CHAPTER 3

Evaluation of Preemergence Herbicides for Control of Diclofop-resistant Italian Ryegrass (*Lolium multiflorum*) in Virginia

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Abstract. Field and greenhouse experiments were conducted to evaluate the efficacy of various preemergence herbicides for Italian ryegrass control. Treatments included varying rates and application timings of acetochlor [emulsifiable concentrate (EC) and microencapsulated (ME) formulations], BAY MKH 6561, BAY MKH 6562, chlorsulfuron, chlorsulfuron plus metsulfuron, diclofop, flufenacet plus metribuzin, flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron, metolachlor, metribuzin, and pendimethalin. Preemergence and delayed preemergence application timings were evaluated. Significant differences were observed in Italian ryegrass control and crop response to herbicide treatments. In the greenhouse experiment, the acetochlor formulations and low rate of flufenacet plus metribuzin provided excellent control of Italian ryegrass and minimal crop injury. However, flufenacet plus metribuzin resulted in injury to wheat at 1.12 kg a.i./ha. Metolachlor provided acceptable control of Italian ryegrass but was injurious to the crops. Chlorsulfuron, chlorsulfuron plus metsulfuron, and diclofop did not result in adequate control of Italian ryegrass. Chlorsulfuron plus metsulfuron resulted in significant injury to barley. In the field experiment, flufenacet plus metribuzin, the most efficacious treatment, resulted in excellent Italian ryegrass control, little crop injury, and acceptable barley yields. Metolachlor and acetochlor treatments resulted in acceptable barley yields, but crop tolerance and Italian ryegrass control were below acceptable levels. Other

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treatments were generally either ineffective in ryegrass control or resulted in unacceptable levels of barley injury.

Nomenclature: Acetochlor, 2-chloro-N-(ethoxymethyl)-N-(2-ethyl-6-methylphenyl)acetamide; BAY MKH 6561 (proposed name, propoxycarbazone-sodium), methyl 2-({[(4-methyl-5-oxo-3-propoxy-4,5-dihydro-1*H*-1,2,4-triazol-1- l)carbonyl]amino}sulfonyl)benzoate sodium salt; BAY MKH 6562 (proposed name, flucarbazone-sodium), 4,5-dihydro-3-methoxy-4-methyl-5-oxo-*N*-[[2-(trifluoromethoxy)phenyl]sulfonyl]-1*H*-1,2,4-triazole-1-carboxamide, sodium salt; chlorsulfuron, 2-chloro-N-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]benzenesulfonamide; diclofop, methyl ester of (±)-2-[4-(2,4-dichlorophenoxy)phenoxy]propanoic acid; flufenacet, N-(4-Flourophenyl)-N-(1-methylethyl)-2-[[5-(trifluoromethyl)-1,3,4-thiadiazol-2-yl]-oxy]acetamide; metolachlor, 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide; metribuzin, 4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one; metsulfuron, (methyl 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoic acid; pendimethalin, N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine; Italian ryegrass, *Lolium multiflorum* Lam. #[2] [LOLMU]; barley, *Hordeum vulgare* L. 'Nomini'; wheat, *Triticum aestivum* 'Roane 98F-ROA-VO93'.

Additional index words: emulsifiable concentrate, flucarbazone-sodium, herbicide resistance, microencapsulated, preemergence, propoxycarbazone-sodium.

Abbreviations: ANOVA, analysis of variance; APP, aryloxyphenoxypropionate; DAT, days after treatment; D-PRE, delayed preemergence; EC, emulsifiable concentrate; LSD, least significant difference; ME, microencapsulated concentrate; PRE, preemergence; PROC-GLM, general linear models procedure; WAP, weeks after planting; WAT, weeks after treatment.

[2] Letters following this symbol are WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available from WSSA, 1508 West University Ave., Champaign, IL 61821 – 3133.

INTRODUCTION

Growing vigorously in winter and early spring, Italian ryegrass (*Lolium multiflorum* Lam.) has become a competitive weed in small grains, especially in the northwestern and southeastern United States (Hall, 1996; Uva et al., 1997; Whitson, et al., 1996). Ryegrass infestations cause yield reductions, field abandonment, and expense of cleaning seed (Mersie and Foy, 1985). Therefore, control of ryegrass through effective herbicide treatments is necessary to attain satisfactory small grain yields (Appleby and Brewster, 1992; Mersie and Foy, 1985; Stone et. al., 1998).

In small grains, Italian ryegrass has generally been controlled with postemergence treatments of diclofop, or diclofop-methyl, a member of the subfamily of the aromatic carboxylic acid family, the aryloxyphenoxypropionates (APP). Diclofop inhibits Acetyl-Coenzyme A carboxylase (ACCase), an important enzyme in plant lipid synthesis (Betts et al., 1992; Burton et al., 1989; Gronwald et al., 1989). Introduced in 1979, diclofop became widely used in wheat-producing areas of Oregon and other northwestern states, and later in the southeastern and mid-Atlantic region of the United States.

The first occurrence of diclofop-resistant Italian ryegrass was reported in the United States in 1987 (Stanger and Appleby, 1989). In Virginia, the first diclofop-resistant biotype was reported in 1993 (Heap, 2004). Subsequently, there has been a significant decline in grower's satisfaction with diclofop efficacy for Italian ryegrass control (Hagood[3], 2004). The spread of diclofop-resistant Italian ryegrass has prompted the search for alternative control methods. The objective of this study was to evaluate the efficacy of various herbicides for Italian ryegrass control.

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MATERIALS AND METHODS

Greenhouse Experiment. Barley[4], wheat[5], and Italian ryegrass[6] seed were sown 2.5 cm-deep in 26- by 18- by 8-cm plastic flats filled with a Ross silt-loam soil (fine-loamy, mixed, mesic cumulic Hapludolls) with 2.3 % organic matter and pH 6.1. Prior to planting, the soil was sieved with a 0.4 cm mesh screen. Each tray was seeded with three rows of barley and three rows of wheat at approximately 20 to 22 seeds per row with 5.5-cm row spacings. Commercially purchased Italian ryegrass seed was broadcast to simulate natural seed dissemination. Flats were irrigated over the top as needed and maintained in a mechanically aerated plastic greenhouse covered with semi-clear plastic. Temperatures in the greenhouse ranged from 18°C to 29°C.

Herbicide treatments included two formulations of acetochlor [emulsifiable concentrate (EC)[7] and microencapsulated (ME)[8]], chlorsulfuron, chlorsulfuron plus metsulfuron, diclofop, flufenacet plus metribuzin, flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron, metolachlor, and pendimethalin. Herbicide treatments were applied preemergence using a stationary spray table[9] equipped with a single TeeJet® 8001 EVS flat fan nozzle tip[10] positioned 30.5 cm above the trays and delivering 234 L/ha at 269 kPa. Percent visual control ratings were taken at 7, 14, 21, 28, and 35 days after treatment (DAT) in each experiment. Visible plant injury was rated from 0 (no injury) to 100 (plant death).

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[4] Barley 'Nomini', Southern States Cooperative, Inc. 16130 Goodes Bridge Road, Amelia Court House, VA 23002-0186.

[5] Wheat 'Roane 98F-ROA-VO93', Virginia Crop Improvement Association. VCIA Foundation Seed Farm. P.O. Box 78, Mt. Holly, VA 22524.

[6] Italian ryegrass (variety not stated). Southern States Cooperative, Inc. 885 Roanoke Street, Christiansburg, VA 24073-3195.

[7] Acetochlor, 0.768 kg a.i./L, emulsifiable concentrate (Surpass® EC). Dow AgroSciences, LLC.

[8] Acetochlor, 0.384 kg a.i./L, microencapsulated concentrate (TopNotch®). Dow AgroSciences, LLC.

[9] Stationary Track Sprayer. Allen Machine Works. 607 E. Miller Road, Midland, MI 48640.

[10] Spraying Systems Co. ®, P.O. Box 7900, Wheaton, IL 60189

Field Experiment. The field study was conducted in Amelia County, Virginia in a cooperator's field with an indigenous population of Italian ryegrass and Appling sandy loam (typic Hapludults) soil with 2.4% organic matter and pH 6.4. Previously, a greenhouse screening verified this particular Italian ryegrass biotype to be resistant to 16 times the normal use rate of diclofop (data not shown).

The first repetition of the field experiment was conducted in the 1998-1999 growing season. However, due to an uncharacteristically long period of drought in the fall of 1998, neither preemergence (PRE) nor delayed-preemergence (D-PRE) treatments received adequate moisture for activation. No treatment provided ryegrass control different than that observed in the control treatment. For this reason, data from this repetition of the field experiment will not be presented.

The second repetition of the field experiment was conducted in the 1999-2000 growing season. On October 14, 1999, the seedbed was conventionally tilled. Barley[11] was planted in 15-cm rows, 2.5-cm deep at the rate of 107.5 kg/ha.

One day after planting (DAP), PRE treatments were applied with a pressurized CO_2 backpack sprayer delivering 210 L/ha at 234 kPa using a 1.83-m wide hand-held boom with four 8003 VS flat fan nozzles[12]. Treatments included varying rates of acetochlor (EC and ME formulations), BAY MKH 6561[13], BAY MKH 6562[14], chlorsulfuron, chlorsulfuron plus metsulfuron, diclofop, flufenacet plus metribuzin, flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron, metolachlor, metribuzin, and pendimethalin. Treatments were applied to 3 m by 8 m-long plots arranged in a randomized complete block design with four replications per treatment. Two days after planting, the area received 1.3 cm of rainfall, followed by an additional 6 cm three days later. D-PRE treatments were identical to PRE treatments and were applied 12 DAP to 2.5-cm

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[11] Barley, 'Nomini', Southern States Cooperative, Inc. 16130 Goodes Bridge Road, Amelia Court House, VA 23002-0186.

[12] Spraying Systems Co.®, P. O. Box 7900, Wheaton, IL 60189.

[13] BAY MKH 6561 (proposed name, propoxycarbazone-sodium). Bayer CropScience LP.

[14] BAY MKH 6562 (proposed name, flucarbazone-sodium). Bayer CropScience LP.

barley and prior to ryegrass emergence. The treatment parameters were identical to those described above for PRE treatments. Five days after application of D-PRE treatments, the location received 0.8 cm of rainfall.

Italian ryegrass control was rated on a scale from 0 (no control) to 100 (plant death) at weekly intervals. Barley was fertilized with a split application of 22 kg/ha of nitrogen plus 45 kg/ha of phosphorus and 90 kg/ha potassium in the fall followed by an additional 90 kg/ha of nitrogen in late-March. At 28 weeks after treatment (WAT), barley was harvested by cutting a 0.9 m swath in the middle of each test plot. Collected plants from each plot were thrashed, and grain was cleaned and weighed. The Grain Analyzer GAC2000[15] was used to determine each sample's moisture and approximate density.

Statistical Analysis. The greenhouse experiment was repeated once and each treatment was replicated four times. Treatments in the field experiment were replicated four times. Experimental designs were randomized complete blocks with a factorial arrangement of treatments. Data were subjected to analysis of variance (ANOVA) using PROC-GLM in Statistical Analysis Systems® (SAS)[16] software. For each experiment, data variance was tested for homogeneity prior to analysis of variance by plotting residuals. Arcsine square-root transformation did not improve variance homogeneity for any experiment so actual data were used in each analysis. In the greenhouse experiment, sums of squares were partitioned in ANOVA to test for the effects of experiment repetition, herbicide treatment, and herbicide rate. Experiment repetition was considered a random variable, and fixed effects were tested by the means square associated with the interaction of the random variable (McIntosh, 1983). In the field experiment, sums of squares were partitioned in ANOVA to test for the effects of application timing, herbicide treatment, and herbicide rate. Fixed effects were separated using

[15] Grain Analyzer, GAC2000. GSF, Inc. 701 SW Ordnance Road, Ankeny, IA 50021.

[16] Statistical Analysis Systems (SAS) software, version 6.12. SAS Institute, Inc. P.O. Box 8000, SAS Circle, Cary, NC 27513.

Fischer's protected LSD ($\alpha = 0.05$). Where significant interactions were observed, mean separation was applied separately among levels of one factor within individual levels of the interacting factor.

RESULTS AND DISCUSSION

Data variance was tested for homogeneity prior to ANOVA, and the data were transformed to the arcsine of the square root, if needed, to stabilize variance. ANOVA indicated that data in the greenhouse experiment could not be combined over repetitions, and data are therefore presented separately for each repetition. Furthermore, the interaction of herbicide treatment and herbicide rate was significant for barley injury ($P = 0.0043$), wheat injury ($P < 0.0001$) and Italian ryegrass control ($P < 0.0001$). Therefore, data and associated mean separation comparisons are presented for each level of one factor within individual levels of the interacting factor.

In the field experiment, the interaction of treatment, rate, and application timing factors was significant for barley yield ($P < 0.0001$). For Italian ryegrass control, only the interaction of treatment and application timing factors was significant ($P < 0.0001$). Therefore, data for Italian ryegrass control were pooled over the herbicide rate factor. Data on response of barley to herbicide treatments was collected at a different date with respect to application timings, and thus are presented separately for each application timing.

Greenhouse Experiment. In the first repetition of the experiment, varying degrees of wheat and barley injury were observed (Table 3.1). Among all herbicide treatments applied at the low rate, the application of metolachlor was significantly more injurious to barley, resulting in 15% injury. The low rate of flufenacet plus metribuzin resulted in 5% injury to barley. No other low-rate treatment resulted in significant injury to barley. Wheat injury in the plots treated with low herbicide rates was minimal and did not differ among herbicide treatments.

In the flats treated with high herbicide rates, barley was most sensitive to metolachlor (24% injury), followed by flufenacet plus metribuzin (16% injury), flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron (10% injury), and chlorsulfuron (9% injury). Other treatments applied at the high rate did not cause significant barley injury. The high application rate of flufenacet plus metribuzin resulted in 33% injury to wheat, significantly greater than any other high-rate treatment in the first repetition of the greenhouse experiment.

In most treatments in the first repetition, no significant differences were observed in barley response to differences in herbicide rates. However, plots treated with the high application rate of flufenacet plus metribuzin exhibited greater injury to wheat than that observed in plots treated with the low application rate of flufenacet plus metribuzin, 33% and 0%, respectively.

In the second repetition of the greenhouse experiment barley and wheat response varied among herbicide treatments within each rate level (Table 3.1). Applied at low rates, chlorsulfuron plus metsulfuron was the most injurious treatment to barley, followed by the chlorsulfuron treatment, resulting in 29% and 14% barley injury, respectively. Other treatments applied at low rates did not differ significantly, causing injury of 8% or less. Similarly, applied at low rates, chlorsulfuron plus metsulfuron was the most injurious treatment to wheat, followed by the chlorsulfuron treatment, resulting in 6% and 3% injury, respectively.

Applied at the high rate in the second repetition, chlorsulfuron plus metsulfuron resulted in 24% barley injury, which was significantly higher than barley injury observed in any other treatment. High-rate treatments of chlorsulfuron plus metsulfuron and flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron resulted in significant barley injury, 13% and 11%, respectively. High-rate treatments of acetochlor (EC), acetochlor (ME), diclofop, and flufenacet plus metribuzin were comparatively safe on barley and did not cause injury in excess of 5%. Only pendimethalin application resulted in a significant difference in barley injury when compared across application rates, with injury increasing from 0% to 8% for low and high application rates, respectively.

On wheat, the high application rate of chlorsulfuron plus metsulfuron resulted in 8% injury to the crop in the second repetition, which was significantly higher than that observed in any other high-rate treatment. Adverse effects of chlorsulfuron plus metsulfuron on wheat and barley have been previously recorded (Bailey et al., 2001). Other high-rate treatments were safe on wheat and did not cause injury in excess of 4%. No significant differences were observed among application rates within individual herbicide treatments.

In both repetitions of the experiment, adequate Italian ryegrass control (>80%) was achieved with both formulations of acetochlor, flufenacet plus metribuzin, and flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron, and metolachlor (Table 3.2). Increasing the application rate of the above-mentioned compounds did not result in a significantly higher degree of the Italian ryegrass control. These results are consistent with those from field evaluations conducted by Bailey et al. (2002) and King and Hagood (2003).

Chlorsulfuron, chlorsulfuron plus metsulfuron, diclofop, and pendimethalin resulted in poor ryegrass control (Table 3.2). In the first repetition of the experiment, among this group of herbicides, pendimethalin efficacy in ryegrass control was higher than that observed in other treatments but did not exceed 6% and 30% control when pendimethalin was applied at low and high rate, respectively. The remaining treatments in the experiment did not result in any Italian ryegrass control.

In the second repetition of the experiment, the efficacy of chlorsulfuron and chlorsulfuron plus metsulfuron methyl for Italian ryegrass control increased to approximately 25% and was significantly higher than that observed in diclofop or pendimethalin treatments.

Field Experiment. At 14 WAT, the response of barley vigor to herbicide treatments was evaluated. The interaction of herbicide treatment and rate was significant ($P < 0.0001$) for barley injury at 14 weeks after treatments (Table 3.3). Mean comparisons between herbicide application timings were not conducted since barley injury evaluations were made at different times relative to the herbicide treatments. Acetochlor was most injurious to barley when applied at high rates or as an EC formulation. Barley injury greater than 30% was not considered commercially acceptable and occurred when barley was treated with BAY MKH 6561, chlorsulfuron, and chlorsulfuron plus metsulfuron, at either rate, or the high rates of acetochlor (EC), flufenacet plus metribuzin, and metribuzin. When applied D-PRE, only the high rate of flufenacet plus metribuzin and either rate of metribuzin injured barley in excess of 30%. Most herbicides did not injure barley appreciably when applied D-PRE at the low rates.

Due to absence of a significant effect of application rate, Italian ryegrass control data were pooled over rates and compared among treatments within each application timing (Table 3.4).

Among all treatments applied PRE, flufenacet plus metribuzin was the most efficacious treatment, resulting in 92% Italian ryegrass control. PRE treatments of acetochlor (EC), acetochlor (ME), flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron, metolachlor, and metribuzin were moderately effective, averaging 80, 77, 81, 80, and 82% Italian ryegrass control. Other PRE treatments were poor in Italian ryegrass control, with pendimethalin treatment being the least efficacious (18% ryegrass control).

Applying treatments D-PRE did not generally have a significant effect on herbicide efficacy in Italian ryegrass control within individual treatments relative to PRE application except for BAY MKH 6561 (15% increase) and metolachlor (21% decrease). Flufenacet plus metribuzin, flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron, and metolachlor were the most efficacious D-PRE treatments, exhibiting 92, 86, and 91% Italian ryegrass control, respectively. The acetochlor formulations were moderately effective, with 70% and 71% Italian ryegrass control for acetochlor (EC) and acetochlor (ME), respectively. Other D-PRE treatments resulted in Italian ryegrass control below commercially acceptable levels, with the pendimethalin D-PRE treatment being the least effective.

Applied PRE at the low rate, acetochlor (ME), flufenacet plus metribuzin, and diclofop resulted in the highest barley yields, 3199, 3128, and 2688 kg/ha, respectively (Table 3.5). Barley yields from plots treated with acetochlor (EC) and metolachlor, 2654 kg/ha and 2610 kg/ha, respectively, were significantly less than those harvested from plots treated with acetochlor (ME) but not flufenacet plus metribuzin or diclofop. Plots treated with chlorsulfuron plus metsulfuron, BAY MKH 6561, and BAY MKH 6562, yielded 643, 882, and 870 kg/ha of barley, respectively. These yields were among the lowest observed with PRE treatments applied at the low rate.

At the high rate, PRE treatment of flufenacet plus metribuzin resulted in approximately 3782 kg/ha of barley, highest of all high-rate PRE treatments in the experiment. Among all PRE treatments applied at the high rate, barley yields obtained from plots treated with BAY MKH 6561, chlorsulfuron plus metsulfuron, and chlorsulfuron, 526, 620, and 937 kg/ha, respectively, were the lowest. Increasing herbicide rate within the PRE application timing improved barley yields for metolachlor and BAY MKH 6562 treatments, from 2610 to 3019 kg/ha and from 870 to 1449 kg/ha, respectively. No significant difference in barley yield could be attributed to the increase in herbicide rate within any other herbicide treatment applied PRE.

Applied D-PRE at the low rate, the metribuzin treatment resulted in 3367 kg/ha of barley, the highest barley yield among all low-rate D-PRE treatments, with BAY MKH 6561 treatment being the lowest, yielding only 774 kg/ha. Barley yields in other D-PRE treatments applied at low rate were relatively similar. Among them, acetochlor (ME), acetochlor (EC), and flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron treatments had the highest barley yields, 2794, 2569, and 2448 kg/ha, respectively.

Increasing herbicide rate within the D-PRE application had a significant effect on barley yield for several treatments. Most notably, the increase in application rate of flufenacet plus metribuzin treatment resulted in 3360 kg/ha of barley, the highest barley yield among all high-rate D-PRE treatments.

Delaying application time significantly increased barley yield for low-rate BAY MKH 6562 treatments from 870 to 2166 kg/ha applied PRE and D-PRE, respectively (Table 3.6). A similar application timing effect was observed for the low-rate metribuzin treatment, where barley yield increased from 2221 to 3367 kg/ha, for PRE and D-PRE treatments, respectively. However, for low-rate treatments of flufenacet plus metribuzin and metolachlor the opposite trend was observed. With low-rate flufenacet plus metribuzin treatments, barley yield decreased from 3128 to 2161 kg/ha for PRE and D-PRE, respectively. For high-rate treatments, delay in application timing generally resulted in barley yield gains, most notably in the metribuzin treatment, where barley yield increased from 2516 to 3247 kg/ha for PRE and D-PRE application timings, respectively.

Barley yield was affected directly or indirectly by the herbicides treatments. PRE and D-PRE treatments of BAY MKH 6561 and PRE treatments of chlorsulfuron and chlorsulfuron plus metsulfuron resulted in significant barley injury (Table 3.3), which subsequently was reflected in the reduced barley yields compared to other treatments (Table 3.5). Overall, less injurious D-PRE treatments yielded more barley than PRE treatments that, in many cases, injured barley and reduced early vigor..

In conclusion, significant differences were observed in Italian ryegrass control and crop response to herbicide treatments. Application of flufenacet plus metribuzin consistently resulted in higher Italian ryegrass control and barley yields than other treatments in this study. While barley yields from plots treated with metolachlor and two acetochlor formulations were not statistically different from those from plots treated with flufenacet plus metribuzin, crop tolerance was of concern and Italian ryegrass control was slightly below commercially acceptable levels. Other treatments were generally either ineffective in ryegrass control or resulted in unacceptable levels of crop injury.

Even though the flufenacet plus metribuzin treatment appears the most promising preemergence treatment, continued research is needed on both postemergence and preemergence alternatives. Furthermore, as with other preemergence treatments, proper timing of application and activation of the herbicide in soil is critical. In part, results of this study were used to obtain a Section 18 registration for flufenacet plus metribuzin use in wheat in Virginia.

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SOURCES OF MATERIALS

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Acetochlor (TopNotch®). Dow AgroSciences LLC. 9330 Zionsville Road, Indianapolis, IN 46268.

BAY MKH 6561® (70 WDG formulation, propoxycarbazone-sodium). Bayer CropScience LP. P.O. Box 12014, 2 T.W. Alexander Drive, Research Triangle Park, NC 27709.

BAY MKH 6562® (70 WG formulation, flucarbazone-sodium). Bayer CropScience LP. P.O. Box 12014, 2 T.W. Alexander Drive, Research Triangle Park, NC 27709.

Chlorsulfuron (Glean® 75DF). DuPont Agricultural Products, 1007 Market St., Wilmington, DE 19898.

Chlorsulfuron plus metsulfuron (Finesse® 75DF). DuPont Agricultural Products, 1007 Market St., Wilmington, DE 19898.

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Table 3.1. Barley and wheat injury at 35 days after treatment in the greenhouse experiment as affected by herbicide treatment, herbicide rate[a], and repetition[b] of the experiment.

	Barley injury						Wheat injury					
	Rep. 1			Rep. 2			Rep. 1			Rep. 2		
Treatment	Low rate	High rate	LSD[c]	Low rate	High rate	LSD[c]	Low rate	High rate	LSD[c]	Low rate	High rate	LSD[c]
	----- (%) -----			----- (%) -----			----- (%) -----			----- (%) -----		
Acetochlor (EC)	0	1	NS	3	4	NS	0	1	NS	0	3	NS
Acetochlor (ME)	1	4	NS	4	3	NS	0	0	NS	0	4	NS
Chlorsulfuron	0	9	NS	14	13	NS	0	0	NS	3	0	NS
Chlorsulfuron plus metsulfuron	3	4	NS	29	24	NS	0	0	NS	6	8	NS
Diclofop	1	0	NS	3	4	NS	0	0	NS	0	1	NS
Flufenacet plus metribuzin	5	16	NS	1	5	NS	0	33	25	1	0	NS
Flufenacet plus metribuzin plus Chlorsulfuron plus metsulfuron	1	10	NS	8	11	NS	0	3	NS	1	3	NS

Metolachlor	15	24	NS	4	10	NS	1	3	NS	0	4	NS
Pendimethalin	1	1	NS	0	8	5	0	0	NS	0	3	NS
LSD[d]	4	9		4	5		1	8		2	3	

[a] Herbicide application rates (kg a.i./ ha) for low and high rates, respectively: acetochlor as 0.768 kg a.i./L, emulsifiable concentrate (EC) (0.56, 1.12); acetochlor as 0.384 kg a.i./L, microencapsulated concentrate (ME) (0.56, 1.12); chlorsulfuron (0.026, 0.05); chlorsulfuron plus metsulfuron (0.026, 0.05), diclofop (0.56, 1.12), flufenacet plus metribuzin (0.56, 1.12), flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron [0.56 + 0.026, 0.56 + 0.05], metolachlor (0.56, 1.12), and pendimethalin (0.56, 1.12).

[b] Homogeneity of variance analysis indicated that data could not be combined over repetition.

[c] Least significant difference (á = 0.05) for mean comparisons among herbicide rates within herbicide treatments.

[d] Least significant difference (á = 0.05) for mean comparisons among herbicide treatments within herbicide rates.

Table 3.2. Italian ryegrass control at 35 days after treatment in the greenhouse experiment as affected by herbicide treatment, herbicide rate[a], and repetition[b] of the experiment.

	Italian ryegrass control					
	Repetition 1			Repetition 2		
Treatment	Low rate	High rate	LSD[c]	Low rate	High rate	LSD[c]
	------- (%) -------			------- (%) -------		
Acetochlor (EC)	99	100	NS	98	100	NS
Acetochlor (ME)	100	100	NS	99	100	NS
Chlorsulfuron	0	0	NS	25	24	NS
Chlorsulfuron plus metsulfuron	0	0	NS	23	28	NS
Diclofop	0	3	NS	14	1	5
Flufenacet plus metribuzin	98	100	NS	99	98	NS
Flufenacet plus metribuzin plus Chlorsulfuron plus metsulfuron	95	98	NS	95	98	NS
Metolachlor	98	100	NS	91	84	NS
Pendimethalin	6	30	20	5	6	NS

LSD[d]	4	5		5	5

[a] Herbicide application rates (kg a.i./ ha) for low and high rates, respectively: acetochlor as 0.768 kg a.i./L, emulsifiable concentrate (EC) (0.56, 1.12); acetochlor as 0.384 kg a.i./L, microencapsulated concentrate (ME) (0.56, 1.12); chlorsulfuron (0.026, 0.05); chlorsulfuron plus metsulfuron (0.026, 0.05), diclofop (0.56, 1.12), flufenacet plus metribuzin (0.56, 1.12), flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron [0.56 + 0.026, 0.56 + 0.05], metolachlor (0.56, 1.12), and pendimethalin (0.56, 1.12).

[b] Homogeneity of variance analysis indicated that data could not be combined over repetition.

[c] Least significant difference (á = 0.05) for mean comparisons among herbicide rates within herbicide treatments.

[d] Least significant difference (á = 0.05) for mean comparisons among herbicide treatments within herbicide rates.

Table 3.3. Response of barley vigor to herbicide treatments at 14 weeks after treatment as affected by herbicide treatment, herbicide rate[a], and application timing[b], with statistical comparison of herbicide treatments and herbicide rates in the field experiment.

	Barley injury					
	PRE			D-PRE		
Treatment	Low rate	High rate	LSD[c]	Low rate	High rate	LSD[c]
	(%)					
Acetochlor (EC)	9	40	6	1	3	NS
Acetochlor (ME)	4	15	6	3	3	NS
BAY MKH 6561	39	51	6	25	28	NS
BAY MKH 6562	16	20	NS	9	9	NS
Chlorsulfuron	35	39	NS	9	16	NS
Chlorsulfuron plus metsulfuron	39	38	NS	9	25	8
Diclofop	5	9	NS	3	1	NS
Flufenacet plus metribuzin	15	36	6	11	38	8
Flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron	50	56	NS	26	28	NS

Metolachlor	8	16	6	4	4	NS
Metribuzin	18	50	6	34	79	8
Pendimethalin	3	4	NS	0	3	NS
LSD[d]	12	12		6		

[a] Herbicide application rates (kg a.i./ ha) for low and high rates, respectively: acetochlor as 0.768 kg a.i./L, emulsifiable concentrate (EC) (0.56, 1.12); acetochlor as 0.384 kg a.i./L, microencapsulated concentrate (ME) (0.56, 1.12); BAY MKH 6561 (0.03, 0.05); BAY MKH 6562 (0.03, 0.05) chlorsulfuron (0.026, 0.05); chlorsulfuron plus metsulfuron (0.026, 0.05), diclofop (0.56, 1.12), flufenacet plus metribuzin (0.56, 1.12), flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron [0.56 + 0.026, 0.56 + 0.05], metolachlor (0.56, 1.12), metribuzin (0.28, 0.56), and pendimethalin (0.56, 1.12).

[b] Denotes application timings, preemergence (PRE) and delayed-preemergence (D-PRE).

[c] Least significant difference (á = 0.05) for mean comparisons among herbicide rates within herbicide treatments for each application timing.

[d] Least significant difference (á = 0.05) for mean comparisons among herbicide treatments within herbicide rates for each application timing.

Table 3.4. Italian ryegrass control 28 weeks after treatment as affected by herbicide treatment and application timing[a] in the field experiment.

Treatment[b]	Italian ryegrass control		
	PRE[c]	D-PRE	LSD[d]
	---------- (%) ----------		
Acetochlor (EC)	80	70	NS
Acetochlor (ME)	77	71	NS
BAY MKH 6561	24	23	NS
BAY MKH 6562	27	42	6
Chlorsulfuron	34	36	NS
Chlorsulfuron plus metsulfuron	30	32	NS
Diclofop	32	31	NS
Flufenacet plus metribuzin	92	92	NS
Flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron	81	86	NS
Metolachlor	80	59	10
Metribuzin	82	91	NS

Pendimethalin	18	20	NS
LSD[e]	8	9	

[a] Denotes application timings, preemergence (PRE) and delayed-preemergence (D-PRE).

[b] Herbicide application rates (kg a.i./ ha) for low and high rates, respectively: acetochlor as 0.768 kg a.i./L, emulsifiable concentrate (EC) (0.56, 1.12); acetochlor as 0.384 kg a.i./L, microencapsulated concentrate (ME) (0.56, 1.12); BAY MKH 6561 (0.03, 0.05); BAY MKH 6562 (0.03, 0.05) chlorsulfuron (0.026, 0.05); chlorsulfuron plus metsulfuron (0.026, 0.05), diclofop (0.56, 1.12), flufenacet plus metribuzin (0.56, 1.12), flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron [0.56 + 0.026, 0.56 + 0.05], metolachlor (0.56, 1.12), metribuzin (0.28, 0.56), and pendimethalin (0.56, 1.12).

[c] Due to absence of significant effect of herbicide rates, data for Italian ryegrass control were pooled over herbicide rates within each application timing.

[d] Least significant difference (á = 0.05) for mean comparisons among application timings within herbicide treatments.

[e] Least significant difference (á = 0.05) for mean comparisons among herbicide treatments within application timings.

Table 3.5. Barley yield at 28 weeks after treatment as affected by herbicide treatment, herbicide rate[a], and application timing[b], with statistical comparison of herbicide treatments and herbicide rates in the field experiment.

	Barley yield					
	PRE			D-PRE		
Treatment	Low rate	High rate	LSD[c]	Low rate	High rate	LSD[c]
	(%)					
Acetochlor (EC)	2654	2493	NS	2569	2502	NS
Acetochlor (ME)	3199	2792	NS	2794	2827	NS
BAY MKH 6561	882	526	NS	774	1249	NS
BAY MKH 6562	870	1449	504	2166	2413	150
Chlorsulfuron	1187	937	NS	2038	1619	NS
Chlorsulfuron plus metsulfuron	643	620	NS	1242	1584	NS
Diclofop	2688	2586	NS	1640	2507	331
Flufenacet plus metribuzin	3128	3782	NS	2163	3360	418
Flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron	2120	2276	NS	2448	1743	NS

Metolachlor	2610	3019	245	1816	2638	133
Metribuzin	2220	2516	NS	3367	3247	NS
Pendimethalin	1590	2136	NS	1653	942	406
LSD[d]	519	371		383	491	

[a] Herbicide application rates (kg a.i./ ha) for low and high rates, respectively: acetochlor as 0.768 kg a.i./L, emulsifiable concentrate (EC) (0.56, 1.12); acetochlor as 0.384 kg a.i./L, microencapsulated concentrate (ME) (0.56, 1.12); BAY MKH 6561 (0.03, 0.05); BAY MKH 6562 (0.03, 0.05) chlorsulfuron (0.026, 0.05); chlorsulfuron plus metsulfuron (0.026, 0.05), diclofop (0.56, 1.12), flufenacet plus metribuzin (0.56, 1.12), flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron [0.56 + 0.026, 0.56 + 0.05], metolachlor (0.56, 1.12), metribuzin (0.28, 0.56), and pendimethalin (0.56, 1.12).

[b] Denotes application timings, preemergence (PRE) and delayed-preemergence (D-PRE).

[c] Least significant difference (á = 0.05) for mean comparisons among herbicide rates within herbicide treatments for each application timing.

[d] Least significant difference (á = 0.05) for mean comparisons among herbicide treatments within herbicide rates for each application timing.

Table 3.6. Barley yield at 28 weeks after treatment as affected by herbicide treatment, herbicide rate[a], and application timing[b], with statistical comparison of herbicide treatments and herbicide application timings in the field experiment.

Treatment	Barley yield					
	Low Rate			High Rate		
	PRE	D-PRE	LSD[c]	PRE	D-PRE	LSD[c]
	(%)					
Acetochlor (EC)	2654	2569	NS	2493	2502	NS
Acetochlor (ME)	3199	2794	NS	2792	2827	NS
BAY MKH 6561	882	774	NS	526	1250	387
BAY MKH 6562	870	2166	93	1449	2413	598
Chlorsulfuron	1187	2038	NS	937	1619	547
Chlorsulfuron plus metsulfuron	643	1242	494	620	1584	455
Diclofop	2688	1640	255	2586	2507	NS
Flufenacet plus metribuzin	3128	2161	964	3782	3360	NS
Flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron	2120	2448	NS	2276	1743	NS

Metolachlor	2610	1816	789	3019	2638	NS
Metribuzin	2221	3367	859	2516	3247	677
Pendimethalin	1590	1653	NS	2136	942	NS
LSD[d]	519	383		371	491	

[a] Herbicide application rates (kg a.i./ ha) for low and high rates, respectively: acetochlor as 0.768 kg a.i./L, emulsifiable concentrate (EC) (0.56, 1.12); acetochlor as 0.384 kg a.i./L, microencapsulated concentrate (ME) (0.56, 1.12); BAY MKH 6561 (0.03, 0.05); BAY MKH 6562 (0.03, 0.05) chlorsulfuron (0.026, 0.05); chlorsulfuron plus metsulfuron (0.026, 0.05), diclofop (0.56, 1.12), flufenacet plus metribuzin (0.56, 1.12), flufenacet plus metribuzin plus chlorsulfuron plus metsulfuron [0.56 + 0.026, 0.56 + 0.05], metolachlor (0.56, 1.12), metribuzin (0.28, 0.56), and pendimethalin (0.56, 1.12).

[b] Denotes application timings, preemergence (PRE) and delayed-preemergence (D-PRE).

[c] Least significant difference (á = 0.05) for mean comparisons among application timings within herbicide treatments and herbicide rates.

[d] Least significant difference (á = 0.05) for mean comparisons among herbicide treatments within herbicide rates and application timings.

Figure 3.1. Barley injury at eight weeks after treatment in plots where flufenacet plus metribuzin and chlorsulfuron plus metsulfuron were applied separately and in combination in the field experiment. A, plot treated with flufenacet plus metribuzin (1.12 kg a.i./ha); B, plot treated with chlorsulfuron plus metsulfuron (0.05 kg a.i./ha); C, plot treated with a combination of flufenacet plus metribuzin (0.56 kg a.i./ha) and chlorsulfuron plus metsulfuron (0.05 kg a.i./ha).