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Common Waterhemp (*Amaranthus rudis*) Control in Corn (*Zea mays*) with Single Preemergence and Sequential Applications of Residual Herbicides[1]

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Abstract: Control of common waterhemp in corn with chloroacetamide and dinitroaniline herbicides can be inconsistent. Common waterhemp control by dimethenamid, *S*-metalochlor, pendimethalin, and three formulations of acetochlor, applied alone or with atrazine as single preemergence (PRE) or sequential PRE followed by postemergence (POST) treatment, was determined. The manufacturer's suggested use rate (1 time) of PRE herbicides was compared with sequential applications (0.66 time PRE followed by 0.34 time POST) of herbicides. POST applications included dicamba to control emerged common waterhemp. Single and sequential herbicide applications controlled common waterhemp at least 98%, 28 d after planting (DAP). But herbicides applied sequentially were more effective than PRE treatments by 56 DAP. Encapsulated acetochlor formulations controlled common waterhemp at least 85% by 56 DAP regardless of application method. Sequential applications of *S*-metolachlor controlled common waterhemp greater than 83%. Atrazine improved common waterhemp control regardless of herbicide or application method 56 DAP. Sequential applications of dimethenamid or *S*-metolachlor alone or with atrazine were more effective than single PRE applications of these herbicides.

Nomenclature: Acetochlor; atrazine; chloroacetamide; dimethenamid; dinitroaniline; pendimethalin; *S*-metalochlor; common waterhemp, *Amaranthus rudis* Sauer #[3] AMATA; corn, *Zea mays* L. 'Pioneer 34R07'.

Additional index words: Chloroacetamide, dinitroaniline, herbicide application timing, sequential applications.

Abbreviations: DAP, days after planting; POST, postemergence; PRE, preemergence.

INTRODUCTION

Common waterhemp is a dioecious *Amaranthus* species indigenous to the Great Plains region of the United States (Horak and Peterson 1995; Sauer 1957). During the past decade common waterhemp has spread from its historical origins in the flood plains of southern and western Illinois to become a significant weed problem in row crop production throughout most of the state (Sauer 1957; Wax 1995). Researchers in other Midwestern states have also reported increased prevalence of common waterhemp in agronomic crops (Hinz and Owen 1997; Horak and Peterson 1995).

Several factors, including the development of herbicide-resistant biotypes, have enabled common waterhemp to become a problematic weed species for corn and soybean [*Glycine max* (L.) Merr.] producers (Horak and Peterson 1995; Sprague et al. 1997). Moreover, common waterhemp has adapted to changes in agronomic practices and weed control techniques. One notable change in agronomic production systems has been the adoption of no-tillage production. Corn planted without tillage increased 40% from 1990 to 2000 in the Midwestern United States (Conservation Technology Information Center 2000). Lack of tillage is beneficial for germination and emergence of small-seeded weed species (Egley and Williams 1990). A recent study reported that common waterhemp emergence was twofold higher under no-tillage conditions than with tillage during the first year of a 4-yr experiment (Steckel et al. 2001). Additionally, corn and soybean producers frequently rely on herbicides for weed control rather than on postplant tillage (Wax 1995). Soil-applied herbicides may not have sufficient residual efficacy to control later-emerging weeds throughout the growing season (Hager et al. 2002), whereas many POST herbicides control only emerged weeds. A combination of contact and residual

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds,* Revised 1999. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

herbicides is generally needed for season-long control of common waterhemp (Hager et al. 1998). These factors, coupled with the subtle trend over the past two decades toward earlier corn planting (Illinois Agricultural Statistics Service 2001), further stress common waterhemp management programs.

Recent studies have found that common waterhemp can emerge later into the growing season than several other summer annual weed species. Hartzler et al. (1999) reported that common waterhemp emerged after giant foxtail (*Setaria faberi* Herrm.), woolly cupgrass [*Eriochloa villosa* (Thunb.) Kunth], and velvetleaf (*Abutilon theophrasti* Medicus) in central Iowa. Common waterhemp emergence was 5 to 25 d later than velvetleaf emergence. Steckel et al. (2001) reported that emergence of common waterhemp on average began in late April and was essentially over by the middle of July. Peak emergence occurred in early June.

One option to manage weeds with long periods of emergence is to use sequential herbicide applications. Watts et al. (1997) reported better sicklepod (*Cassia obtusifolia* L.) control in soybean with sequential PRE metribuzin or metribuzin plus chlorimuron followed by POST imazaquin than with PRE- or POST-only applications. Control of woolly cupgrass and wild-proso millet (*Panicum miliaceum* L.) was improved when a POST application of nicosulfuron followed PRE alachlor, *S*-metolachlor, acetochlor, dimethenamid, and pendimethalin, compared with PRE- or POST-only treatments (Rabaey and Harvey 1997).

Although encapsulated herbicide formulations can extend herbicide persistence in the soil, the duration of weed control has been inconsistent. Buhler et al. (1994) reported that starch-encapsulated alachlor plus atrazine and metalochlor plus atrazine controlled several annual grasses and redroot pigweed (*Amaranthus retroflexus* L.) by 100 and 30 d, respectively, compared with the nonencapsulated commercial formulations. But redroot pigweed control was similar with encapsulated and nonencapsulated formulations by 60 d after application. Fleming et al. (1992) reported no difference in grass control among encapsulated and nonencapsulated alachlor formulations.

Corn producers in Illinois generally attempt to achieve season-long weed control with a single PRE or POST herbicide application. Common waterhemp control after a single herbicide application has generally been inconsistent (Hager et al. 1998; Wax 1995). The objectives of this research were to (1) evaluate the relative efficacy of pendimethalin and various chloroacetamide herbicides for common waterhemp control, (2) determine if common waterhemp control could be improved by adding atrazine to each herbicide, and (3) determine if the duration of common waterhemp control could be extended with a sequential (0.66-time rate PRE followed by 0.34-time rate POST) application compared with a single PRE (1 time) application of these residual herbicides.

MATERIALS AND METHODS

Field experiments were conducted in Illinois at Urbana (2000), Brownstown (2000 and 2001), Altamont (2000), and St. Elmo (2001) to evaluate common waterhemp control with dimethenamid, *S*-metalochlor, pendimethalin, and acetochlor (0.38CS, 0.46CS, and 0.84EC formulations [in kg ai/L]) applied alone or with atrazine. The 0.38CS and 0.46CS formulations of acetochlor are encapsulated. Simazine plus atrazine treatments, applied PRE and sequentially, also were included. Weed-free and nontreated controls were included for comparison. The weed-free treatment received a PRE application of *S*-metalochlor plus atrazine at a rate recommended by the manufacturer, supplemented with hand-weeding as needed throughout the season. Soil at Urbana was a Drummer silty clay loam (fine-silty, mixed, superactive, mesic Typic Endoaquolls), whereas soil at Brownstown and Altamont was a Cisne silt loam (fine, smectitic, mesic Vertic Albaqualfs). Soil at St. Elmo was a Bluford silt loam (fine, smectitic, mesic Aeric Chromic Vertic Epiaqualfs). Soil pH ranged from 6.1 to 6.7 at all locations, and soil organic matter ranged from 1.4 to 1.8% at all locations except Urbana (5%). Corn (Pioneer 34R07) was planted at 64,200 seeds/ha without tillage at Brownstown, Altamont, and St. Elmo. The existing vegetation was controlled with glyphosate at 840 g ae/ha applied 10 d before planting. At Urbana, corn (Pioneer 34R07) was planted at 74,100 seeds/ha after fall chisel plowing and a single pass with a field cultivator in spring. Plot size was four rows 9.1 m long with 76-cm spacing. Corn was planted in early May at Urbana, Altamont, Brownstown, and St. Elmo (2001) and in late May (2000) at Brownstown.

Herbicide application rates were consistent with label recommendations for soil series and organic matter content. Herbicide formulations and application rates are presented in Table 1. All herbicides were applied at their respective recommended rate as a single PRE application (1 time) and a sequential application (0.66-time rate PRE followed by 0.34-time rate POST). Control of any common waterhemp that emerged after the initial 0.66-time–rate PRE application was achieved by the addition of

Table 1. Herbicide formulations, formulated products, and application rates based on soil texture and organic matter content.[a]

		1.2% Organic matter[c]			5% Organic matter[d]		
			Sequential			Sequential	
Herbicide formulation[b]	Product name	PRE only	PRE	POST[e]	PRE only	PRE	POST[e]
		kg/ha					
Acetochlor 0.38CS	Topnotch*[f]	2.0	1.33	0.77	2.2	1.45	0.75
Acetochlor 0.46CS	Degree™[g]	2.0	1.33	0.77	2.46	1.63	0.83
Acetochlor 0.84EC	Harness®[g]	1.96	1.3	0.66	2.35	1.55	0.8
Dimethenamid	Frontier®[h]	1.05	0.7	0.35	1.34	0.89	0.45
S-metolachlor	Dual II Magnum®[i]	1.42	0.94	0.48	1.7	1.12	0.58
Pendimethalin	Prowl®[h]	1.39	0.93	0.46	1.74	1.15	0.59
Acetochlor and atrazine 0.47CS	Fultime*[f]	3.37	2.22	1.15	3.84	2.54	1.3
Acetochlor and atrazine 0.48CS	Degree Xtra™[g]	3.25	2.14	1.11	3.55	2.34	1.21
Acetochlor and atrazine 0.37L	Harness Xtra®[g]	3.14	2.06	1.08	3.77	2.49	1.27
Dimethenamid and atrazine	Guardsman®[h]	2.46	1.62	0.84	3.2	2.11	1.09
S-metolachlor and atrazine	Bicep II Magnum®[i]	0.86	0.57	0.29	1.07	0.75	0.32
Pendimethalin plus atrazine	Prowl®[h] plus AAtrex®[i]	1.39 + 1.19	0.92 + 0.79	0.47 + 0.4	1.58 + 1.68	1.05 + 1.12	0.53 + 0.56
Simazine plus atrazine	Princep®[i] plus AAtrex®[i]	1.34 + 1.19	0.88 + 0.79	0.46 + 0.4	1.68 + 1.68	1.11 + 1.12	0.57 + 0.56

[a] Abbreviations: POST, postemergence; PRE, preemergence.

[b] Herbicide formulations are in kg ai/L.

[c] Soil organic matter for Brownstown, Altamont, and St. Elmo.

[d] Soil organic matter for Urbana.

[e] POST applications included 0.22 kg ai/ha of dicamba.

[f] Dow AgroSciences LLC, Indianapolis, IN 46268.

[g] Monsanto Company, 800 N. Linbergh Boulevard, St. Louis, MO 63167.

[h] BASF Corporation, Box 13528, Research Triangle Park, NC 27709.

[i] Syngenta Crop Protection, Inc., Box 183000, Greensboro, NC 27419.

Table 2. Single degree of freedom contrasts comparing the effect of herbicide application timings and the addition of atrazine on common waterhemp control at POST application timing, 28, and 56 DAP, on common waterhemp density 56 DAP, and on corn grain yield. Data are pooled across five environments.[a]

Contrast	Common waterhemp control[b] at POST	Common waterhemp control[b] 28 DAP	Common waterhemp control[b] 56 DAP	Common waterhemp density 56 DAP	Corn grain yield
	%	%	%	plants/m^2	kg/ha
PRE	99	97	75	7	9,600
Sequential	99	98	88	2	9,660
Pr > F	0.4017	0.0937	0.0001	0.0014	0.1006
Without atrazine	99	96	76	7	8,970
With atrazine	99	99	87	2	9,160
Pr > F	0.2201	0.0883	0.0001	0.0001	0.317

[a] Abbreviations: POST, postemergence; DAP, days after planting; PRE, preemergence; Pr, probability; F, F-value.

[b] Visual determination of common waterhemp biomass reduction in the treated plot compared with a nontreated control.

dicamba at 0.22 kg ai/ha with all sequential POST applications. All PRE herbicide applications were made within 3 d after corn planting, whereas all POST herbicide applications were made 17 to 23 d after planting. Precipitation (23 to 86 mm) was received within 7 d after PRE applications for each environment. Corn was at the VE to V2 stages of growth (Ritchie et al. 1986) when the POST applications were made. Herbicides were applied with a pressurized CO_2 backpack sprayer calibrated to deliver 187 L/ha at 276 kPa using XR11003[4] flat fan spray nozzles spaced 51 cm apart.

Common waterhemp control was evaluated at POST application timing, 28, and 56 d after planting (DAP) using a scale of 0 (no control) to 100 (complete control) based on visual estimates of common waterhemp biomass and stand reduction in the treated-plot area compared with the nontreated control. Additionally, common waterhemp density within a 1-m^2 area between the two middle rows of corn in each plot was determined at each evaluation timing. Corn grain yield was determined at the Urbana and Brownstown locations by mechanically harvesting the two center rows of each plot. Grain yield was adjusted to 15% moisture.

The experimental design was a randomized complete block with three replications. Data were analyzed using the SAS MIXED procedure (SAS 2000). Main effects and all possible interactions were tested using the appropriate expected mean square values as recommended by McIntosh (1983). Each year–location combination was considered an environment sampled at random from a population as suggested by Carmer et al. (1989). Environments, replications (nested within environments), and all interactions containing these effects were declared random effects in the model; herbicide treatment and application timing were designated as fixed effects. Mean separation for individual treatment differences was performed using Fisher's protected LSD test at $P < 0.05$. Single degree of freedom contrasts were used to compare the effect of herbicide application timings and the addition of atrazine on common waterhemp control at POST application, 28, and 56 DAP, on common waterhemp density 56 DAP, and on corn grain yield, averaged across the five environments. Nontransformed means for common waterhemp control and density are presented because arcsine and square root transformation did not improve the normality of the data.

[4] XR11003 Teejet spray nozzles. Spraying Systems Co., North Avenue, Wheaton, IL 60189.

RESULTS AND DISCUSSION

Common Waterhemp Control and Density. Common waterhemp control was at least 98% at the POST application timing and greater than 90% 28 DAP regardless of herbicide application timing (Tables 2–4). Common waterhemp densities averaged less than 1 plant/m^2 at the POST and 28 DAP evaluation (data not presented), which closely reflected visual estimates of common waterhemp control at these timings. Control of any common waterhemp that had emerged after the initial 0.66-time–rate PRE application was achieved by the addition of dicamba at 0.22 kg ai/ha with all sequential POST applications. All herbicides, except pendimethalin applied PRE, reduced common waterhemp density 56 DAP compared with the nontreated control (Tables 3 and 4). Single degree of freedom contrasts of herbicide application timing indicated no difference in common waterhemp control at the POST application timing or at the 28 DAP evaluation (Table 2). In contrast, by 56 DAP, sequential herbicide applications controlled common waterhemp more effectively by reducing common waterhemp density more compared with the PRE-only appli-

Table 3. Common waterhemp control with chloroacetamide herbicides and pendimethalin at POST application timing, 28, and 56 DAP, averaged across five environments.[a]

	Common waterhemp control[b]						Common waterhemp density			
	POST		28 DAP		56 DAP		56 DAP		Corn grain yield	
Herbicide	PRE	Sequential	PRE	Sequential	PRE	Sequential	PRE	Sequential	PRE	Sequential
	%						plants/m²		kg/ha	
Acetochlor 0.38CS	99	99	99	99	85	94	7	1	8,220	9,030
Acetochlor 0.42CS	99	99	99	99	95	94	2	1	8,970	8,910
Acetochlor 0.84EC	99	99	98	99	61	89	15	1	9,340	9,410
Dimethenamid	99	98	91	94	61	75	12	6	8,720	9,850
S-metolachlor	99	99	95	97	57	83	14	4	8,720	9,280
Pendimethalin	99	98	93	95	46	58	21	10	8,530	9,340
Nontreated	—	—	—	—	—	—	23		7,400	
Weed-free	—	—	—	—	—	—	—		8,530	
LSD (0.05)	NS		NS		13		8		1,670	

[a] Abbreviations: POST, postemergence; DAP, days after planting; PRE, preemergence.

[b] Visual determination of common waterhemp biomass reduction in treated plot compared with a nontreated control.

cations (Table 2). Additionally, single degree of freedom contrasts comparing treatments with and without atrazine, averaged across application timings, indicated that atrazine did not improve common waterhemp control at the POST application timing or at the 28 DAP evaluation. But by 56 DAP, the addition of atrazine improved common waterhemp control from 76 to 87%, and common waterhemp density was reduced from 7 to 2 plants/m² (Table 2). The atrazine plus simazine treatment, regardless of application timing, did not control common waterhemp adequately by 56 DAP (Table 4). The extended emergence of common waterhemp (Hartzler et al. 1999; Steckel et al. 2001) frequently results in multiple emergence events during the growing season. Our results suggest that common waterhemp control can be extended later into the growing season by using sequential applications of residual herbicides or with the addition of atrazine.

The encapsulated acetochlor formulations, 0.38CS and 0.46CS, controlled common waterhemp 56 DAP more effectively than did any PRE-only treatments (Table 3). The encapsulated 0.46CS formulation of acteochlor also reduced common waterhemp density more than did all nonacetochlor treatments or the nonencapsulated acetochlor formulation. PRE-only applications of dimethenamid, *S*-metolachlor, pendimethalin, and the nonencapsulated acetochlor formulation 0.84EC controlled common waterhemp not more than 61%. Common waterhemp control with acetochlor 0.84EC, dimethenamid, and *S*-metolachlor was similar; control with acetochlor 0.84EC and dimethenamid also was greater than control with pendimethalin. Sequential applications of the en-

Table 4. Common waterhemp control and density with herbicide premixtures at POST application timing, 28, and 56 DAP when pooled across five environments.[a]

	Common waterhemp control[b]						Common waterhemp density			
	POST		28 DAP		56 DAP		56 DAP		Corn grain yield	
Herbicide	PRE	Sequential	PRE	Sequential	PRE	Sequential	PRE	Sequential	PRE	Sequential
	%						plants/m²		kg/ha	
Acetochlor 0.38CS and atrazine	99	99	99	99	93	96	1	1	8,910	8,840
Acetochlor 0.46CS and atrazine	99	99	99	99	96	99	1	1	8,470	9,090
Acetochlor 0.84EC and atrazine	99	99	98	99	91	97	1	1	8,910	8,840
Dimethenamid and atrazine	99	99	97	99	78	93	6	4	7,960	8,470
S-metolachlor and atrazine	99	99	98	99	83	96	4	2	9,280	8,910
Pendimethalin plus atrazine	99	98	98	99	69	77	10	5	9,470	9,890
Simazine plus atrazine	99	99	98	99	75	80	3	6	9,780	9,340
Nontreated	—	—	—	—	—	—	23		7,440	
Weed-free	—	—	—	—	—	—	—		8,530	
LSD (0.05)	NS		NS		13		8		1,380	

[a] Abbreviations: POST, postemergence; DAP, days after planting; PRE, preemergence.

[b] Visual determination of common waterhemp biomass reduction in the treated plot compared with a nontreated control.

capsulated acetochlor formulations did not improve common waterhemp control compared with the PRE-only applications of the same herbicides. In contrast, sequential applications of the nonencapsulated acetochlor, dimethenamid, and *S*-metolachlor increased common waterhemp control compared with PRE-only applications. Common waterhemp density was reduced more after sequential applications of the nonencapsulated acetochlor, *S*-metolachlor, and pendimethalin compared with PRE-only applications of these herbicides (Table 3). Even though common waterhemp control 56 DAP was improved with sequential applications of all nonencapsulated herbicides except pendimethalin, common waterhemp control after these sequential applications remained poor except with the nonencapsulated acetochlor (89%) and *S*-metolachlor (83%) applications.

All acetochlor plus atrazine premixtures applied PRE only controlled common waterhemp at least 91% by 56 DAP. The remaining herbicide treatments controlled common waterhemp less than 84% (Table 4). By 56 DAP, the acetochlor plus atrazine formulations and *S*-metolachlor plus atrazine reduced common waterhemp density more than did pendimethalin plus atrazine applied PRE only. There were no differences in common waterhemp control among PRE-only applications of dimethenamid plus atrazine, pendimethalin plus atrazine, or simazine plus atrazine. But *S*-metolachlor plus atrazine controlled common waterhemp better than did pendimethalin plus atrazine. Sequential applications of dimethenamid plus atrazine and *S*-metolachlor plus atrazine increased common waterhemp control 56 DAP compared with PRE-only applications, but sequential applications of other treatments did not improve common waterhemp control.

Corn Grain Yield. A single degree of freedom contrast comparing application timings indicated that there was no difference in corn grain yield (Table 2). An additional single degree of freedom contrast indicated that corn yield was not affected by atrazine treatments. Common waterhemp interference in the nontreated control reduced corn grain yield 13% compared with weed-free corn grain yield (Tables 3 and 4). Overall, common waterhemp interference did not affect corn grain yield, even though complete common waterhemp control was not achieved with any treatment by 56 DAP. Lack of differences in corn yield may be related to the excellent early-season common waterhemp control by most of the herbicide treatments in this study. Massinga et al. (2001) reported that interference of a related *Amaranthus* sp., Palmer amaranth (*Amaranthus palmeri* S.), did not reduce corn yield if weed emergence occurred after the six-leaf corn stage.

Common waterhemp control in Illinois has been inconsistent after PRE- or POST-only herbicide applications partly because of its extended emergence characteristic noted by Hartzler et al. (1999) and Steckel et al. (2001). Improving the consistency of common waterhemp control may be accomplished by the use of encapsulated herbicide formulations, by the addition of atrazine, or by applying herbicides sequentially (or all). In our research, PRE-only applications of the encapsulated acetochlor formulations controlled common waterhemp throughout the season, whereas common waterhemp control with the other chloroacetamides was improved by atrazine. Although corn grain yield did not differ among treatments, the level of common waterhemp control achieved may not adequately meet grower expectations. In general, sequential herbicide applications improved common waterhemp control with many of these herbicides.

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