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Impact of Acetochlor Rate and Application Timing on Multiple-Herbicide-Resistant Waterhemp Control in Corn and Soybean

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Abstract

Documented 6-way (Groups 2, 4, 5, 9, 14, and 27) and 5-way (Groups 2, 5, 9, 14, and 27) multiple-herbicide-resistant (MHR) waterhemp have been confirmed in the US and Canada, respectively causing corn and soybean yield losses > 70%. The objective of this study was to determine the effect of acetochlor application timing and rate on non-emerged MHR waterhemp control in corn and soybean. Acetochlor is not yet registered in Canada, but it could be useful component of an integrated MHR waterhemp control program. Two studies, one in corn and one in soybean, were conducted in southwestern Ontario, Canada from 2020 to 2022. Three rates of acetochlor were applied preplant (PP), preemergence (PRE) and postemergence (POST) to non-emerged waterhemp. In corn, acetochlor [Emulsifiable Concentrate (EC)] applied at 1,225, 2,100 and 2,950 g ai ha^{-1} controlled MHR waterhemp 81, 85, and 90%, respectively, at 8 weeks after POST application (WAC). Acetochlor EC applied POST or PRE provided better control than when applied PP at 4, 8, and 12 WAC. In soybean, acetochlor [Capsule suspension (CS)] applied at 1,050, 1,375, and 1,700 g ai ha^{-1} controlled MHR waterhemp 63, 70, and 74%, respectively, at 8 WAC. The timing of acetochlor CS application did not affect MHR waterhemp control. Acetochlor applied at the low, medium, and high rate reduced waterhemp density by 87, 89, and 92% in corn, and by 82, 84, and 87% in soybean, respectively. The high rate of acetochlor provides acceptable control of MHR waterhemp in corn; control in soybean was inadequate.

Keywords: acetochlor, application timing, glyphosate-resistance, multiple-herbicide-resistant, waterhemp, *Amaranthus tuberculatus* (Moq.) J. D. Sauer

1. Introduction

Waterhemp (*Amaranthus tuberculatus* (Moq.) J.D. Sauer) is a summer annual, broadleaf weed found throughout North America; it can cause substantial yield losses in corn and soybean (Costea et al., 2005; Nordby et al., 2007). Waterhemp needs to be managed with a diversified integrated control program. One component of a waterhemp control program is the judicious use of efficacious herbicides applied at the optimal rate and application timing (Sarangi et al., 2017).

Waterhemp is one of the most competitive species in the Amaranthaceae family that includes redroot pigweed (*Amaranthus retroflexus* L.) and Palmer amaranth (*Amaranthus palmeri* S. Watson) (Sellers et al., 2003). Waterhemp is a fast growing, aggressive, C4 species that can grow up to 4 m in height in warm, moist conditions (Costea et al., 2005; Nordby et al., 2007). In conventional tilled fields in Ontario, Schryver et al. (2017) documented that waterhemp begins emerging in May and continues to emerge until late October; emergence is highest during the month of June (Vyn et al., 2006). Waterhemp seed production occurs via outcrossing among male plants that produce pollen, and female plants that produce small, round, black seeds (Bell & Tranel, 2010; Government of Canada, 2017). Pollen travels predominantly by wind and pollinates female plants that are nearby; this cross pollination allows for remarkable genetic diversity among genotypes (Bell & Tranel, 2010; Liu et al., 2012). Waterhemp has high fecundity; a single plant has been reported to produce up to 4.8 million seeds, demonstrating how rapidly waterhemp can become the predominant weed species after it invades a new area (Hartzler et al., 2004).

The wide genetic diversity in waterhemp has resulted in the evolution of resistance to a number of herbicide modes of action. The first herbicide-resistant population of waterhemp was identified in Iowa and Illinois in 1993; both populations were resistant to the acetolactate synthase (ALS) inhibiting herbicides (WSSA Group 2). In the years since, waterhemp has evolved resistance to seven modes of action in the US. Currently, waterhemp biotypes have evolved resistance to the ALS-inhibitors, synthetic auxins (WSSA Group 4), photosystem II (PSII)-inhibitors (WSSA Group 5), 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS)-inhibitors (WSSA Group 9), protoporphyrinogen oxidase (PPO)-inhibitors (WSSA Group 14), very long-chain fatty acid elongases (VLCFAE)-inhibitors (WSSA Group 15), and the 4-hydroxyphenylpyruvate dioxygenase (HPPD)-inhibitors (WSSA Group 27) (Heap 2022). One population in Missouri, US has evolved resistance to WSSA Groups 2, 4, 5, 9, 14, and 27 referred to as multiple-herbicide-resistant (MHR) waterhemp (Shergill et al., 2018). The problem of MHR waterhemp is not limited to the US. In Ontario, Canada, 5-way resistance to the Groups 2, 5, 9, 14, and 27 herbicides has been confirmed in seven counties, with 2, 3, and 4-way resistance to a combination of the aforementioned herbicide Groups in 11 other counties (Heap, 2022; Symington et al., 2022).

Acetochlor is a soil-applied, residual, chloroacetanilide herbicide that belongs to WSSA Group 15 herbicides (Shaner, 2014). It is a VLCFAE-inhibitor that prevents the addition of a carboxyl group to a fatty acid in the endoplastic reticulum, characterizing it as a cell growth disruptor (Shaner, 2014). The 18:1 oleic acid is the hypothesized target site of acetochlor (Boger, 1997; Wu et al., 1999). Registered by the US Environmental Protection Agency (EPA) in 1994, acetochlor is widely used in US corn, soybean, and cotton production applied preplant (PP), preplant incorporated (PPI), preemergence (PRE), or early postemergence (ePOST) (Anonymous, 2020a, 2020b; Cahoon et al., 2015; Murschell & Farmer, 2019). In 2018, in US corn and soybean production, acetochlor was the 3rd and 6th most used herbicide with 17.2 and 2.3 million kilograms, respectively (NASS, 2019). Acetochlor provides control of many non-emerged small-seeded annual grass and select small-seeded broadleaf weeds; it does not control emerged weeds (Anonymous, 2020a, 2020b; Jhala et al., 2015). The weed control efficacy of acetochlor is influenced by application rate and timing. Jhala et al. (2015) found that waterhemp control with acetochlor was greater when applied PRE as opposed to two weeks before planting; a higher herbicide rate did not increase control. Nagy (2008) investigated acetochlor applied at 1,600 and 2,000 g ai ha^{-1} for the control of barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.) and concluded that control was more consistent when applied at the high rate. Another study that evaluated application timing of Group 15 herbicides found 98% control of giant foxtail (*Setaria faberi* Herrm) when herbicides were applied PRE; control declined to 96, 90, and 85% when applications were made PPI, 30 days before planting, and 60 days before planting, respectively (Parker et al., 2005). Furthermore, the formulation of acetochlor can influence crop safety and weed control efficacy. Fogleman et al. (2018) found 48% injury to rice at 2 WAA from the EC formulation, while injury from the CS formulation was only 22%. The CS formulation is a polymer coated product that slowly releases acetochlor over time which provides longer residual weed control and improved crop safety (Cahoon et al., 2015; Fogleman et al., 2018; Li et al., 2008; Rao, 2000). However, other studies have found little to no differences among acetochlor formulations (Ferebee et al., 2019; Jursik et al., 2015).

Corn and soybean are two of the most important crops grown in the US and Ontario, Canada. The US produced 32% of the global corn crop (USDA, 2022), greater than any other country, in 2020, with a value of just over $61 billion (USD) (USDA, 2021a). Canada is the 11th largest producer of corn (USDA, 2022) with Ontario producing 62% of the country's corn crop (StatsCan, 2015). In 2019, over 850,000 ha of grain corn was harvested in Ontario which made it the highest value row-crop crop in the province with a total value of over $1.8 billion (CAD) (OMAFRA, 2021). In 2020, over $46 billion worth of soybean was produced in the US on 33 million hectares of land (USDA, 2021a, 2021b). In Ontario, just under 1.3 million hectares of soybean were grown in 2020, accounting for 61% of Canadian production (Soy Canada, 2021). Corn and soybean are very sensitive to weed interference and yields can be reduced substantially when they are not controlled (Soltani et al., 2016, 2017, 2019; Steckel & Sprague, 2004; Vyn et al., 2007). When no control tactics are implemented, waterhemp interference can cause corn and soybean yield losses of up to 73 and 74%, respectively (Steckel & Sprague, 2004; Vyn et al., 2007).

Given the rapid geographical spread of MHR waterhemp in the US and Ontario, Canada, it is crucial that effective means of control are developed. The impact of acetochlor rate and application timing on waterhemp control has not been investigated in Ontario. The objective of this study was to determine the effect of acetochlor application timing and rate on MHR waterhemp control.

2. Materials and Methods

Eight corn and soybean field trials were conducted during three years from 2020 to 2022. In 2020, trials were conducted near Cottam, ON (42.149046°N, -82.683986°W), on Walpole Island, ON (42.561915°N, -82.502111°W), and near Port Crewe, ON (42.192390°N, -82.215453°W). In 2021, trials were conducted near Cottam and Newbury, ON (42.690833°N, -81.822589°W). In 2022, trials were performed near Cottam, Newbury (42.727962°N, -81.822588°W), and on Walpole Island. All sites were naturally infested with MHR waterhemp resistant to the Group 2, 5, 9, 14, and 27 herbicides. Soil characteristics are presented in Table 1 for each site-year.

Table 1. Year, location and soil characteristics for eight field trials conducted in southwestern Ontario, Canada in 2020, 2021 and 2022

Year	Location	Soil texture	Sand	Silt	Clay	OM	pH	CEC
			------------------------- % -------------------------					
2020	Cottam	Sandy loam	70	19	11	2.6	5.9	7.5
2020	Walpole Island	Sandy loam	76	15	9	2.5	7.8	12.7
2020	Port Crewe	Clay loam	24	37	39	3.8	6.6	15.5
2021	Cottam	Sandy loam	62	23	15	2.3	5.9	7.7
2021	Newbury	Loamy sand	79	14	6	2.8	6.5	7.9
2022	Cottam	Sandy loam	55	27	17	2.2	5.7	9.1
2022	Newbury	Loamy sand	84	11	4	2.5	6.7	11.6
2022	Walpole Island	Sandy loam	65	24	11	2.1	7.1	14.9

Note. Abbreviations: OM, organic matter; CEC, cation exchange capacity.

[a] Soil analysis performed by A&L Canada Laboratories Inc. (2136 Jetstream Road, London, Ontario, Canada, N5V 3P5) from 15 cm deep soil cores.

Seedbed preparation began in the fall with vertical tillage and was completed in the spring with a tandem disc and cultivator. Corn was planted at approximately 83,000 seeds ha^{-1} in rows spaced 75 cm apart to a depth of approximately 4 cm. Corn hybrids DKC42-60RIB®, DKC39-97RIB®, and DKC46-82RIB® (Bayer CropScience Canada Inc., 160 Quarry Boulevard SE, Calgary, Alberta, Canada, T2C 3G3) were planted at each site in 2020, 2021, and 2022, respectively; all corn hybrids were glyphosate-resistant. Enlist E3™ soybean cultivars resistant to glyphosate, glufosinate, and 2,4-D choline were planted in the soybean trials. The soybean cultivar B161ME™ was planted in 2020, and B061FE™ (Brevant, Corteva Agriscience Canada, Calgary, Alberta, Canada, T2P 1M4) was planted in 2021 and 2022. Soybean was planted approximately 3.75 cm deep in 75 cm-spaced rows at a density of approximately 400,000 seeds ha^{-1}. Each plot measured 8 m long and 2.25 m wide (3 rows wide). Each study was established as a three by four factorial with four replicates. Three levels of application timing were evaluated: preplant (PP), 14 days after the PP application (preemergence, PRE) and 14 days after the PRE application (postemergence, POST). Four rates of acetochlor were evaluated. Rates in corn included a nontreated control, 1,225, 2,100, and 2,950 g ai ha^{-1} of acetochlor (Anonymous 2020a; Harness ®, EC, Bayer CropScience, St. Louis, Missouri). In soybean, the four rates of acetochlor (Anonymous 2020b; Warrant®, CS, Bayer CropScience, St. Louis, Missouri) evaluated were a nontreated control, 1,050, 1,375, and 1,700 g ai ha^{-1}. Emerged waterhemp at the time of treatment application was controlled with glufosinate (Liberty® 200 SN, BASF Canada, Mississauga, ON) applied at 500 g ai ha^{-1}. All herbicide treatments were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 200 L ha^{-1} of spray solution at a pressure of 240 kPa. A four-nozzle boom equipped with ultra-low-drift (ULD 120-02, Hypro, Pentair Ltd., London, UK) nozzles spaced 50 cm apart was used for herbicide application producing a 2 m spray width.

Assessments of visible corn and soybean injury were performed on a percent scale from 0 to 100 (0—no crop injury, 100—complete plant death). Visible crop injury in the PP and PRE-treated plots was assessed two weeks after the PRE application. Crop injury in the POST-treated plots was evaluated two weeks after the POST application. Visible MHR waterhemp control was evaluated on a 0 to 100 percent scale as an estimate of the MHR biomass reduction relative to the nontreated control in each replicate (0—no control, 100—complete control). Control was first assessed two weeks after the PP, PRE, and POST applications, respectively, with subsequent assessments taking place at 4, 8, and 12 weeks after the POST application (WAC). At 8 WAC, MHR waterhemp density and biomass were determined. A 0.25 m^2 quadrat was arbitrarily placed between the two center crop rows at two different locations within each plot and the number of waterhemp within each quadrat were summed to calculate waterhemp density. Then all waterhemp plants within each quadrat were cut at the soil surface, placed into paper bags, and dried to a constant moisture at which time biomass was weighed. At harvest maturity, two corn rows, or two soybean rows, were combined with a small-plot research combine; weight and moisture were recorded. Prior to data analysis, all yields were adjusted to 15.5% standard moisture for corn, and 13.5% standard moisture for soybean. At both sites in 2021, waterhemp was not removed prior to the PRE treatment applications, so only the assessments of crop injury were included in the statistical analysis; all waterhemp data from this treatment was removed prior to analysis.

2.1 Statistical Analysis

Corn and soybean study analyses were conducted separately. Crop injury and yield, waterhemp control, density, and shoot biomass data were analyzed using a generalized linear mixed model variance analysis in SAS v. 9.4 (SAS Institute Inc., Cary, NC). Acetochlor application timing, acetochlor rate, and their interaction were identified as the fixed effects. The random effects included the environment (site-year), block within the environment, and the interaction of environment on application timing and rate. The significance of fixed effects was determined with an F-test, while the Z-test evaluated the significance of random effects. A minimum statistical significance level of $\alpha = 0.05$ was used. All data were pooled for analysis. The Shapiro-Wilk test statistic and studentized residual plots were used to confirm that assumptions were met of normality, that the residuals were random, independent, homogenous, have a mean of zero, and were normally distributed. The nontreated control was not included for analysis of crop injury or waterhemp control. Corn and soybean yield and MHR waterhemp control data did not require a transformation to normalize data. Corn and soybean injury data was transformed using the arcsine square root transformation. Waterhemp density and shoot biomass followed a lognormal distribution. The lognormal and arc sine square root transformations were both back-transformed for the presentation of results.

3. Results and Discussion

3.1 Corn Study (Acetochlor EC Formulation)

At 2 WAA, acetochlor caused < 1% corn injury (data not presented). In contrast, Armel et al. (2003) reported that acetochlor plus mesotrione caused 10-20% corn injury when excessive rainfall fell within 7 days of application, though injury in that study was likely due to mesotrione. Acetochlor EC is safened with furilazole thus making it safer from a crop tolerance standpoint and explaining why very little corn injury was observed.

No significant interactions between acetochlor application timing and rate were detected for control of non-emerged MHR waterhemp at 2 WAA and 4, 8, and 12 WAC so the main effects are presented (Table 2). At 2 WAA, there was no effect of acetochlor application timing or rate on MHR waterhemp control. At 4, 8, and 12 WAC, acetochlor applied PP, PRE or POST controlled MHR waterhemp 78 to 87%, 87 to 91%, and 90 to 93%, respectively. Acetochlor applied PRE or POST controlled MHR greater than acetochlor applied PP; acetochlor PRE and POST provided similar waterhemp control (Table 2). Parker et al. (2005) evaluated weed control efficacy with various WSSA Group 15 herbicides including metolachlor, *S*-metolachlor, flufenacet plus metribuzin, and three formulations of acetochlor applied at 60 and 30 days before planting, PPI, and PRE; the Group 15 herbicides applied PRE provided highest weed control. At 4 WAC, acetochlor applied at 1,225, 2,100 and 2,950 g ai ha^{-1} controlled MHR waterhemp 87, 91, and 93%, respectively; the medium and high rates provided greater control of waterhemp than the low rate. At 8 WAC, the high rate of acetochlor provided better waterhemp control than the medium or low rate; control was 5 and 9% greater than the medium and low rates, respectively. At 12 WAC, acetochlor at the low, medium, and high rate controlled MHR waterhemp 80, 85, and 89%, respectively; the high rate provided better control than the low rate while the medium rate provided intermediate control and was similar to both (Table 2). Nagy (2008) also reported more consistent and higher weed control when acetochlor was applied at the high rate of 2,000 g ai ha^{-1} compared to the lower rate of 1,600 g ai ha^{-1}. It was also reported that the high rate of acetochlor was less reliant on an activating rainfall to provide acceptable control (Nagy, 2008).

Table 2. Main effects and interaction for multiple-herbicide-resistant (MHR) waterhemp control 2 WAA and 4, 8, and 12 WAC, density and biomass of MHR waterhemp, and corn yield as affected by acetochlor (EC formulation) application timing and rate across eight field trials conducted in southwestern Ontario, Canada in 2020, 2021, and 2022

Main effects	MHR waterhemp control in corn				Density	Biomass	Yield
	2 WAA	4 WAC	8 WAC	12 WAC			
	--------------------------- % ---------------------------				plants m^{-2}	g m^{-2}	t ha^{-1}
Application timing	NS	**	**	**	**	**	NS
PP	87	87 b	79 b	78 b	76 b	61 b	8.6
PRE	98	91 a	87 a	87 a	59 b	30 b	8.6
POST	82	93 a	90 a	90 a	36 a	19 a	9.0
SE	2	2	2	2	10	6	0
Herbicide rate (g ai ha^{-1})	NS	**	**	**	**	**	**
None	0	0	0	0	301 b	226 b	7.7 b
1,225	86	87 b	81 b	80 b	39 a	24 a	8.9 a
2,100	90	91 a	85 b	85 ab	33 a	18 a	8.9 a
2,950	92	93 a	90 a	89 a	25 a	13 a	9.3 a
SE	2	2	2	2	10	6	0
Timing × rate	NS	NS	NS	NS	NS	NS	NS

Note. Abbreviations: PP, preplant; PRE, preemergence; POST, postemergence; SE, standard error of the mean.

a-c Within each main effect, means followed by the same letter (a-c) within a column are not significantly different according to Tukey-Kramer Grouping at $p < 0.05$.

* and ** denote significance at $p < 0.05$ and 0.01, respectively; NS, not significant at $p < 0.05$.

There was no interaction between acetochlor application timing and rate for MHR waterhemp density and biomass so the main effects are presented (Table 2). Acetochlor applied PP, PRE, or POST had waterhemp densities of 76, 59, and 36 plants m^{-2}, respectively; there were fewer waterhemp with acetochlor applied POST than PRE or PP. The POST application of acetochlor also reduced waterhemp biomass greater than the PRE or PP treatments. As the acetochlor application timing was delayed there was improved MHR control later in the growing season: however, this only occurs if there is no waterhemp present at the time of the POST application. Relative to the control, the three rates of acetochlor reduced waterhemp density 87 to 92% and biomass 90 to 94%; there was no difference among the three acetochlor rates evaluated (Table 2).

The interaction of acetochlor application timing and herbicide rate was not significant for corn yield, so the main effects are presented (Table 2). There was no effect of acetochlor application timing on corn yield. Reduced MHR waterhemp interference with acetochlor applied at 1,225, 2,100 and 2,950 g ai ha^{-1} resulted in an increase in corn yield of 15, 16, and 20%, respectively; there was no difference in corn yield among the three rates of acetochlor. Janak and Grichar (2016) observed a numerical but non-significant increase in corn yield from the application of acetochlor; however, the rate applied was 2X the label rate (3,800 g ai ha^{-1}).

3.2 Soybean Study (Acetochlor CS Formulation)

Acetochlor caused less than < 2% soybean injury regardless of timing or rate (data not presented). The results from this study are in agreeance with Jhala et al. (2015), who reported < 10% soybean injury when acetochlor was applied at 3,370 g ai ha^{-1} and with three sequential applications at 1,680 g ai ha^{-1} each. A microencapsulated formulation of acetochlor was used in this study which creates a slow release of the herbicide thus improving crop safety, hence explaining why very little injury was observed in soybean.

There was no interaction between acetochlor application timing and rate on MHR waterhemp control at 2 WAA, and 4, 8, and 12 WAC so the main effects are presented (Table 3). There was no effect of acetochlor application timing on MHR waterhemp control at 2 WAA and 4, 8, and 12 WAC. There was no effect of acetochlor rate on MHR waterhemp control at 2 WAA and 12 WAC. However, at 4 and 8 WAC, acetochlor at the high rate provided greater control than the low rate; the medium rate provided intermediate control and was similar to both the low and high rates. Acetochlor applied at 1,050, 1,375, and 1,700 g ai ha^{-1} controlled waterhemp 63 to 76%, 70 to 83%, and 74 to 85% at 4 and 8 WAC, respectively (Table 3).

Table 3. Main effects and interaction for multiple-herbicide-resistant (MHR) waterhemp control 2 WAA and 4, 8, and 12 WAC, density and biomass of MHR waterhemp, and soybean yield as affected by application timing and rate of the capsule suspension formulation of acetochlor from eight field trials conducted in southwestern Ontario, Canada in 2020, 2021, and 2022

Main effects	MHR waterhemp control in soybean				Density	Biomass	Yield
	2 WAA	4 WAC	8 WAC	12 WAC			
	--------------------------- % ---------------------------				plants m^{-2}	g m^{-2}	t ha^{-1}
Application timing	NS	NS	NS	NS	NS	**	NS
PP	81	80	66	62	128	408 b	2.1
PRE	93	85	73	66	98	196 a	2.0
POST	76	80	68	61	130	231 a	2.2
SE	2	2	2	2	17	8	0
Herbicide rate (g ai ha^{-1})	NS	*	*	NS	**	**	**
None	0	0	0	0	487 b	724 b	1.8 b
1,050	79	76 b	63 b	57	89 a	244 a	2.1 ab
1,375	85	83 ab	70 ab	65	78 a	202 a	2.3 a
1,700	87	85 a	74 a	67	62 a	152 a	2.2 a
SE	2	2	2	2	17	8	0
Timing × rate	NS	NS	NS	NS	NS	NS	NS

Note. Abbreviations: PP, preplant; PRE, preemergence; POST, postemergence; SE, standard error of the mean; NS, not significant.

a-b Within each main effect, means followed by the same letter (a-b) within a column are not significantly different according to Tukey-Kramer Grouping at $p < 0.05$.

* and ** denote significance at $p < 0.05$ and 0.01, respectively; NS, not significant at $p < 0.05$.

There was no interaction between acetochlor application timing and rate on MHR waterhemp density or biomass so the main effects are presented (Table 3). There was no effect of acetochlor application timing on waterhemp density. Acetochlor applied at 1,050, 1,375, and 1,700 g ai ha^{-1} reduced MHR waterhemp density 82, 84, and 87%, respectively, relative to where no acetochlor was applied; all rates reduced waterhemp density similarly. Acetochlor applied PRE or POST resulted in lower waterhemp shoot biomass than when applied PP (Table 3). Parker et al. (2005) found that biomass reductions were slightly higher when acetochlor was applied PRE compared to PP but differences were non-significant. Acetochlor applied at 1,050, 1,375, and 1,700 g ai ha^{-1} reduced MHR waterhemp biomass 66, 72, and 79%, respectively; there was no differences in waterhemp biomass reduction among the three rates evaluated.

MHR waterhemp control was consistently lower in the soybean study than the corn study even though the studies were conducted at the same locations and sprayed on the same dates. The authors provide two possible reasons for these differences: a) the EC formulation was used in corn studies while the CS was used in soybean; it is possible that the slow release of the CS product resulted in lower waterhemp control, and b) the acetochlor application rate was lower in the soybean study compared to the corn study. The acetochlor rates used in these studies are consistent with the US labelled rates.

The interaction of acetochlor application timing and herbicide rate was not significant for soybean yield, so the main effects are presented (Table 3). Jhala et al. (2015), reported that reduced weed interference with acetochlor applied PP and PRE resulted in higher soybean yield relative to the nontreated control. In one year, soybean yield was higher with acetochlor applied PRE than PP, however this was not observed at the other site (Jhala et al., 2015). In the current study, reduced MHR waterhemp interference with acetochlor applied at 1,050, 1,375, and 1,700 g ai ha^{-1} resulted in an increase in soybean yield of 13, 25, and 17%, respectively; there was no difference in soybean yield among the three rates of acetochlor. The low rate of acetochlor resulted in soybean yield that was similar to the nontreated control (Table 3). Jhala et al. (2015) also reported that in soybean at one of two locations, reduced weed interference with acetochlor applied at 3,370 g ai ha^{-1} resulted in higher soybean yield than acetochlor applied at 1,680 g ai ha^{-1}.

This research demonstrates that acetochlor applied in corn provides control of MHR waterhemp. POST applications generally provided slightly better control of non-emerged waterhemp in corn. Acetochlor alone will not control emerged waterhemp or other weeds that have emerged; therefore, another herbicide would be necessary to control emerged weeds present at the time of the POST application. Additionally, this research demonstrated that acetochlor applied in soybean for MHR waterhemp control needs to be used in combination with additional weed management tactics.

4. Conclusions

No significant interaction occurred between acetochlor application timing and rate in either the corn or soybean studies. In the corn study, acetochlor applied PRE or POST provided better non-emerged MHR waterhemp control, though only the POST application resulted in a greater reduction in MHR waterhemp density and biomass. There was improved MHR waterhemp control in corn and soybean as the rate of acetochlor was increased at 4 and 8 WAC. In both the corn and soybean studies, all rates of acetochlor reduced waterhemp density and shoot biomass relative to the nontreated plots, but there were no differences detected among rates. In corn and soybean, the use of acetochlor resulted in higher crop yield than the nontreated control. Overall, application timing did have an effect on waterhemp control in corn, but not in soybean. Though application rate did influence waterhemp control in both studies, control in soybean was generally inadequate regardless of rate or timing. Studies are needed to determine whether the application of acetochlor POST with a different class of chemistry applied PRE could be an effective weed management program for reducing the spread of waterhemp and limiting its ability to evolve further herbicide resistance.

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