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Management of Italian Ryegrass (*Lolium perenne* ssp. *multiflorum*) in Western Oregon with Preemergence Applications of Pyroxasulfone in Winter Wheat

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Management of Italian ryegrass in cereal-based cropping systems continues to be a major production constraint in areas of the United States, including the soft white winter wheat producing regions of the Pacific Northwest. Pyroxasulfone is a soil-applied herbicide with the potential to control broadleaf and grass weed species, including grass weed biotypes resistant to group 1, 2, and 7 herbicides, in several crops for which registration has been completed or is pending, including wheat, corn, sunflower, dry bean, and soybean. Field experiments were conducted from 2006 through 2009 near Corvallis, OR, to evaluate the potential for Italian ryegrass control in winter wheat with applications of pyroxasulfone. Application rates of PRE treatments ranged from 0.05 to 0.15 kg ai ha^{-1}. All treatments were compared to standard Italian ryegrass soil-applied herbicides used in winter wheat, including diuron, flufenacet, and flufenacet + metribuzin. Visual evaluations of Italian ryegrass and ivyleaf speedwell control and winter wheat injury were made at regular intervals following applications. Winter wheat yields were quantified at grain maturity. Ivyleaf speedwell control was variable, and Italian ryegrass control following pyroxasulfone applications ranged from 65 to 100% and was equal to control achieved with flufenacet and flufenacet + metribuzin treatments and greater than that achieved with diuron applications. Winter wheat injury from pyroxasulfone ranged from 0 to 8% and was most associated with the 0.15–kg ha^{-1} application rate. However, this early-season injury did not negatively impact winter wheat yield. Pyroxasulfone applied at the application rates and timings in these studies resulted in high levels of activity on Italian ryegrass and excellent winter wheat safety. Based on the results, pyroxasulfone has the potential to be used as a soil-applied herbicide in winter wheat for Italian ryegrass management and its utility for management of other important grass and broadleaf weeds of cereal-based cropping systems should be evaluated.
Nomenclature: Diuron; flufenacet; pyroxasulfone; metribuzin; Italian ryegrass, *Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot; ivyleaf speedwell, *Veronica hederifolia* L.; wheat, *Triticum* spp.
Key words: Crop safety, soil-applied herbicides.

El manejo de *Lolium perenne* ssp. *multiflorum* en sistemas de cultivos a base de cereales, continúa siendo una de las mayores limitantes en áreas de U.S.A., incluyendo el Pacífico Noroeste que es la zona productora de trigo blanco-suave de invierno. Pyroxasulfone es un herbicida aplicado al suelo con potencial de control de malezas de hoja ancha y zacates, incluyendo zacates resistentes a herbicidas de los Grupos 1, 2 y 7, en varios cultivos para los cuales el registro se ha completado o está pendiente incluyendo trigo, maíz, girasol, frijoles y soya. Se realizaron experimentos de campo durante 2006-2009 cerca de Corvallis, OR, para evaluar el potencial de control de *L. perenne* ssp. *multiflorum* en trigo de invierno con aplicaciones de pyroxasulfone. Las dosis de aplicación de tratamientos PRE estuvieron en el rango 0.005-015 kg ai ha^{-1}. Todos los tratamientos fueron comparados con los tratamientos estándar de herbicidas aplicados al suelo para el control de dicha maleza, los cuales incluyeron diuron, flufenacet, y flufenacet + metribuzin. Evaluaciones visuales del control de *L. perenne* ssp. *multiflorum* y *Veronica hederifolia* y el daño en el trigo fueron realizadas a intervalos regulares después de las aplicaciones. El rendimiento del trigo fue cuantificado cuando los granos alcanzaron la madurez. El control de *V. hederifolia* fue variable,mientras que el de *L. perenne* ssp. *multiflorum* después de las aplicaciones con pyroxasulfone fueron de 65 a 100%, que fue igual al control alcanzado con los tratamientos de flufenacet y flufenacet + metribuzin, y mayor al control con aplicaciones de diuron. El daño en el trigo causado por pyroxasulfone fue 0 a 8% y estuvo más asociado a la dosis de 0.15 kg ha^{-1}. Sin embargo, este daño, temprano en el ciclo del cultivo, no afectó negativamente el rendimiento. Las aplicaciones de pyroxasulfone a las dosis y momentosusados en estos estudios, resultaron en altos niveles de actividad sobre *L. perenne* ssp. *multiflorum* y excelente seguridad para el trigo de invierno. Basado en los resultados, pyroxasulfone tiene el potencial de ser usado como herbicida aplicado al suelo en trigo de invierno para el manejo de *L. perenne* ssp. *multiflorum* y se debería evaluar su importancia para el manejo otras malezas de hoja ancha y zacates en sistemas de cultivos a base de cereales.

The climate in western Oregon, with an abundant winter rainfall pattern and relatively moderate temperatures, is well suited for the production of many winter cereal grains, including winter wheat. Management of grass weed species, such as Italian ryegrass, several annual and perennial *Bromus* spp., and annual bluegrass (*Poa annua* L.), in these cereal grains is difficult because of the similar biology of these weed species to the crop species. Italian ryegrass is a cool-season bunchgrass that was introduced from southern Europe to North America as a forage crop and has subsequently become a major annual weed of cropping systems worldwide, including the Pacific Northwest (PNW). Italian ryegrass is reported as an important weed that can cause significant economic loss in cereal-based cropping systems in all wheat

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production areas of the United States, except the Northern Great Plains, and is among the top 10 most troublesome weeds in the wheat-growing regions of the southern United States (Elmore 1988). The invasiveness of this weed is in part because of its adaptability to a diversity of growing conditions and soil types, its widespread use as a cool-season forage in the southern United States, and the extensive Italian ryegrass seed production industry in Oregon.

Italian ryegrass causes economic loss because it is very competitive with winter wheat, contributes to lodging, and results in grain quality and grain dockage complications at wheat harvest. Italian ryegrass competes with winter wheat for mineral nutrients, water, space, and light (Carson et al. 1999; Forcella 1984; Hashem et al. 1998). Specifically, its competitive ability contributes to reduced winter wheat photosynthesis, decreased tiller number, and reduced plant height, resulting in yield loss (Carson et al. 1999; Stone et al. 1998). Appleby et al. (1976) documented that increasing Italian ryegrass densities from approximately 1.0 to 93 plants m^{-2} decreased winter wheat grain yield more than 60% compared to weed-free plots.

The adoption of no- or minimum-tillage practices to reduce soil disturbance from farming operations has limited mechanical weed control methods and has further increased the reliance on POST herbicide applications in winter wheat production to manage Italian ryegrass and broadleaf weeds. Consequently, this extensive herbicide use has resulted in the selection of cross- and multiple-herbicide resistance to several different herbicide groups including ACCase inhibitors (group 1), acetolactase synthase (ALS) –inhibiting herbicides (group 2), photosystem II inhibitors (group 5), and inhibitors of very-long-chain fatty acid synthesis (group 15) in Italian ryegrass populations in the PNW and other production regions (Ellis et al. 2008, 2010; Kuk and Burgos 2007; Mallory-Smith et al. 2007; Rauch et al. 2010).

PRE or early-POST (EPOST) chemical control options for Italian ryegrass for use in winter wheat are limited. Standard management methods for Italian ryegrass in western Oregon include the use of flufenacet, metribuzin, or flufenacet + metribuzin applied soon after planting, but after winter wheat has germinated and is emerging (Anonymous 2011a) and diuron or diuron + chlorsulfuron and metsulfuron often applied soon after the wheat is planted and up to the two-leaf growth stage (Anonymous 2011b; Grey and Bridges 2003).

Pyroxasulfone is a soil-applied herbicide with the potential to control many broadleaf and grass weed species when applied PRE in several crops including wheat, corn (*Zea mays* L.), sunflower (*Helianthus annuus* L.), dry bean (*Phaseolus vulgaris* L.), and soybean [*Glycine max* (L.) Merr.] (Anonymous 2006). Registration for use has been completed or is pending in some of these crops. The site of action of pyroxasulfone has been reported to be similar to that of group 15 inhibitors of very-long-chain fatty acid synthesis (Tanetani et al. 2009). Although this site of action is already utilized for control of Italian ryegrass in Oregon through EPOST applications of flufenacet, pyroxasulfone may represent a true PRE herbicide option in winter wheat that would improve management of Italian ryegrass populations and biotypes that germinate and emerge with the winter wheat crop and an option that could possibly replace less effective soil-applied herbicides currently used in winter wheat.

Application rates of pyroxasulfone are dependent on soil type and organic-matter content of soils. Knezevic et al. (2009) conducted field experiments in soils with a range of organic matter in Nebraska to develop dose-response curves for weed control and corn tolerance. Results from these experiments indicate that excellent control of grass weed species, including green foxtail [*Setaria viridis* (L.) Beauv.] and large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and broadleaf species, including tall waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] and velvetleaf (*Abutilon theophrasti* Medik.), are possible with pyroxasulfone application rates of 0.2 to 0.3 kg ai ha^{-1} with no injury to corn. Dose-response experiments utilizing rigid ryegrass (*Lolium rigidum* Gaudin) in a range of soil types conducted by Walsh et al. (2011) suggest that activity of pyroxasulfone is greatest in relatively sandy soils and decreases with increasing clay content and soil organic matter content. Pyroxasulfone dissipated at slower rates compared to *S*-metolachlor, which resulted in comparable weed control with lower application rates of pyroxasulfone compared to *S*-metolachlor in studies conducted in clay loam and sandy loam soils in Colorado (Westra et al. 2010). Excellent control of broadleaf weeds including velvetleaf, kochia [*Kochia scoparia* (L.) Schrad.], and wild buckwheat (*Polygonum convolvulus* L.) has been documented with PRE applications of pyroxasulfone with application rates ranging from 0.166 to 0.250 kg ha^{-1} in furrow-irrigated corn production systems (King and Garcia 2008).

To prevent and mitigate further development of herbicide resistance in Italian ryegrass, herbicides representing a variety of application timings and sites of action must be made available to winter wheat producers. However, limited weed management field research to determine the utility of pyroxasulfone uses in winter wheat production systems has been conducted. Additionally, there are limited data on the effectiveness of PRE pyroxasulfone applications to winter annual grass weeds in relatively high rainfall winter wheat production environments such as those located in western regions of the PNW. Therefore, the objective of this research was to evaluate the use of pyroxasulfone in winter wheat for Italian ryegrass management in western Oregon.

Materials and Methods

In 2006, 2007, and 2008 studies were initiated in winter wheat to evaluate the effectiveness of pyroxasulfone for management of Italian ryegrass and broadleaf weed species. The studies were planted at Hyslop Field Research Farm near Corvallis, OR. The soil type at this farm is a Woodburn silt loam with an organic matter content of 2.6%, a pH of 5.5, and a cation exchange capacity of 14.1. The winter wheat cultivar 'ORCF 101' was planted in 2006 and 2007 and 'Goetze' was planted in 2008 to mirror the rapid adoption of this locally adapted cultivar by winter wheat growers in western Oregon in 2008. These studies were overseeded with Italian ryegrass prior to planting winter wheat each year and contained high-density background populations of ivyleaf speedwell, a difficult-to-control broadleaf weed common to winter wheat production in western Oregon, in 2007 through 2008 and 2008 through 2009 (Aldrich-Markham 1995). Winter wheat was planted

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Table 1. Mean daily high and low temperatures and total monthly precipitation for the months of October–July in 2006–2009 at the Hyslop Field Research Farm near Corvallis, OR. The months of October–July represent the critical winter wheat growing season in western Oregon.

	2006–2007										2007–2008	
	October	November	December	January	February	March	April	May	June	July	October	November
Mean daily high (C)	19.1	11.8	8.1	7.5	10.8	15.1	16.1	20.0	23.2	28.4	15.9	11.3
Mean daily low (C)	3.5	4.3	0.9	−0.6	2.8	3.6	3.3	5.8	8.3	12.4	5.6	1.9
Total precipitation (cm)	2.8	41.1	21.3	9.9	14.5	6.9	5.1	4.1	1.6	1.0	10.9	10.9

October 13 in each year of the studies with a grain drill at a rate of 135 kg ha^{-1} and depth of 3.8 cm in 15.2-cm rows. The winter wheat was fertilized and treated with fungicides to control *Septoria* leaf blotch and stripe rust (*Puccinia striiformis*) as needed each year in accordance with local winter wheat production standards (Hart et al. 2009).

The experimental design of these studies was a randomized complete block with four replications, and individual plot size was 2.4 m wide by 10.9 m long. Herbicide treatments were applied with the use of a compressed-air unicycle sprayer equipped with flat-fan XR8003 nozzles (TeeJet Technologies, P.O. Box 7900, Wheaton, IL 60189-7900) calibrated to deliver 187 L ha^{-1} at 138 kPa. Herbicide treatments consisted of an untreated control and four PRE rates of pyroxasulfone (Kumiai Chemical Industry Co., Ltd., Taitoh, Tokyo, 110-872, Japan) (0.05, 0.08, 0.10, and 0.15 kg ha^{-1}) each year. Comparison treatments of a PRE application of diuron (Dupont™ Karmex® DF, E. I. du Pont de Nemours and Company,1007 Market Street, Wilmington, DE 19898) (1.68 kg ai ha^{-1}) in 2006, EPOST applications of a commercial premix of flufenacet + metribuzin (Axiom® DF, Bayer CropScience LP, P.O. Box 12014, 2 T.W. Alexander Drive, Research Triangle Park, NC 27709) (0.47 kg ai ha^{-1}) in 2006 and 2007, and EPOST applications of flufenacet (Define™ DF, Bayer CropScience LP) (0.38 kg ai ha^{-1}) in 2007 and 2008 were also included in the studies. The variability in the comparison treatments over time was a reflection of changing flufenacet winter wheat registrations and flufenacet product availability in the region. PRE applications were made to the winter wheat within 7 d of planting and EPOST applications were made to one-leaf winter wheat, which corresponded to 10 to14 d after wheat planting each year. A nontreated weedy control was included each year for winter wheat yield comparisons.

Visual ratings of Italian ryegrass and ivyleaf speedwell control and winter wheat injury were made approximately every 14 d throughout the growing season. A rating scale of 0 to 100 was used, where 0 was equal to the weed population in the untreated control plots or no crop injury and 100 indicated complete control of the Italian ryegrass and ivyleaf speedwell or crop death. The final weed control rating, approximately 4 mo after winter wheat planting each year, represents season-long pyroxasulfone efficacy and crop safety. Winter wheat yield was obtained by harvesting the center 1.6 m of each plot with the use of a small plot combine when the grain moisture content reached 13.5%.

Statistical Analysis. Data analysis was conducted with the use of the statistical software R 2.10.1 (R Foundation for Statistical Computing, http://www.r-project.org/). Herbicide treatments, years, replications, and interactions were tested for their affect on the visual ratings of winter wheat injury, Italian ryegrass, and ivyleaf speedwell control and winter wheat yield with the use of ANOVA. These data were subjected to arcsin of the square-root transformation, but the results were similar to untransformed data that are presented herein. Treatments were compared by Tukey's honestly significant difference means comparison at the $P < 0.05$ level.

Results and Discussion

Environmental conditions varied significantly between each year of the studies (Table 1). The 2006 through 2007 growing season was characterized by the wettest and warmest weather conditions of the three experimental years followed by the 2008 through 2009 and 2007 through 2008 growing seasons, respectively. There was a significant treatment by year interaction ($F = 8.61$, $P < 0.001$) and comparison herbicide treatments were not the same every year, therefore, the weed control ratings, winter wheat injury, and winter wheat yield were analyzed separately for each year of the studies.

Italian Ryegrass. Italian ryegrass control was quantified during each study (Table 2). All the herbicide treatments provided 98–100% Italian ryegrass control during the 2007–2008 growing season. These high levels of Italian ryegrass control are likely related to the large amount of rainfall that occurred in October of 2007 (11 cm) resulting in optimum soil moisture conditions for soil-applied herbicide activation following winter wheat planting and herbicide applications (Table 1). Italian ryegrass control was more variable during the 2006 through 2007 and 2008 through 2009 growing seasons. In 2006 through 2007, pyroxasulfone applied at 0.10 and 0.15 kg ha^{-1} resulted in similar Italian ryegrass control compared to the flufenacet + metribuzin treatment. Results were similar in 2008 through 2009 between the two highest rates of pyroxasulfone applied and the flufenacet treatment. The lowest rate of pyroxasulfone applied did not provide adequate control (<80%) of Italian ryegrass in 2006 through 2007 and 2008 through 2009. The 0.10 and 0.15 kg ha^{-1} pyroxasulfone rates performed similarly to the industry standard rates of flufenacet + metribuzin and flufenacet applied alone and provided greater than 80% Italian ryegrass control in each year of the study. Overall, Italian ryegrass control resulting from the highest pyroxasulfone rate was 90% or greater each year and more consistent than control resulting from the lower pyroxasulfone rates.

Ivyleaf Speedwell. Ivyleaf speedwell populations were present in the trial areas in 2007 through 2008 and 2008 through

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Table 1. Extended.

2007–2008								2008–2009									
December	January	February	March	April	May	June	July	October	November	December	January	February	March	April	May	June	July
7.9	6.0	10.8	11.3	13.6	19.3	21.8	28.6	17.7	12.9	7.1	8.1	10.0	11.1	15.7	20.6	23.4	29.8
1.4	−0.7	0.5	0.8	2.6	7.5	7.4	10.3	4.3	5.2	−0.9	0.2	0.2	1.7	2.9	5.8	10.7	11.8
24.0	22.1	6.8	11.4	6.0	1.0	2.6	0.1	3.8	12.0	15.3	9.4	8.4	9.7	3.3	9.3	1.6	2.0

2009. In 2007 through 2008, the addition of metribuzin to the flufenacet treatment improved ivyleaf speedwell control from 70 to 98% (Table 2). The two highest rates of pyroxasulfone resulted in 86 and 95% control, respectively, which was similar to the 70 to 75% control by flufenacet alone or the second highest pyroxasulfone rate and greater than the 63% by the lowest rate. During the 2008 through 2009 growing season, ivyleaf speedwell control was limited with all treatments. Regardless of pyroxasulfone rate, control was never greater than 53% and flufenacet applied alone only provided 5% control (Table 2). The relative differences of control between years may have been caused by environmental factors. Speedwell species are more competitive in moist conditions (Mennan and Uygur 1994; Roberts and Lockett 1978; Shuiliang and Yanghan 1998) and the 2008 through 2009 growing season had more rainfall from February through May than 2007 through 2008 (Table 1). In addition, the October 2008 mean daily low temperature was cooler than in October 2007 (Table 1). Cool soil temperatures may inhibit ivyleaf speedwell germination or decrease total germination (Angonin et al. 1996). These factors may have decreased ivyleaf speedwell germination during the fall of 2008, when the herbicide treatments were applied, but increased the ivyleaf speedwell competition over the duration of the 2008 through 2009 growing season as a result of later-emerging or spring-emerging cohorts of these populations that were not controlled by the soil-applied herbicide treatments. Given the variable response in ivyleaf speedwell control when evaluated over the two growing seasons in these studies, the effectiveness of using pyroxasulfone to manage this species successfully in winter wheat could not be determined.

Winter Wheat. Winter wheat safety was evaluated by visual ratings of injury throughout the growing season and final winter wheat grain yield. Injury consisted primarily of early-season stand loss rather than a reduction in growth vigor or plant height. Except for the 13 or 8% injury still remaining at the end of the growing season resulting from the flufenacet + metribuzin application in 2006 through 2007 or the highest pyroxasulfone rate in 2007 through 2008, respectively, less than 3% season-end injury was observed (data not shown). When yield was evaluated each year, there was a treatment effect only in 2006 through 2007 (Table 3). Differences in wheat yield that year seemed to relate to Italian ryegrass control because the treatments with the highest yields, flufenacet + metribuzin and the two highest pyroxasulfone rates, had 83 to 100% control compared to 65% or less by the other herbicide treatments (Table 2). All herbicide treatments that year resulted in yields greater than the untreated control yield. In 2007 through 2008 and 2008 through 2009, there was no significant yield difference among herbicide treatments. It is unclear why no winter wheat yield increase was documented in these 2 yr as a result of the herbicide applications, but this finding may be the result of Italian ryegrass densities not being great enough to impact winter wheat yield, or environmental conditions, such as fall and summer soil moisture conditions, that were not limiting to winter wheat growth. As previously noted, the 2006 through 2007 growing season was characterized by the wettest weather conditions, particularly during the months of November and December, which may have increased Italian ryegrass competition compared to the drier growing seasons the following production years, which may in turn have favored the winter wheat and reduced overall Italian ryegrass competition

Table 2. Effect of pyroxasulfone and standard herbicide treatments in winter wheat on season-long Italian ryegrass and ivyleaf speedwell control at Corvallis, OR, in 2006–2009.[a]

		2006–2007	2007–2008		2008–2009	
Treatment	kg ha^{-1}	Italian ryegrass[b]	Ivyleaf speedwell	Italian ryegrass	Ivyleaf speedwell	Italian ryegrass
		% Control				
Pyroxasulfone	0.05	65 b	63 b	100 a	38 a	78 b
Pyroxasulfone	0.08	65 b	75 ab	100 a	35 a	88 ab
Pyroxasulfone	0.10	83 ab	86 a	100 a	43 a	94 a
Pyroxasulfone	0.15	90 a	95 a	100 a	53 a	91 a
Flufenacet + metribuzin	0.47	100 a	98 a	100 a	NA[c]	NA
Flufenacet	0.38	NA	70 ab	98 a	5 b	94 a
Diuron	1.68	43 b	NA	NA	NA	NA

[a] The final weed control rating, approximately 4 mo after winter wheat planting each year, represents season-long weed control efficacy and crop safety.

[b] Means within a column followed by the same letter are not significantly different ($P < 0.05$). Mean separations were performed with the use of Tukey's honestly significant difference means comparison.

[c] Abbreviation: NA = treatment was not applied that growing season.

Table 3. Winter wheat yields following pyroxasulfone and standard herbicide treatments at Corvallis, OR, in 2006–2009.

Treatment	kg ai ha^{-1}	Wheat yield		
		2006–2007[a]	2007–2008	2008–2009
		kg ha^{-1}		
Untreated control		6464 d	8585	9609
Pyroxasulfone	0.05	7767 c	8736	9436
Pyroxasulfone	0.08	7885 c	8485	9436
Pyroxasulfone	0.10	8292 bc	8600	9742
Pyroxasulfone	0.15	8527 ab	8193	9742
Flufenacet + metribuzin	0.47	8982 a	8266	NA[b]
Flufenacet	0.38	NA	8141	9797
Diuron	1.68	7759 c	NA	NA

[a] Means within a column followed by the same letter are not significantly different ($P < 0.05$). Mean separations were performed with the use of Tukey's honestly significant difference means comparison. There were no differences in winter wheat yield among treatments in 2007–2008 and 2008–2009.

[b] Abbreviations: NA = treatment was not applied that growing season.

(Table 1). Winter wheat that is subjected to saturated soil moisture or flooding conditions during early developmental stages often exhibits poor long-term growth and yield potential (M. Flowers, personal communication, November 3, 2011). However, all winter wheat yields in these studies were commercially acceptable and are above the average winter wheat yield from 2000 through 2006 (6014 kg ha^{-1}) for Linn County, OR, a major wheat-producing county in western Oregon (U.S. Department of Agriculture–National Agricultural Statistics Service [USDA-NASS] 2010).

These results suggest that pyroxasulfone at the highest rate, 0.15 kg ha^{-1}, and possibly the next highest rate of 0.10 kg ha^{-1}, evaluated in this study could be used effectively for Italian ryegrass management in winter wheat and are comparable to current standard treatments of flufenacet or flufenacet + metribuzin. Pyroxasulfone has been successfully used in the control of rigid ryegrass (*L. rigidum* Gaudin) in southern Australia (Boutsalis et al. 2010), and multiple field trials in wheat throughout the United States with pyroxasulfone application rates similar to those discussed here have shown both excellent control of Italian ryegrass and limited crop injury (Tan et al. 2011). Although the mode of action for pyroxasulfone is similar to that of other group 15 herbicides, it is not known exactly; therefore, utilization of this herbicide for Italian ryegrass control may help delay resistance to currently used herbicides or control some herbicide-resistant weed biotypes (Tanitani et al. 2009). The adoption and integration of pyroxasulfone into an Italian ryegrass chemical management system in winter wheat may not add a new, distinct herbicide site of action, but it will add another soil-applied herbicide useful for overall weed management in winter wheat production systems. Further studies are needed to observe what other weed species in the PNW winter wheat cropping systems can be controlled by addition of pyroxasulfone into the management system and to explore further timing methods and combinations of herbicides that could be applied with pyroxasulfone in winter wheat.

In summary, pyroxasulfone has a unique fit for use in winter wheat production systems because of its PRE application timing and activity on Italian ryegrass. Depending on its exact site of action, pyroxasulfone may also be a valuable addition to cereal-based cropping systems in terms of herbicide resistance management of both grass and broadleaf weed species. We anticipate that through continued experimentation with pyroxasulfone in winter wheat production systems its utility for management of other important grass and broadleaf weeds of cereal-based cropping systems will be determined, and we agree with Walsh et al. (2011) that integrated Italian ryegrass management strategies will be needed to maintain the utility of pyroxasulfone over time.

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Literature Cited

Anonymous. 2006. KIH-485 experimental herbicide technical information. White Plains, NY: Kumiai Chemical Industry 8.

Anonymous. 2011a. Axiom® DF herbicide supplemental label. Research Triangle Park, NC: Bayer CropScience LP, http://www.cdms.net/LDat/ld27J005.pdf. Accessed: May 1, 2011.

Anonymous. 2011b. Dupont™ Karmex® DF herbicide label. Wilmington, DE: E. I. du Pont de Nemours and Company, http://www.cdms.net/LDat/ld7QS008.pdf. Accessed: May 1, 2011.

Aldrich-Markham, S. 1995. The Speedwells. Corvallis, OR: Pacific Northwest Extension, Oregon State University, Publication No. 396.

Angonin, C., J. P. Caussanel, and J. M. Meynard. 1996. Competition between winter wheat and *Veronica hederifolia* influence of weed density and the amount and timing of nitrogen application. Weed Res. 36:175–187.

Appleby, A. P., P. D. Olsen, and D. R. Colbert. 1976. Winter wheat yield reduction from interference by Italian ryegrass. Agron. J. 68:463–466.

Boutsalis, P., G. Gill, and C. Preston. 2010. New mode of action herbicides to combat herbicide resistant rigid ryegrass (*Lolium rigidum*) in Australian cereal production. Proc. Aust. Weeds. Conf. 17:278–280.

Carson, K. H., N. T. Cralle, J. M. Chandler, T. D. Miller, R. W. Bovey, S. A. Senseman, and M. J. Stone. 1999. *Triticum aestivum* and *Lolium multiflorum* interaction during drought. Weed Sci. 47:440–445.

Ellis, A. T., G. D. Morgan, and T. C. Mueller. 2008. Mesosulfuron-resistant Italian ryegrass (*Lolium multiflorum*) biotype from Texas. Weed Technol. 22:431–434.

Ellis, A. T., L. E. Steckel, C. L. Main, M.S.C. de Melo, D. R. West, and T. C. Mueller. 2010. A survey for diclofop-methyl resistance in Italian ryegrass from Tennessee and how to manage resistance in wheat. Weed Technol. 24:303–309.

Elmore, C. D. 1988. Weed survey–southern states. Res. Rep. South. Weed Sci. Soc. 41:406–408.

Forcella, F. 1984. Wheat and ryegrass competition for pulses of mineral nitrogen. Aust. J. Exp. Agric. Anim. Husb. 24:421–425.

Grey, T. L. and D. C. Bridges. 2003. Alternatives to diclofop for the control of Italian ryegrass (*Lolium multiflorum*) in winter wheat (*Triticum aestivum*). Weed Technol. 17:219–223.

Hart, J. M., M. D. Flowers, R. J. Roseberg, N. W. Christensen, and M. E. Mellbye. 2009. Soft white winter wheat nutrient management guide (western Oregon). Corvallis, OR: Oregon State University Report EM 8963-E.

Hashem, A., S. R. Radosevich, and M. L. Roush. 1998. Effect of proximity factors on competition between winter wheat (*Triticum aestivum*) and Italian ryegrass (*Lolium multiflorum*). Weed Sci. 46:181–190.

King, S. R. and J. O. Garcia. 2008. Annual broadleaf control with KIH-485 in glyphosate-resistant furrow-irrigated corn. Weed Technol. 22:420–424.

Knezevic, S. Z., A. Datta, J. Scott, and P. Porpiglia. 2009. Dose-response curves of KIH-485 for preemergence weed control in corn. Weed Technol. 23:34–39.

Kuk, Y. I. and N. R. Burgos. 2007. Cross-resistance profile of mesosulfuron-methyl-resistant Italian ryegrass in the southern United States. Pest Manag. Sci. 63:349–357.

Mallory-Smith, C., A. G. Hulting, D. Thill, D. Morishita, and J. Krenz. 2007. Herbicide-resistant weeds and their management. Moscow, ID: University of Idaho, Pacific Northwest Extension Publication No. 437.

Mennan, H. and F. N. Uygur. 1994. Determination of weed species in wheat fields in Samsun province. Ondokuz Mayis Univ. J. Agric. Fac. 9:225–235.

Rauch, T. A., D. C. Thill, S. A. Gersdorf, and W. J. Price. 2010. Widespread occurrence of herbicide-resistant Italian ryegrass (*Lolium multiflorum*) in northern Idaho and eastern Washington. Weed Technol. 24:281–288.

Roberts, H. A. and P. M. Lockett. 1978. Seed dormancy and periodicity of seedling emergence in *Veronica hederifolia* L. Weed Res. 18:41–48.

Shuiliang, G. and L. Yanghan. 1998. Ecological characteristics of *Veronica hederifolia* in China. Yingyong-shengtai-Xuebao 9:133–138.

Stone, M. J., H. T. Cralle, J. M. Chandler, T. D. Miller, and K. H. Carson. 1998. Above and belowground interference of wheat (*Triticum aestivum*) by Italian ryegrass (*Lolium multiflorum*). Weed Sci. 46:438–441.

Tan, S., R. Bond, S. J. Bowe, R. A. Liebl, Y. Yamaji, H. Honda, and T. Ambe. 2011. Management of Italian ryegrass with pyroxasulfone in winter wheat. WSSA Abstracts 51:313.

Tanetani, Y., K. Kaku, K. Kawai, T. Fujioka, and T. Shimizu. 2009. Action mechanism of a novel herbicide, pyroxasulfone. Pestic. Biochem. Phys. 95:47–55.

[USDA-NASS] U.S. Department of Agriculture–National Agricultural Statistics Service. 2010. QuickStats Ad-hoc Query Tool. Accessed February 24, 2011. http://quickstats.nass.usda.gov/.

Walsh, M. J., T. M. Fowler, B. Crowe, T. Ambe, and S. B. Powles. 2011. The potential for pyroxasulfone to selectively control resistant and susceptible rigid ryegrass (*Lolium rigidum*) biotypes in Australian grain crop production systems. Weed Technol. 25:30–37.

Westra, E. P., D. Shaner, and P. Westra. 2010. Soil interaction and biological activity of pyroxasulfone. Proc. West. Soc. Weed Sci. 63:16.

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