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Comparison of Herbicides for Control of Diclofop-Resistant Italian Ryegrass in Wheat

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Abstract: Diclofop-resistant Italian ryegrass (*Lolium perenne* L. ssp. *Multiflorum* (Lam.) Husnot) is a dominant weed problem in non-irrigated winter wheat (*Triticum aestivum* L.) in mid-south USA. Field studies were conducted from 2001 to 2007 to evaluate the efficacy of herbicides for diclofop-resistant ryegrass control and effect on wheat yield. In 2001 through 2004, chlorsulfuron/metsulfuron at 0.026 kg ha^{-1} preemergence (PRE) followed by (fb) mesosulfuron at 0.048 kg ha^{-1} at 4-leaf to 2-tiller ryegrass provided 89% control of diclofop-resistant Italian ryegrass, resulting in the highest wheat yield (3201 kg ha^{-1}). Flufenacet/metribuzin at 0.476 kg ha^{-1} applied at 1- to 2-leaf wheat had equivalent Italian ryegrass control (87%), but lesser yield (3013 kg ha^{-1}). In 2005–2006, best treatments for Italian ryegrass control were chlorsulfuron/metsulfuron, 0.013 kg ha^{-1} PRE fb mesosulfuron 0.015 kg ha^{-1} at 3- to 4-leaf ryegrass (92%); metribuzin, 0.280 kg ha^{-1} at 2- to 3- leaf wheat fb metribuzin at 2- to 3-tiller ryegrass (94%); chlorsulfuron/metsulfuron (0.026 kg ha^{-1}) (89%); and flufenacet/metribuzin at 1- to 2-leaf wheat (89%). Chlorsulfuron/metsulfuron fb mesosulfuron provided higher yield (3515 kg ha^{-1}) than all other treatments, except metribuzin fb metribuzin.

Keywords: flufenacet; metribuzin; chlorsulfuron; mesosulfuron; metsulfuron

1. Introduction

Herbicide-resistant (HR) weeds have been a prominent issue in commercial crop production for many years. The number of HR weeds has increased drastically since herbicides were commercialized for in-crop usage, possibly due to overreliance on herbicides, a low-dose selection from herbicide drift, incorrect application rates and timing [1], and persistent selection pressure across vast croplands. Currently, 471 weed species have been identified and documented as herbicide-resistant, making chemical weed control challenging in multiple cropping systems [2]. In Arkansas, USA, Italian ryegrass (*Lolium perenne* L. ssp. *multiflorum*) is one of the most common and problematic weed species in winter wheat (*Triticum aestivum* L.) [3,4]. Italian ryegrass is one of the 10 most troublesome weeds in wheat in ten of the 13 southern states of the USA [5]. Italian ryegrass has evolved resistance to three herbicide modes of action: acetyl-CoA carboxylase (ACCase) inhibitors, acetolactate synthesis (ALS) inhibitors, and 5-enolpyruvyl-shikimate-3-phosphate synthase (EPSPS) inhibitors in Arkansas [2]. ACCase-inhibiting herbicides are most commonly used for Italian ryegrass control. There are three chemical families in the ACCase-inhibiting herbicide group—the aryloxyphenoxypropionates (AOPP), cyclohexanediones (CHD), and phenylpyrazolins (PPZ).

Diclofop is an ACCase-inhibiting herbicide which is used for postemergence control of Italian ryegrass in wheat [6]. After years of repeated use, the first case of diclofop-resistant Italian ryegrass in the United States was reported in Oregon in 1987 [7–9]. Diclofop-resistant Italian ryegrass is the most problematic issue in wheat in Arkansas. Previous studies have reported that 10 Italian ryegrass plants m^{-2} reduced wheat yield by 4% [10], whereas wheat yield was reduced by 61% with 93 Italian ryegrass plants m^{-2} [11]. This high level of infestation is common in wheat fields.

Italian ryegrass can be controlled by alternating different herbicide modes of action. For example, Grey and Bridges [12] reported >80% control of Italian ryegrass at 151 d after planting with metribuzin, metribuzin + flufenacet, chlorsulfuron, or chlorsulfuron + metsulfuron. Recently, an ACCase-inhibiting herbicide in the PPZ family, pinoxaden (Axial®), has been used to control diclofop-resistant Italian ryegrass [13]. In a three-year study, Bararpour et al. [14] reported that pinoxaden applied to 1- to 2-tiller diclofop-resistant Italian ryegrass provided 65 to 68% and 45 to 49% control, at four and seven months after application, respectively. Although pinoxaden and diclofop have the same mode of action, pinoxaden binds differently to the catalytic site due to its significantly different chemical structure [15,16]. Hence, it is generally effective on diclofop-resistant Italian ryegrass. However, relying on pinoxaden to control diclofop-resistant Italian ryegrass may select for cross-resistance. Wheat producers can prolong the life of pinoxaden by using other herbicide modes of action on diclofop-resistant Italian ryegrass populations such as ALS- and microtubule assembly (MTA)-inhibiting herbicides. ALS-inhibiting herbicides such as mesosulfuron can control diclofop-resistant Italian ryegrass populations [17]. In addition to ALS-inhibiting herbicides, MTA-inhibiting herbicides such as pendimethalin, or very long chain fatty acid inhibitors such as pyroxasulfone can be used prior to a foliar herbicide application to increase control of Italian ryegrass in wheat [18–20]. Bararpour and Oliver [21] conducted a seven-year (2001–2007) study comparing wheat herbicides for diclofop-resistant Italian ryegrass and found that chlorsulfuron + metsulfuron (Finesse) followed by (fb) mesosulfuron (Osprey) was the best herbicide combination (96% control) in four years of study. However, metribuzin (Sencor) fb metribuzin provided 94% control in two years of study. In 2007, the greatest control (97%) was attained with flufenacet + metribuzin (Axiom) on seedling Italian ryegrass. Chlorsulfuron + metribuzin or a split application of metribuzin, and flufenacet + metribuzin can control diclofop-resistant Italian ryegrass. The ALS-inhibitor, mesosulfuron, provided 55 to 68% and 73 to 74% control of diclofop-resistant Italian ryegrass at four and seven months after application, respectively [14]. Mesosulfuron alone provided 24% higher control of diclofop-resistant Italian ryegrass than pinoxaden alone. Pinoxaden alone was not the best herbicide for diclofop-resistant Italian ryegrass. If pinoxaden is used, it will need to be split-applied and mixed with another herbicide such as metribuzin or flufenacet + metribuzin to control diclofop-resistant Italian ryegrass throughout the growing season [14].

Thus, diclofop-resistant Italian ryegrass in wheat cropping systems can be effectively controlled with the use of herbicides with different modes of action in each season. Relying on a single mode of action, such as an ACCase-inhibiting herbicide, can select for cross-resistance in diclofop-resistant Italian ryegrass. Therefore, the objective of our study was to evaluate the efficacy of herbicides available to Arkansas producers for control of diclofop-resistant Italian ryegrass in non-irrigated winter wheat.

2. Materials and Methods

Field studies were conducted for six years from 2001 to 2007 at the Agricultural Research and Extension Center in Fayetteville, Arkansas. The research was conducted on a silt loam soil with 21% sand, 70% silt, 9% clay, 0.5% organic matter, and a pH of 5.8. Wheat was planted in October- November and harvested in June or July (Table 1). Wheat cultivar Pioneer 2684 and Beretta 989 were used in

2001–2005 and 2006–2007, respectively. Wheat seeding rate was 112 kg ha^{-1} and row spacing was 18 cm. Wheat plots were fertilized with 23 kg P ha^{-1} and 56 kg K ha^{-1} prior to planting in October. The wheat plots also received 112 kg N ha^{-1} in early March.

Table 1. Wheat planting, emergence, and harvesting date from 2001 to 2007.

Year	Planting	Emergence	Harvest
2001–2002	22-October	1-November	20-June
2002–2003	23-October	2-November	16-June
2003–2004	20-October	25-October	18-June
2004–2005	21-October	26-October	28-June
2005–2006	28-October	5-November	7-June
2006–2007	24-October	3-November	25-June

The experiment was designed as a randomized complete block design with four replications. The research plot contained a uniform, natural infestation (±323 plants m^{-2}) of diclofop-resistant Italian ryegrass. The plot size was 6 m × 2 m. The herbicide treatments, their trade names and manufacturer information are listed in Table 2. The herbicide treatments, their application rate, and timing information are provided in Table 3. The PRE herbicide applications were applied at the time of wheat planting. A CO_2-pressurized backpack sprayer with four 8002 flat-fan nozzles (TeeJet Technologies, Springfield, IL, USA) mounted on a handheld boom calibrated to deliver 187 L ha^{-1} at 276 kPa was used. A non-treated control was also included to evaluate the effects of different herbicide treatments on wheat yield. Glyphosate at 0.84 kg ae ha^{-1} was broadcast-applied to the entire experimental area immediately after planting to burn down undesirable vegetation.

Italian ryegrass control and wheat yield were measured. Crop injury and weed control were scored on a scale of 0–100 (0 being no injury or weed control and 100 being complete crop death or weed control). The visual rating for weed control or crop injury were made based on the whole plot area in comparison to the non-treated control plot. Wheat yield was adjusted to 12% moisture content. No yield data was collected in 2007 due to frost and stripe rust (*Puccinia striiformis*) damage to wheat. Data from 2001 through 2004 and from 2005 through 2006 were analyzed separately because different herbicide treatments were used. Monthly total rainfall and average temperature data for Fayetteville, AR from 2001 to 2007 was obtained from National Weather Service-National Oceanic and Atmospheric Administration (NOAA) website [22] (https://www.weather.gov/tsa/climo_fyv_pcp_month). The Italian ryegrass control data from 2007 were analyzed separately because of the unusual weather event in that year. Data were analyzed by SAS Statistical Software v 9.3 using PROC GLM procedure. Means were separated using Fisher's Protected Least Significant Difference (LSD) at the $p < 0.05$ probability level. Our initial analysis showed no interactions between the years and treatments and therefore, data were pooled over years.

Table 2. Herbicide treatments, their trade names, and manufacturers, used in this study from 2001 to 2007.

Year	Herbicide Treatments (Common Names)	Trade Name	Manufacturer
2001–2004	Flufenacet/metribuzin	Axiom	Bayer CropScience, Research Triangle Park, North Carolina, USA
	Chlorsulfuron/metsulfuron	Finesse	DuPont, Wilmington, Delaware, USA
	Chlorsulfuron/metsulfuron fb † Mesosulfuron + MSO	Finesse fb Osprey	Dupont; Bayer CropScience
	Mesosulfuron + UAN ‡	Osprey	Bayer CropScience, Research Triangle Park, North Carolina, USA
	Mesosulfuron + MSO †† + UAN	Osprey	Bayer CropScience, Research Triangle Park, North Carolina, USA
	Metribuzin fb Metribuzin	Sencor fb Sencor	Bayer CropScience, Research Triangle Park, North Carolina, USA
2005–2007	Flufenacet/Metribuzin	Axiom	Bayer CropScience, Research Triangle Park, North Carolina, USA
	Chlorsulfuron/Metsulfuron	Finesse	DuPont, Wilmington, Delaware, USA
	Chlorsulfuron/Metsulfuron fb Mesosulfuron	Finesse fb Osprey	Dupont; Bayer CropScience
	Mesosulfuron	Osprey	Bayer CropScience, Research Triangle Park, North Carolina, USA
	Mesosulfuron fb Mesosulfuron	Osprey fb Osprey	Bayer CropScience, Research Triangle Park, North Carolina, USA
	Metribuzin fb Metribuzin	Sencor fb Sencor	Bayer CropScience, Research Triangle Park, North Carolina, USA

† fb means followed by; †† MSO is methylated seed oil applied at 1% v/v; ‡ UAN (Urea Ammonium Nitrate) is fertilizer additive applied at 1.25% v/v.

Table 3. Herbicide treatments, their application rate and application timing used in this study from 2001 to 2007.

Year	Herbicide Treatments	Application Rate (kg ai ha^{-1})	Application Timing
2001–2004	Flufenacet/metribuzin	0.476	1–2 leaf stage wheat
	Chlorsulfuron/metsulfuron	0.026	PRE †
	Chlorsulfuron/metsulfuron fb † Mesosulfuron + MSO	0.026 fb 0.048	PRE; 3–4 leaf ryegrass
	Mesosulfuron + UAN ‡	0.048	1- to 2-tiller ryegrass
	Mesosulfuron + MSO †† + UAN	0.048	1- to 2-tiller ryegrass
	Metribuzin fb Metribuzin	0.280 fb 0.280	2–3 leaf stage wheat; 2–3 tiller wheat
2005–2007	Flufenacet/Metribuzin	0.476	1–2 leaf stage wheat
	Chlorsulfuron/Metsulfuron	0.026	PRE
	Chlorsulfuron/Metsulfuron fb Mesosulfuron	0.013 fb 0.015	PRE; 3–4 leaf ryegrass
	Mesosulfuron	0.015	1- to 2-tiller ryegrass
	Mesosulfuron fb Mesosulfuron	0.008 fb 0.008	1–2-tiller ryegrass; 4-leaf to 2-tiller ryegrass
	Metribuzin fb Metribuzin	0.280 fb 0.280	2–3 leaf stage wheat; 2–3 tiller stage wheat

† Abbreviations: fb—followed by; PRE—Pre-emergence weed control herbicide application; †† MSO is methylated seed oil applied at 1% v/v; ‡ UAN (Urea Ammonium Nitrate) is fertilizer additive applied at 1.25% v/v.

3. Results

3.1. Weather Conditions during the Growing Seasons

The total annual rainfall during the years 2003, 2005, and 2007 was less than 1000 mm (Table 4). All other years had total annual rainfall of more than 1000 mm. The average annual temperature at the study site ranged from 13.7 °C to 15.1 °C.

3.2. 2001 through 2004

There was no wheat injury from any herbicide application. Mesosulfuron + UAN (65%) and Chlorsulfuron/metsulfuron (58%) had significantly lower Italian ryegrass control than all other herbicide treatments (82 to 89%) (Table 5). The highest control (89%) was attained with chlorsulfuron/metsulfuron followed by (fb) mesosulfuron + MSO, which resulted in the highest wheat yield (3201 kg ha^{-1}) compared to other treatments. The addition of MSO to mesosulfuron + UAN increased Italian ryegrass control by 20% compared to mesosulfuron+UAN (85 vs. 65%). Metribuzin (0.28 kg ha^{-1}) at 2- to 3- leaf wheat fb metribuzin at 2- to 3-tiller wheat; flufenacet/metribuzin (0.476 kg ha^{-1}) at 1- to 2-leaf wheat and mesosulfuron + MSO + UAN had similar ryegrass control as with chlorsulfuron/metsulfuron fb mesosulfuron + MSO. However, the wheat yields from mesosulfuron + MSO + UAN and metribuzin fb metribuzin were 439 and 565 kg ha^{-1} lower than that of chlorsulfuron/metsulfuron fb mesosulfuron + MSO, respectively (Figure 1). Higher control of Italian ryegrass with mesosulfuron + MSO + UAN and metribuzin fb metribuzin did not increase wheat yield relative to mesosulfuron + UAN or chlorsulfuron/metsulfuron. All herbicide treatments resulted in higher wheat yield compared to the non-treated control (Figure 1). The natural infestation of diclofop-resistant Italian ryegrass in this location reduced wheat yield 77% as compared to the highest yielding treatment.

3.3. 2005 and 2006

There was no wheat injury from any herbicide application. The best Italian ryegrass control was observed with metribuzin fb metribuzin (94%), which was comparable to the control with chlorsulfuron/metsulfuron (PRE) fb mesosulfuron at 3- to 4-leaf ryegrass, chlorsulfuron/metsulfuron; and flufenacet/metribuzin at 1- to 2-leaf wheat (Table 5). Significantly lower control of Italian ryegrass was provided by the mesosulfuron fb mesosulfuron (0.008 kg ha^{-1}) (81%) and mesosulfuron (0.015 kg ha^{-1}) (86%) which resulted in reduced wheat yields as compared to metribuzin fb metribuzin and chlorsulfuron/metsulfuron fb mesosulfuron. The highest wheat yield was obtained from chlorsulfuron/metsulfuron fb mesosulfuron; metribuzin fb metribuzin ranked second (Figure 2). Wheat yield from chlorsulfuron/metsulfuron fb mesosulfuron was 502, 502, 1004, 1036 and 2197 kg ha^{-1} higher than the flufenacet/metribuzin, chlorsulfuron/metsulfuron, mesosulfuron (0.015 kg ha^{-1}), mesosulfuron fb mesosulfuron (0.008 kg ha^{-1}) and non-treated control, respectively. The natural infestation of diclofop-resistant Italian ryegrass at this location in these years reduced wheat yield 63% as compared to the highest yielding treatment (chlorsulfuron/metsulfuron fb mesosulfuron).

3.4. 2007

Control of diclofop-resistant Italian ryegrass was best with flufenacet/metribuzin (97%) and chlorsulfuron/metsulfuron fb mesosulfuron (93%) (Figure 3). The control of Italian ryegrass did not differ between mesosulfuron, mesosulfuron fb mesosulfuron, metribuzin fb metribuzin and chlorsulfuron/metsulfuron treatments.

Table 4. Monthly total rainfall and average temperature at Fayetteville, AR from 2001 to 2007.

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual Total/Average
						Monthly Total Rainfall (mm)							
2001	61	162	15	45	179	131	73	34	138	156	95	123	1213
2002	91	25	141	155	126	89	53	168	35	67	18	127	1095
2003	3	74	54	35	201	99	56	94	76	92	108	77	972
2004	50	30	74	287	57	185	201	17	14	140	153	30	1239
2005	141	52	49	92	85	112	36	42	92	46	27	10	783
2006	45	17	92	103	97	52	41	189	183	82	184	52	1137
2007	117	52	18	80	113	107	80	65	66	118	9	65	890
						Monthly Average Temperature (°C)							
2001	0.7	5.4	6.5	16.8	18.4	22.3	26.4	25.8	19.4	13.5	11.4	4.6	14.3
2002	3.2	3.5	7.3	15.2	17.7	22.8	25.4	24.8	21.5	12.9	6.6	3.9	13.7
2003	0.9	2.3	8.8	14.3	18.5	20.9	25.4	26.0	18.7	15.1	10.1	4.2	13.8
2004	2.7	3.1	10.5	14.2	19.4	22.1	23.4	22.2	20.6	16.6	10.6	3.9	14.1
2005	5.3	6.7	7.8	13.7	17.7	23.5	25.3	26.6	23.4	15.1	10.2	2.4	14.8
2006	7.2	3.5	10.2	17.5	19.3	22.5	26.6	27.3	18.7	13.7	9.2	5.4	15.1
2007	1.2	3.3	13.4	11.7	19.7	23.0	24.4	27.1	21.7	16.5	9.6	4.3	14.7

Table 5. Italian ryegrass control as affected by herbicide treatments used from 2001 to 2006.

Year	Herbicide Treatments	Application Rate	Italian Ryegrass Control ‡
		kg ai ha^{-1}	%
2001–2004	Flufenacet/metribuzin	0.476	87 a
	Chlorsulfuron/metsulfuron	0.026	58 b
	Chlorsulfuron/metsulfuron fb † Mesosulfuron + MSO †	0.026 fb 0.048	89 a
	Mesosulfuron + UAN §	0.048	65 b
	Mesosulfuron + MSO § + UAN	0.048	85 a
	Metribuzin fb Metribuzin	0.280 fb 0.280	82 a
2005–2006	Flufenacet/Metribuzin	0.476	89 abc
	Chlorsulfuron/Metsulfuron	0.026	89 abc
	Chlorsulfuron/Metsulfuron fb Mesosulfuron	0.013 fb 0.015	92 ab
	Mesosulfuron	0.015	86 bc
	Mesosulfuron fb Mesosulfuron	0.008 fb 0.008	81 c
	Metribuzin fb Metribuzin	0.280 fb 0.280	94 a

† fb means followed by; § MSO is methylated seed oil applied at 1% v/v; § UAN (Urea Ammonium Nitrate) is fertilizer additive applied at 1.25% v/v; ‡ Values in the same column followed by the similar letter are not statistically different at $p \leq 0.05$. Means were compared separately for 2001–2004 and 2005–2006 data.

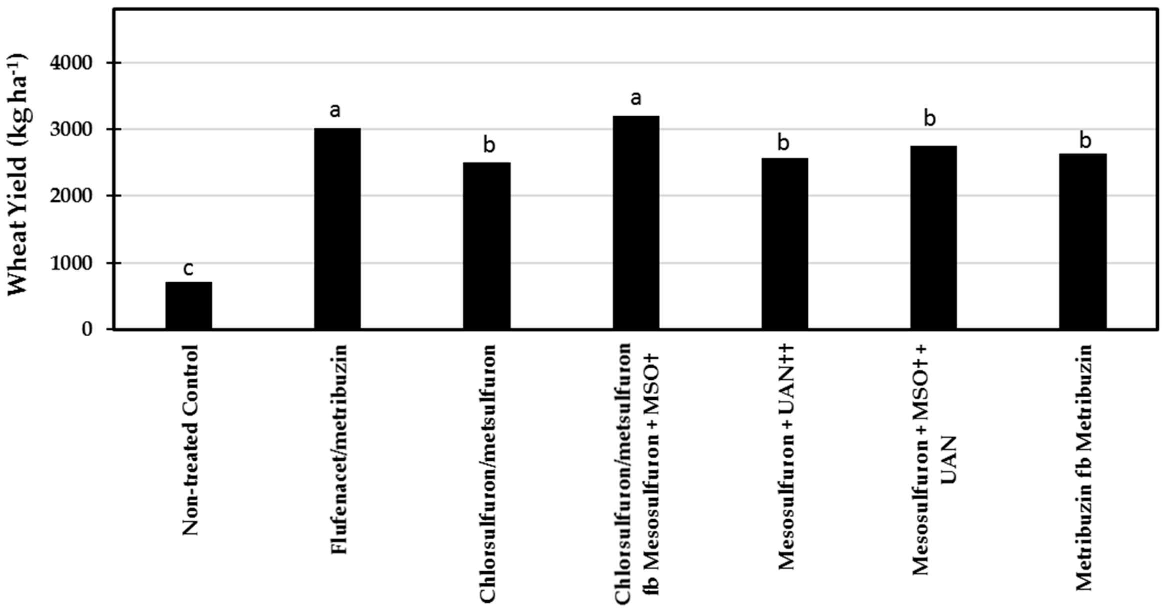

Figure 1. Wheat yield as affected by herbicide treatments used from 2001 to 2004. MSO is methylated seed oil applied at 1% v/v. UAN (Urea Ammonium Nitrate) is a fertilizer additive applied at 1.25% v/v. fb means followed by. A similar letter on bars indicate no statistical difference at $p \leq 0.05$.

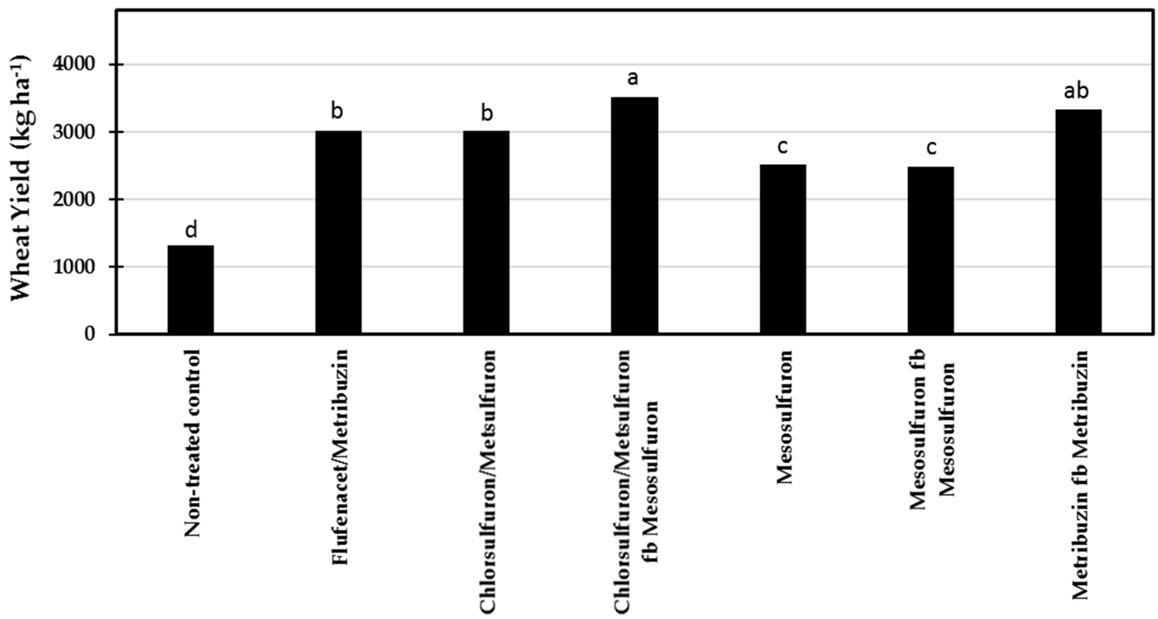

Figure 2. Wheat yield as affected by herbicide treatments in 2005–2006. Similar letter on bars indicates no statistical difference at $p \leq 0.05$. fb means followed by.

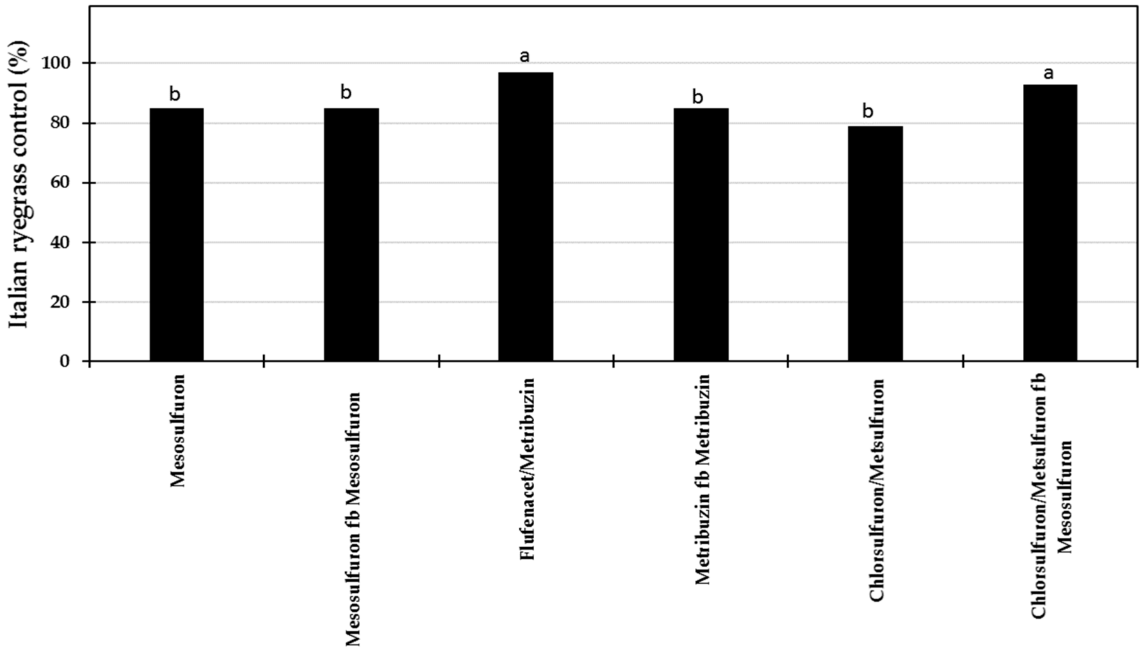

Figure 3. Italian ryegrass control as affected by the herbicide treatments in 2007. Similar letter on bars indicates no statistical difference at $p \leq 0.05$. fb means followed by.

4. Discussion

Across six years, flufenacet/metribuzin provided 87% or higher control of Italian ryegrass, which consequently increased wheat grain yields when compared to non-treated control. Flufenacet in the flufenacet/metribuzin herbicide mixture has residual herbicidal activity. Flufenacet inhibits the biosynthesis of very long chain fatty acids which are substrates for the formation of cuticular waxes and membrane phospholipids in plants [23]. Greater control of Italian ryegrass with flufenacet/metribuzin might have occurred due to its early application (1–2-leaf stage wheat) when weeds were small. Furthermore, the combination of these two modes of action ensures complete control of susceptible species and broadens the spectrum of control. The targets of these herbicides (metribuzin being a photosynthesis inhibitor) are enzymes in biochemical pathways that are critical for plant survival. Many studies have reported similar results with the use of flufenacet/metribuzin [12,16] for Italian ryegrass control. Ellis, Steckel, Main, De Melo, West and Mueller [16] reported 84 to 96% control of diclofop-resistant Italian ryegrass with flufenacet + metribuzin in Tennessee. Grey and Bridges [12] also reported 80% or higher control of Italian ryegrass with flufenacet plus metribuzin PRE at all rates including 0.304 + 0.76, 0.344 + 0.86, and 0.376 + 0.94 kg ha^{-1}. The performance of flufenacet plus metribuzin could vary widely, depending on environmental conditions. During the dry fall season, ryegrass control could be poor due to lack of herbicide activation. In Tennessee, flufenacet + metribuzin application at two- to three-leaf wheat stage resulted in 55% and 97% Italian ryegrass control in 1999 and 2000, respectively, which contributed to the highest wheat yield obtained compare to the other herbicide treatments used in their study [12].

Italian ryegrass control by metribuzin fb metribuzin ranged from 79% in 2007 to 94% in 2005–2006. Metribuzin fb metribuzin effect on wheat yield also varied between years. About 82% control of Italian ryegrass from 2001 to 2004 did not increase wheat yield significantly relative to other herbicide treatments. Metribuzin has been reported to cause injury to wheat. Tolerance to metribuzin differs significantly among varieties. Grey and Bridges [12] reported that wheat yields were reduced because of injury to wheat by metribuzin, irrespective of application timing and rates.

Chlorsulfuron/metsulfuron mixture provided lower control (<85%) in 2001 to 2004 and in 2007, but higher control (89%) in 2005–2006. Bond, Stephenson IV, Barnes, Bararpour and Oliver [7] also reported 89% Italian ryegrass control 30 d after wheat emergence with chlorsulfuron/metsulfuron mixture applied PRE. Ryegrass control with this mixture increased to >90% at 49 d after wheat emergence. Lower Italian ryegrass control results in greater competition with wheat plants and consequently, reduced wheat yield. Injury from chlorsulfuron/metsulfuron might also be responsible for lower wheat yields with this treatment. Grey and Bridges [12] reported 28% and 10% wheat injury with chlorsulfuron/metsulfuron mixture at 54 and 151 d after planting, respectively, whereas less than 5% injury was reported by Bond, Stephenson IV, Barnes, Bararpour and Oliver [7]. Mesosulfuron application at 3–4 leaf stage ryegrass after PRE application of chlorsulfuron/metsulfuron increased Italian ryegrass control and wheat yield when compared to the application of chlorsulfuron/metsulfuron alone, due to the control of Italian ryegrass that emerged after the loss of residual activity of PRE application of chlorsulfuron/metsulfuron.

The addition of sprayable nitrogen (N) and adjuvants often improves herbicide efficacy [24]. Mesosulfuron can be applied with MSO or with non-ionic surfactants + N fertilizer. In our study, the use of UAN (urea ammonium nitrate) with mesosulfuron only provided 65% control of Italian ryegrass. Grey et al. [24] reported that use of MSO and UAN with mesosulfuron provided maximum and most consistent Italian ryegrass control which indicated that a nitrogen additive is needed to increase uptake and translocation of mesosulfuron. In the same study, Italian ryegrass control varied from 44 to 97% when UAN was used with mesosulfuron due to unfavorable environmental conditions. The use of MSO with mesosulfuron in 2001 to 2004 increased Italian ryegrass control when compared to mesosulfuron alone, but it did not increase yield significantly. The MSO is a kind of fatty acid obtained from seed oil esterified with methyl alcohol [25]. Oil-based adjuvants enhance herbicide efficacy by spreading the spray droplets more on leaf surfaces and increasing herbicide penetration into the leaf cuticle [26]. The MSO can increase the wetted areas of droplets on both waxy and hairy leaves by decreasing the surface tension and contact angle [27,28].

5. Conclusions

In Arkansas, diclofop-resistant Italian ryegrass is a major weed problem in wheat. The natural infestation of Arkansas diclofop-resistant Italian ryegrass interference reduced wheat yield an average of 70% over the 6 years. The use of MSO with mesosulfuron + UAN increased Italian ryegrass control compared to mesosulfuron + UAN alone. Mesosulfuron + MSO application after preemergence application of chlorsulfuron/metsulfuron improves Italian ryegrass control compared to chlorsulfuron/metsulfuron applied alone. This indicates that split application of different herbicides might be necessary to provide season-long control of Italian ryegrass. In Arkansas, USA, flufenacet/metribuzin (87–97% control) at 1–2 leaf stage of wheat and chlorsulfuron/metsulfuron (PRE) followed by mesosulfuron at 3–4-leaf ryegrass (89–93% control) are the most effective options for controlling diclofop-resistant Italian ryegrass in wheat.

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