5	2
Pyroxasulfone	166	19	11	6
Pyroxasulfone	332	40	34	28
Dimethanamid-P	1100	0	0	0
LSD (0.05)		7		

Navy bean stand count decreased with increasing pyroxasulfone rate in most environments. When data was combined, pyroxasulfone at 166 g ai ha^{-1} reduced stand count. A reduction in stand count occurred in all 2008 environments from 166 g ai ha^{-1} pyroxasulfone. Navy bean stand counts at Prosper 2009 were significantly higher at all treatments compared to all other environments (Table 13). Reasons for the increase in stand count at Prosper 2009 are unknown.

Table 13. Herbicide effect on navy bean stand count.

		Environment						
Treatment		H08[a]	H09[b]	T08[c]	T09[d]	P08[e]	P09[f]	Combined
	g ai ha^{-1}	plants/m row						
Pyroxasulfone	84	11.0	9.5	11.5	10.3	9.3	14.3	11.0
Pyroxasulfone	125	9.8	10.3	11.0	10.3	8.3	14.5	10.7
Pyroxasulfone	166	8.3	9.8	9.8	10.5	6.0	15.0	9.9
Pyroxasulfone	332	8.0	9.0	8.3	9.5	2.0	12.3	8.2
Dimethanamid-P	1100	11.3	10.3	11.5	11.0	11.5	14.8	11.7
LSD (0.05)		1.4						1.5

[a] H08, Hatton 2008
[b] H09, Hatton 2009
[c] T08, Thompson 2008
[d] T09, Thompson 2009
[e] P08, Prosper 2008
[f] P09, Prosper 2009

There were differences in navy bean height between treatments at individual environments, but no significant differences were observed when all environments were combined. Navy bean height at Prosper 2008 and Thompson 2009 was significantly decreased at 332 g ai ha^{-1} within environment (Table 14). Reasons for the difference in height between environments are unknown, but may be due to different planting dates and subsequent weather events that provided 1 inch of rainfall with one week of planting.

Navy bean yield showed no environment by treatment interaction; however, there were significant differences among treatments when all harvested environments were averaged together. Pyroxasulfone applied at 166 and 332 g ai ha^{-1} resulted in decreased yields as compared to the control across all environments (Table 15).

Table 14. Herbicide effect on navy bean height.

Treatment		Environment					
		H08[a]	H09[b]	T08[c]	T09[d]	P08[e]	P09[f]
	g ai ha^{-1}	cm					
Pyroxasulfone	84	46.8	50.6	34.5	40.4	43.8	54.8
Pyroxasulfone	125	44.5	49.1	34.3	39.8	42.0	54.0
Pyroxasulfone	166	44.5	50.4	34.0	43.5	40.8	55.1
Pyroxasulfone	332	43.8	48.1	34.8	35.6	14.5	53.5
Dimethanamid-P	1100	47.5	53.5	34.5	43.1	43.5	53.1
LSD (0.05)		6.5					

[a] H08, Hatton 2008
[b] H09, Hatton 2009
[c] T08, Thompson 2008
[d] T09, Thompson 2009
[e] P08, Prosper 2008
[f] P09, Prosper 2009

Table 15. Herbicide effect on navy bean yield at all harvested locations in 2008 and 2009.

Treatment		Yield
	g ai ha^{-1}	kg ha^{-1}
Pyroxasulfone	84	2220
Pyroxasulfone	125	2180
Pyroxasulfone	166	2040
Pyroxasulfone	332	1890
Dimethanamid-P	1100	2360
LSD (0.05)		180

Yield data suggests that navy beans are tolerant to pyroxasulfone applied at a reduced rate of 84 g ai ha^{-1} or less on the tested soil types. Navy beans at Prosper 2008 were unable to be harvested due to precipitation and wet soils throughout the harvest season. Based on the visible injury levels at Prosper 2008, navy bean yields may have fluctuated enough to change the result that navy beans are tolerant to pyroxasulfone applied at rates of 84 g ai ha^{-1} or less. Due to the variations in data between environments and based on the results of other research (Sikkema et al. 2007, Sikkema et al. 2008, Soltani et al. 2009), navy beans are not tolerant to pyroxasulfone at levels acceptable for registration.

Pinto Bean Tolerance to Pyroxasulfone

Environment, pyroxasulfone rate, and evaluation timing all influenced pinto bean injury from pyroxasulfone. Pyroxasulfone rate by evaluation timing and pyroxasulfone rate by environment interactions are discussed (ANOVA not shown). Data for pyroxasulfone rate by environment interaction were averaged across three evaluation timings.

Pyroxasulfone rates used in this experiment were 84, 125, 166 and 332 g ai ha^{-1} and represent a one-half, three-fourths, full, and double rate (Kumiai 2006). Dimethanamid-P was used as the standard and applied at the rate of 1100 g ai ha^{-1} which is the recommended rate for the soil type (Zollinger et al. 2010).

Pinto bean injury from pyroxasulfone at all locations consisted of stunting, leaf and cotyledon necrosis, and leaf chlorosis. There was a pyroxasulfone rate by environment interaction. Pinto bean injury was most severe at Prosper 2008. Injury significantly increased as rate was increased above 125 g ai ha^{-1}. Injury to pinto bean was not observed at Prosper 2009, but significant injury did occur in all other environments from 332 g ai ha^{-1} pyroxasulfone. Also, pyroxasulfone at 332 g ai ha^{-1} was the only rate to show significant injury when data was combined across all environments. Pinto beans in the Hatton environments were injured more from 332 g ai ha^{-1} pyroxasufone in 2008 and 2009 compared to pinto beans in the Thompson environments (Table 16). This is most likely due to higher soil organic matter levels at Thompson that adsorbed more herbicide molecules and resulted in lower herbicide activity. These results are consistent with those reported by Knezevic et al. (2007). Reasons for increased pinto bean injury at Prosper 2008 are unknown, but likely include a combination of an extreme activating rainfall event at bean emergence (Bellinder 2008) and damage from standing water.

Table 16. Herbicide effect on pinto bean injury across all evaluation dates.

Treatment		Environment						Combined
		H08[a]	H09[b]	T08[c]	T09[d]	P08[e]	P09[f]	
	g ai ha^{-1}	% injury						
Pyroxasulfone	84	0	0	0	0	2	0	1
Pyroxasulfone	125	0	0	0	0	7	0	1
Pyroxasulfone	166	1	2	0	2	18	0	4
Pyroxasulfone	332	11	13	7	7	50	0	14
Dimethanamid-P	1100	0	0	0	0	0	0	0
LSD (0.05)		3						9

[a]H08, Hatton 2008
[b]H09, Hatton 2009
[c]T08, Thompson 2008
[d]T09, Thompson 2009
[e]P08, Prosper 2008
[f]P09, Prosper 2009

There was also a significant interaction between pyroxasulfone rate and time after emergence on pinto bean. Pyroxasulfone applied at 332 g ai ha^{-1} increased pinto bean injury significantly from 14 d after emergence to 28 d after emergence (Table 17). Injury then decreased significantly from 28 d after emergence to 56 d after emergence. The increase and later decrease in injury is most likely due to the residue of soil-applied pyroxasulfone affecting the plant followed by herbicide degradation over time.

Pinto bean stand count was affected by an environment by pyroxasulfone interaction; however, there was no significant difference among treatments averaged across environments. The lowest stand counts were measured at Prosper 2008 at 125, 166, and 332 g ai ha^{-1} of pyroxasulfone, and resulted in a significant decrease of plants per meter of row as pyroxasulfone rate increased above 84 g ai ha^{-1} (Table 18). At Hatton 2008 and Thompson 2008 significantly lower stand counts were produced, within respective environments, when pyroxasulfone was applied at 332 g ai ha^{-1}. Decreased stand counts at Prosper 2008 were likely due to the extremely wet conditions at emergence of the beans and also contributed to the high visual injury observations.

Table 17. Herbicide effect on pinto bean injury over time in 2008 and 2009 at all locations.

		Days after emergence		
Treatment		14	28	56
	g ai ha^{-1}	% injury		
Pyroxasulfone	84	1	1	0
Pyroxasulfone	125	2	1	0
Pyroxasulfone	166	4	5	3
Pyroxasulfone	332	13	20	11
Dimethanamid-P	1100	0	0	0
		5		

Table 18. Herbicide effect on pinto bean stand count.

		Environment					
Treatment		H08[a]	H09[b]	T08[c]	T09[d]	P08[e]	P09[f]
	g ai ha^{-1}	plants/m row					
Pyroxasulfone	84	12.3	11.5	10.0	11.8	10.3	11.8
Pyroxasulfone	125	12.3	11.0	10.5	12.3	8.5	11.0
Pyroxasulfone	166	12.5	12.3	10.3	12.5	6.8	12.3
Pyroxasulfone	332	10.5	11.5	9.0	12.0	4.8	11.5
Dimethanamid-P	1100	12.8	11.8	10.5	12.0	11.3	12.3
LSD (0.05)		1.4					

[a] H08, Hatton 2008
[b] H09, Hatton 2009
[c] T08, Thompson 2008
[d] T09, Thompson 2009
[e] P08, Prosper 2008
[f] P09, Prosper 2009

Pinto bean height was averaged across all environments due to a lack of interaction of environment by treatment. Pyroxasulfone decreased pinto bean height at all rates, with 332 g ai/ha resulting in the greatest plant height reduction (Table 19).

There were no significant interactions for pinto bean yield (data not shown). Pinto beans at Prosper 2008 displayed the highest levels of injury and were unable to be harvested; however, with the exception of 332 g ai ha^{-1} of pyroxasulfone the injury was not severe. Pyroxasulfone is not labeled on pinto beans. These results from two years of research show a potential for adequate tolerance of pyroxasulfone on pinto bean; however, more research may show different results in other environments and soil textures. If pyroxasulfone is registered, there is a risk of pinto bean injury from weather variability, but this research shows that a yield reduction may not occur.

Table 19. Herbicide effect on pinto bean height at all locations in 2008 and 2009.

Treatment		Height
	g ai ha^{-1}	--- cm ---
Pyroxasulfone	84	53.3
Pyroxasulfone	125	53.2
Pyroxasulfone	166	53.1
Pyroxasulfone	332	51.8
Dimethanamid-P	1100	54.8
LSD (0.05)		1.5

Dry Pea Tolerance to Pyroxasulfone

Dry pea tolerance was not affected by any factor or interaction (ANOVA not shown). No visible injury was observed at all environments. No significant interactions were found for stand count or height and treatments did not significantly alter either factor. Also, yield was not significantly affected within or across environments.

Pyroxasulfone rates used in this experiment were 84, 125, 166 and 332 g ai ha^{-1} and represent a one-half, three-fourths, full, and double rate (Kumiai 2006). Sulfentrazone was used as the standard and applied at the rate of 105 g ai ha^{-1} which is the recommended rate for the soil type (Zollinger et al. 2010).

Dry pea was tolerant to all rates of pyroxasulfone and no injury or yield loss was observed. Pyroxasulfone is not registered on dry pea. Two years results of this research show adequate tolerance. However, additional dry pea tolerance research may be required to validate these results because insufficient rainfall at all locations failed to activate pyroxasulfone as was evidenced by the lack of weed control.

Lentil Tolerance to Pyroxasulfone

Lentil tolerance was not affected by any factor or interaction at all environments other than stand count, and a treatment by time interaction for injury at Minot in 2009 (ANOVA not shown). No visible lentil injury was observed at all other environments. No significant interactions were found for height and herbicide treatments did not significantly alter height at all other environments. Lentil height was not affected at Minot 2009. Lentil yield was not significantly affected within or across all environments, including Minot 2009.

Pyroxasulfone rates used in this experiment were 84, 125, 166 and 332 g ai ha^{-1} and represent a one-half, three-fourths, full, and double rate (Kumiai 2006). Pendimethalin was used as the standard and applied at the rate of 560 g ai ha^{-1} which is the recommended rate for the soil type (Zollinger et al. 2010).

Visual injury from pyroxasulfone was observed on lentils at Minot 2009 and consisted of decreased plant vigor, stunting, and leaf hyponasty. There was a significant interaction of treatment by time. Lentil injury significantly increased at 166 and 332 g ai ha^{-1} from 14 d after emergence to 28 days after emergence and from 28 d after emergence to 56 d after emergence lentil injury significantly decreased from pyroxasulfone at 125, 166, and 332 g ai ha^{-1} (Table 20). At 56 d after emergence, only 332 g ai ha^{-1} of pyroxasulfone resulted in significant visible injury. Injury likely increased from 14 to 28 d after emergence, due to the time needed for the plant to absorb the herbicide and exhibit visual symptoms. Lentil injury decreased later in the season as plants metabolized the herbicide and continued normal growth.

Table 20. Herbicide effect on lentil injury over time in 2009 at Minot.

Treatment		Days after emergence		
		14	28	56
	g ai ha^{-1}		% injury	
Pyroxasulfone	84	2	4	0
Pyroxasulfone	125	4	8	0
Pyroxasulfone	166	8	14	3
Pyroxasulfone	332	15	21	8
Pendimethalin	560	0	0	0
LSD (0.05)			6	

Lentil height was significantly decreased at 332 g ai ha^{-1}; however, all other treatments were not significantly different (data not shown). Based on two years research, lentils are tolerant to pyroxasulfone at all rates tested as yield was not significantly different for any treatment. Additional research to validate these results may be needed because the herbicide was not activated in all environments other than Minot 2009, as was evidenced by the lack weed control.

Pyroxasulfone Weed Control

The objective of the weed control experiments was to evaluate the efficacy of pyroxasulfone applied EPP and PRE compared to industry standards. As pyroxasulfone has not been registered the rates used were provided by the manufacturer, Kumiai Chemical Industry, Co., LTD. The recommended rate for silty loam soil was 166 g ai ha^{-1} (Kumiai 2006). Due to different field conditions, weather, and weed emergence, ratings were performed at different time intervals after application in 2008 and 2009, each experiment was statistically analyzed individually.

Weed control in the 2008 EPP experiment resulted in a treatment by time interaction for all weeds present, except for redroot pigweed, which was not present to rate until the 70 d after application rating. At 14 d after application all treatments resulted in no weed control (Table 21). S-metolachlor provided no control of wild mustard, marshelder, and common ragweed 35 d after application. Weed control was observed from all applications at other timings. Acetochlor controlled a greater level of marshelder compared to all rates of pyroxasulfone 35 d after application. Acetochlor and all rates of pyroxasulfone, except for 125 g ai ha^{-1}, were similar in control of yellow foxtail, wild mustard, and hairy nightshade 35 d after application. Pyroxasulfone applied at 209 g ai ha^{-1} and acetochlor provided the highest level of common lambsquarter control 35 d after application. Common ragweed control 35 d after application was greatest from pyroxasulfone applied at 332 g ai ha^{-1}. S-metolachlor provided the least control of all weed species 35 d after application compared to all other herbicides.

Weed control levels were lower 70 d after application for many treatments compared to 35 d after application (Table 21). Control of yellow foxtail was lower 70 d after application compared to 35 d after application in treatments of S-metolachlor or 166 and 209 g ai ha^{-1} pyroxasulfone. Pyroxasulfone at 332 g ai ha^{-1} and acetochlor controlled yellow foxtail 70 d after application and is consistent with control observed 35 d after application. Control of yellow foxtail 70 d after application was highest from applications of acetochlor or applications of pyroxasulfone at 209 and 332 g ai ha^{-1}. Wild mustard 70 d after application was higher than 35 d after application at 125 and 166 g ai ha^{-1} pyroxasulfone, and all other applications were not different from ratings 35 d after application. Pyroxasulfone applied at 166 g ai ha^{-1} and greater gave the highest levels of wild mustard control, which was comparable to acetochlor. Control of marshelder was lower 70 d after application compared to 35 d after application at all rates of pyroxasulfone and acetochlor, while S-metolachlor remained zero. Acetochlor provided higher levels of marshelder control compared to all other treatments 70 d after application. Common lambsquarter control was lower for all herbicide treatments 70 d after application compared to 35 d after application. Acetochlor provided the highest level of common lambsquarter control 70 d after application compared to all treatments. Pyroxasulfone at 166 g ai ha^{-1}, S- metolachlor, and acetochlor controlled hairy nightshade at lower levels 70 d after application compared to 35 d after application; however, all treatments of pyroxasulfone and acetochlor provided similar control of hairy nightshade 70 d after application. Common ragweed control 70 d after application was lower in all pyroxasulfone treatments and in the acetochlor treatment compared to 35 d after application. Acetochlor provided higher common ragweed control compared to all treatments 70 d after application. S-metolachlor provided lower levels of control compared to all other herbicide treatments 70 d after application, with the exception of marshelder treated with 125 g ai ha^{-1} pyroxasulfone.

Redroot pigweed control by pyroxasulfone at rates of 166 g ai ha^{-1} and greater was 99% and comparable to acetochlor. S-metolachlor provided no control of redroot pigweed 70 d after application (Table 21).

Rainfall is necessary to incorporate pyroxasulfone into the soil to result in weed control. The 14 d after application rating which showed no weed control, followed by weed control at 35 d after application is evidence of the necessity of rainfall for pyroxasulfone to provide weed control. No rainfall was received between application and

14 d after application. Total precipitation received during the time period between the 14 and 35 d after application ratings was 165 mm. Table 21 displays the ability of pyroxasulfone to control weeds actively growing prior to herbicide activation.

Table 21. 2008 EPP percent weed control.

		yeft[a]	wimu[b]	mael[c]	colq[d]	hans[e]	corw[f]	rrpw[g]
Treatment		------------------ % control 14 Days after application -----------------						
	g ai ha^{-1}							
Pyroxasulfone	125	0	0	0	0	0	0	-
Pyroxasulfone	166	0	0	0	0	0	0	-
Pyroxasulfone	209	0	0	0	0	0	0	-
Pyroxasulfone	332	0	0	0	0	0	0	-
S-metolachlor	1430	0	0	0	0	0	0	-
Acetochlor	2200	0	0	0	0	0	0	-
Untreated		0	0	0	0	0	0	-
		----------------- % control 35 Days after application -----------------						
Pyroxasulfone	125	83	44	31	77	88	50	-
Pyroxasulfone	166	98	62	37	72	98	58	-
Pyroxasulfone	209	99	78	39	90	96	73	-
Pyroxasulfone	332	99	81	62	82	96	83	-
S-metolachlor	1430	59	0	0	34	17	0	-
Acetochlor	2200	99	70	73	92	99	69	-
Untreated		0	0	0	0	0	0	-
		--------------- % control 70 Days after application -----------------						
Pyroxasulfone	125	73	62	6	18	87	20	86
Pyroxasulfone	166	64	88	30	28	92	36	99
Pyroxasulfone	209	85	88	26	35	94	36	99
Pyroxasulfone	332	93	90	36	56	92	43	99
S-metolachlor	1430	35	0	0	0	7	0	0
Acetochlor	2200	91	79	65	71	93	52	99
Untreated		0	0	0	0	0	0	0
LSD (0.05)		12	12	7	10	6	4	3

[a] yeft, yellow foxtail
[b] wimu, wild mustard
[c] mael, marshelder
[d] colq, common lambsquarter
[e] hans, hairy nightshade
[f] corw, common ragweed
[g] rrpw, redroot pigweed

Weed control in the 2009 EPP experiment was affected by treatment. All treatments provided weed control compared to the untreated (Table 22). S-metolachlor provided less control than all other treatments on all weed species present. Pyroxasulfone applied at 209 and 332 g ai ha^{-1} provided control similar to acetochlor on all four weed species. Yellow foxtail and redroot pigweed control from pyroxasulfone applied at 166 g ai ha^{-1} was similar to higher pyroxasulfone rates and acetochlor.

Table 22. 2009 EPP percent weed control.

Treatment		yeft[a]	colq[b]	wibw[c]	rrpw[d]
	g ai ha^{-1}	----------- % control 42 Days after application -----------			
Pyroxasulfone	125	60	64	58	65
Pyroxasulfone	166	78	71	70	78
Pyroxasulfone	209	83	79	84	86
Pyroxasulfone	332	89	81	81	88
S-metolachlor	1430	48	14	26	15
Acetochlor	2200	86	88	92	90
Untreated		0	0	0	0
LSD (0.05)		12	13	16	13

[a] yeft, yellow foxtail
[b] colq, common lambsquarter
[c] wibw, wild buckwheat
[d] rrpw, redroot pigweed

Weed control in the PRE 2008 experiment resulted in differences between treatments on yellow foxtail, common ragweed, and redroot pigweed (Table 23). Yellow foxtail and common ragweed control was higher when pyroxasulfone was applied at 209 g ai ha^{-1} or acetochlor was applied at 1489 g ai ha^{-1}. Redroot pigweed control was highest at pyroxasulfone rates of 125 g ai ha^{-1} and greater as well as 1489 g ai ha^{-1} of acetochlor.

Control of wild mustard, marshelder, common lambsquarter, and hairy nightshade resulted from the glyphosate burndown that was included in all treatments (Table 23). These species did not grow or appear in the plots after herbicide application. Yellow foxtail and redroot pigweed typically emerge later in the season and continue to emerge throughout the season (Iowa State University EXT); therefore, new plants emerged after application and weed control was not similar between treatments. Glyphosate may not control common ragweed (Zollinger et al. 2010). All treatments, other than S-metolachlor, provided higher common ragweed control compared to the untreated which consisted of only a glyphosate burndown and provided 68% control of common ragweed.

Table 23. 2008 PRE percent weed control.

Treatment	g ai ha^{-1}	yeft[a]	wimu[b]	mael[c]	colq[d]	hans[e]	corw[f]	rrpw[g]
		% control 14 Days after application						
Pyroxasulfone	83	38	99	99	99	99	73	83
Pyroxasulfone	125	54	99	99	99	99	80	93
Pyroxasulfone	166	73	99	99	99	99	80	98
Pyroxasulfone	209	83	99	99	99	99	88	99
S-metolachlor	1430	63	99	99	99	99	68	44
Acetochlor	1489	88	99	99	99	99	90	97
Untreated		10	99	99	99	99	68	22
LSD (0.05)		11	NS	NS	NS	NS	3	7

[a] yeft, yellow foxtail
[b] wimu, wild mustard
[c] mael, marshelder
[d] colq, common lambsquarter
[e] hans, hairy nightshade
[f] corw, common ragweed
[g] rrpw, redroot pigweed

Weed control in the PRE 2009 experiment resulted in a treatment by time interaction for common lambsquarter only (Table 24). Yellow foxtail, wild buckwheat, and redroot pigweed were combined and analyzed by treatment. Control of common lambsquarter decreased over time at all rates of pyroxasulfone and acetochlor. S-metolachlor and 83 g ai ha^{-1} of pyroxasulfone provided the lowest control of common lambsquarter 28 d after application and did not provide control 42 d after application. Acetochlor provided higher common lambsquarter control compared to all other treatments at 28 and 42 d after application. Yellow foxtail, wild buckwheat, and redroot pigweed were controlled at higher levels by treatments of acetochlor and 209 g ai ha^{-1} of pyroxasulfone.

Table 24. 2009 PRE percent weed control.

Treatment		yeft[a]	wibw[b]	rrpw[c]	colq[d]	
	g ai ha^{-1}				28 DAA	42 DAA
		------------------------ % weed control ------------------------				
Pyroxasulfone	83	30	50	48	20	9
Pyroxasulfone	125	53	48	58	45	20
Pyroxasulfone	166	74	55	74	58	37
Pyroxasulfone	209	81	73	82	78	54
S-metolachlor	1430	41	12	16	13	5
Acetochlor	1489	88	77	87	89	70
Untreated		0	0	0	0	0
LSD (0.05)		8	11	8	------11------	

[a] yeft, yellow foxtail, combined across ratings
[b] wibw, wild buckwheat, combined across ratings
[c] rrpw, redroot pigweed combined across ratings
[d] colq, common lambsquarter

Weed control data suggests that under most environments tested, pyroxasulfone will consistently control weeds at higher levels than S-metolachlor (Tables 21, 22, 23, 24). Only yellow foxtail control where treatments of 83 g ai ha^{-1} pyroxasulfone were applied was similar to S-metolachlor. Pyroxasulfone applied at recommended rates for soil texture can consistently control most weeds tested similarly to acetochlor early in the growing season, with the exception of marshelder. Pyroxasulfone must be applied higher than the recommended rates to consistently provide weed control similar to acetochlor, especially to control weeds later in the growing season.

Greenhouse Experiments

Pyroxasulfone Activation Timing

The objective of this experiment was to evaluate crop injury from pyroxasulfone activated at the PRE, emergence, and first unifoliate stages of navy bean, as well as compare levels of injury between two soils of the same type with high and low levels of organic matter. Treatment by growth stage and growth stage by time provided significant results (Table 25). Soil type also had a significant effect on crop injury (ANOVA not shown).

Injury was observed from all rates of pyroxasulfone and at the labeled rate of dimethanamid-P when activation occurred at the emergence stage of navy bean (Table 25). Pyroxasulfone at 84, 166, and 250 g ai ha^{-1} caused more injury compared to dimethanamid-P. These results were consistent with the dry weight data of the harvested navy bean plants from 166 and 250 g ai ha^{-1} of pyroxasulfone (Table 26). Pyroxasulfone applied at 84 g ai ha^{-1} did not reduce dry weight compared to dimethanamid-P, but did reduce dry weight compared to unactivated herbicide. Navy bean injury from pyroxasulfone activation at the emergence stage decreased from 38% 7 d after treatment to 29% 14 d after treatment (data not shown). These results are similar to those of field experiments in New York (Bellinder 2008). Navy beans grown in soil with low organic matter were injured at higher levels than navy beans grown in soil with high organic matter for all treatments. These results are consistent with other studies (Knezevic 2007). Based on these results pyroxasulfone appears to bind to organic matter in the soil. Suggested rate structures from Kumiai Chemical Industry Co., Ltd should be reevaluated to consider organic matter levels as well as soil type.

Table 25. Navy bean injury as affected by herbicide treatment and bean growth stage at herbicide activation on two soil types.

		Herbicide activation timing			
Treatment		Unactivated	Cracking	First Unifoliate	Preemergence
	g ai ha^{-1}	% injury			
Pyroxasulfone	84	0	34	0	0
Pyroxasulfone	166	0	50	0	0
Pyroxasulfone	250	0	56	1	0
Dimethanamid-p	1100	3	26	1	0
Untreated		0	3	0	0
LSD(0.05)		4			

Table 26. Navy bean dry harvest weight as affected by herbicide treatment and bean growth stage at herbicide activation on two soil types.

		Herbicide activation timing			
Treatment		Unactivated	Cracking	First Unifoliate	Preemergence
	g ai ha^{-1}	grams			
Pyroxasulfone	84	.53	.37	.59	.40
Pyroxasulfone	166	.47	.24	.49	.42
Pyroxasulfone	250	.45	.27	.53	.40
Dimethanamid-p	1100	.43	.40	.51	.36
Untreated		.33	.52	.58	.42
LSD(0.05)		0.1			

Pyroxasulfone Soil Placement

Pyroxasulfone was incorporated to the top, middle (seed zone), and bottom third of the soil in greenhouse pots at an elevated rate of 250 g ai ha^{-1} to ensure crop injury to determine uptake of the herbicide into navy bean by the root, shoot, or both. All treatments were significantly different (ANOVA not shown).

Pyroxasulfone incorporated in the top, middle, and bottom third of the soil in the pot resulted in some level of injury. Navy bean injury from pyoxasulfone incorporated into the top third was lower than when pyroxasulfone was incorporated into the bottom and middle portions (Table 27). Dry weight of navy bean plants harvested was not affected by injury observed on plants grown in soil with pyroxasulfone incorporated into the top layer of soil. Pyroxasulfone incorporated into the bottom layer or the middle layer caused navy bean plants to yield decreased dry weights (Table 28).

Table 27. Navy bean injury by herbicide placement.

Soil Placement	% injury
Bottom	74
Middle	96
Top	19
Untreated	0
LSD(0.05)	18

Table 28. Navy bean dry harvest weight by herbicide placement.

Soil Placement	grams
Bottom	.13
Middle	.04
Top	.45
Untreated	.56
LSD(0.05)	.14

Reported uptake of pyroxasulfone into plants is through both the roots and shoots (Porpiglia et al. 2005). Pyroxasulfone soil placement data suggests that roots absorb more pyroxasulfone than shoots and has a greater effect in slowing and stopping plant growth. A combination of root and shoot uptake as the seed germinates appears to be nearly lethal. Root uptake displays the importance of activation of pyroxasulfone, as the herbicide must be in the root zone to be taken up at lethal levels. Navy bean tolerance to pyroxasulfone is dependent on environmental conditions as severe injury can occur in specific environments as was shown in both greenhouse studies.

SUMMARY

Field and greenhouse experiments were conducted to meet the following research objectives: (1) Evaluate crop tolerance of navy and pinto dry edible beans, dry pea, and lentil, to pyroxasulfone. (2) Evaluate residual weed control in no-tillage and conventional tillage systems. (3) Evaluate dry edible bean tolerance as influenced by moisture in the greenhouse. (4) Evaluate the nature of plant uptake of pyroxasulfone.

Navy bean response to pyroxasulfone was different among environments. Injury to navy bean resulted from pyroxasulfone at 166 g ai ha^{-1} at all locations in 2008. Injury was not observed for rates lower than 332 g ai ha^{-1} at all locations in 2009. Pyroxasulfone injury to navy bean decreased over time. Plant height was not affected by pyroxasulfone treatment across environments; however, height was decreased at Prosper 2008 and Thompson 2009 from pyroxasulfone at 332 g ai ha^{-1}. Plant population of navy bean decreased as rate of pyroxasulfone increased to 166 and 332 g ai ha^{-1}. Pyroxasulfone rates of at least 166 g ai ha^{-1} resulted in yield reduction of navy bean.

Navy bean tolerance to pyroxasulfone is low. Risk of moderate to severe injury potential is high, depending on environmental conditions, especially moisture. Yield reduction of navy bean is likely from pyroxasulfone at the tested rates higher than 84 g ai ha^{-1}.

Pinto bean response to pyroxasulfone was different among environments. Injury to pinto bean increased as pyroxasulfone rate increased at Prosper 2008. No injury was observed at Prosper 2009. Pinto bean injury resulted from 332 g ai ha^{-1} of pyroxasulfone at all other environments. Injury to pinto bean from pyroxasulfone at 332 g ai ha^{-1} increased from 14 to 28 d after emergence, then decreased at 56 d after emergence. Plant population was affected by pyroxasulfone within environments. Plant populations were lowest at Prosper 2008 and the populations decreased as pyroxasulfone rate increased compared to the control. At Hatton 2008 and Thompson 2008, decreased plant populations occurred when pyroxasulfone was applied at 332 g ai ha^{1}. Pinto bean height decreased at all rates of pyroxasulfone and 332 g ai/ha resulted in the greatest reduction. Pinto bean yield was not reduced from pyroxasulfone.

Pyroxasulfone could be labeled on pinto bean as this study showed adequate tolerance, but should be used with caution and at reduced rates based on soil texture for adequate dry bean safety. Visual pinto bean injury may occur and will vary due to environmental conditions; however, yield will not likely be decreased.

Dry pea was tolerant to pyroxasulfone in all environments tested. However, no weed control in all environments suggested that pyroxasulfone was not activated by precipitation, and therefore the experiments may not reflect the injury possible in wetter environments. More research should be conducted on dry pea tolerance to pyroxasulfone to confirm or reject these results before pyroxasulfone is labeled for application on dry pea.

Lentil was tolerant to pyroxasulfone in all environments tested, except for Minot 2009. Lentil injury was observed from pyroxasulfone applied at 166 and 332 g ai ha^{-1} at Minot 2009. Lentil injury increased over time from 14 to 28 d after emergence. No lentil injury was observed 56 d after emergence when pyroxasulfone was applied at 166 g ai ha^{-1}. Lentil height decreased when pyroxasulfone was applied at 332 g ai ha^{-1} across all environments. Lentil yield was not affected by treatment in any environment.

Pyroxasulfone can safely be applied to lentil at the recommended rates. However, no weed control in all environments, with the exception of Minot 2009, suggested that pyroxasulfone was not activated by precipitation, and may not reflect injury possible in environments that receive more precipitation. Research should be continued to confirm results before pyroxasulfone is labeled for application on lentil.

Weed control experiments showed the potential and inconsistency of pyroxasulfone. The 35 d after application rating in 2008 EPP, demonstrated the ability of pyroxasulfone to control emerged weeds. Yellow foxtail and hairy nightshade were controlled at 166 g ai ha^{-1} of pyroxasulfone 35 d after application. Increased rates of pyroxasulfone were needed for control of wild mustard, common lambsquarter, common ragweed, and marshelder 35 d after application. Wild mustard control improved and was controlled with hairy nightshade and redroot pigweed 70 d after application at 166 g ai ha^{-1} of pyroxasulfone. Weed control of all species required increased rates from the recommended rate of pyroxasulfone at 166 g ai ha^{-1} in the 2009 EPP study. Weed control in PRE 2008 showed excellent control of redroot pigweed at a reduced rate of 125 g ai ha^{-1} of pyroxasulfone. Yellow foxtail was controlled at an increased rate of 209 g ai ha^{-1} pyroxasulfone. Common ragweed control ratings showed the increase in control over glyphosate alone with all rates of pyroxasulfone tank-mixed. Weed control in the PRE 2009 study ranged from 9-82% for all species at all rates of pyroxasulfone. Common lambsquarter control decreased over time for all treatments of pyroxasulfone.

Pyroxasulfone weed control experiments suggest that pyroxasulfone will consistently control weeds better than S-metolachlor, with the exception of yellow foxtail when 83 g ai ha^{-1} of pyroxasulfone is applied. Pyroxasulfone at the recommended rate can control all weeds tested, except for marshelder, comparably to acetochlor. Marshelder control was higher from acetochlor. As the growing season progresses, pyroxasulfone rates greater than the recommended rate are required to provide comparable weed control to acetochlor.

Navy bean injury from pyroxasulfone activated by moisture at crop emergence displayed the potential for severe injury at all rates of pyroxasulfone, providing evidence that pyroxasulfone use should not be labeled on navy bean. Lower injury symptoms with higher organic matter provides evidence that organic matter should be factored into future rate structure investigations along with soil texture.

The soil placement of pyroxasulfone experiments confirmed that pyroxasulfone can be taken into a plant through both the roots and shoot. However, root uptake is more important than shoot uptake.

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APPENDIX

A1. Soil texture classification

Location	% Sand	% Silt	%Clay	Soil Texture
Carrington 2008	35.7	50.4	13.9	Silt Loam
Carrington 2009	36.8	50.5	12.7	Silt Loam
Hatton 2008	72.6	21.1	6.3	Sandy Loam
Hatton 2009	58.0	28.6	13.4	Sandy Loam
Minot 2008 (Lentil)	58.8	31.7	9.5	Sandy Loam
Minot 2008 (Pea)	41.1	45.0	13.9	Loam
Minot 2009 (Lentil)	43.4	42.6	14.0	Loam
Minot 2009 (Pea)	37.6	51.5	10.9	Silt Loam
Prosper 2008 (Dry Bean)	37.1	43.2	19.7	Loam
Prosper 2009 (Dry Bean)	29.8	44.4	25.8	Loam
Prosper 2008 (Weed Control)	26.4	53.2	20.4	Silt Loam
Prosper 2009 (Weed Control)	27.1	54.1	18.8	Silt Loam
Thompson 2008	24.3	58.8	16.9	Silt Loam
Thompson 2009	23.2	56.4	20.4	Silt Loam
Williston 2008	45.9	42.8	11.4	Loam
Williston 2009	37.6	51.0	11.4	Silt Loam