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Influence of corn on common waterhemp (*Amaranthus rudis*) growth and fecundity

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Four experiments were conducted in central Iowa during 2001 and 2002 to determine the effects of weed emergence time and corn row spacing on common waterhemp growth and fecundity. Four common waterhemp emergence cohorts were established in each experiment and corresponded to the VE, V3, V5, and V8 stages of corn grown in rows spaced 38 and 76 cm apart. Common waterhemp mortality averaged 20, 56, 97, and 99% for the first, second, third, and fourth cohorts, respectively. Mean mature common waterhemp height for the first cohort was 140 cm, whereas plants emerging at the V8 corn stage were only 5 cm tall. Biomass of the first cohort was 20% less in 38-cm rows than in 76-cm rows, but later cohorts were not affected by row spacing. Biomass and seed production of waterhemp emerging at the V3, V5, and V8 corn stages decreased 80, 97, and 99%, respectively in comparison with the first cohort. Overall results indicate that common waterhemp biomass, survival, and fecundity decline sharply with delayed emergence relative to corn, but weeds emerging at or before the V5 corn stage may still contribute significantly to the seed bank.

Nomenclature: Common waterhemp, *Amaranthus rudis* Sauer AMATA; corn, *Zea mays* L.

Key words: Delayed emergence, row spacing, fecundity.

Common waterhemp is native to the Midwestern United States (Pammel 1913), but it has only developed into a serious problem in corn and soybean [*Glycine max* (L.) Merr.] in the last 15 yr because of the changes in production practices (Hager et al. 1997). The repeated use of triazine (Anderson et al. 1996), acetolactate synthase–inhibiting herbicides (Foes et al. 1998; Hinz and Owen 1997), and protoporphyrinogen oxidase–inhibiting herbicides (Patzoldt et al. 2002) has selected resistant biotypes of common waterhemp. A decrease in tillage allows common waterhemp seed to remain at or near the soil surface, therefore providing optimum conditions for germination (Buhler 1992).

Common waterhemp typically initiates emergence in mid May in Iowa, whereas other important annual weeds, such as velvetleaf (*Abutilon theophrasti* Medik.), giant foxtail (*Setaria faberi* Herrm.), and woolly cupgrass [*Eriochloa villosa* (Thunb.) Kunth], begin emerging in the latter part of April (Hartzler et al. 1999). The delayed emergence of common waterhemp allows it to escape many control tactics but places the plant at a competitive disadvantage with the previously established crop. Because weed emergence is delayed relative to the crop, crop yield losses are reduced. Corn yield was only slightly affected by redroot pigweed (*Amaranthus retroflexus* L.) (Knezevic et al. 1994) and common waterhemp (Murphy et al. 1996; Steckel and Sprague 2002) that emerged after the V5 stage of corn development.

Although late-emerging weeds may not affect crop yield, they are still capable of interfering with harvest, reducing crop quality, and contributing to the weed seed bank. Biomass and seed production of common waterhemp decreased sharply with delayed emergence in soybean (Hartzler et al. 2003). Biomass of redroot pigweed also decreased with delayed emergence in sorghum [*Sorghum bicolor* (L.) Moench] (Knezevic and Horak 1998). Redroot pigweed developing under a corn canopy had less branching and an increased proportion of dry matter allocated to the upper portion of the plant canopy when compared with plants grown in full sunlight (McLachlan et al. 1993). Delayed redroot pigweed emergence in sorghum decreased allocation of dry matter to reproductive structures (Knezevic et al. 2001). Knezevic et al. (1994) reported an 81% reduction in redroot pigweed seed when emergence was delayed from the V3 to V5 stages of corn development. Palmer amaranth (*Amaranthus palmeri* S.Wats.) seed production decreased from 140,000 seed m^{-2} when emerging with corn to 1,800 seed m^{-2} when emerging at the V4 to V7 corn stages (Massinga et al. 2001). Delaying emergence of common waterhemp in soybean from VE to V6 decreased common waterhemp seed production 99% (Hartzler et al. 2004).

The effect of delayed emergence on weed survival has rarely been reported. Common waterhemp survival was 91% when it emerged with soybeans but only 19% when it emerged at the V6 soybean stage (Hartzler et al. 2003). However, Mohler and Calloway (1992) found that late-emerging weeds in sweet corn had a better chance for survival than weeds emerging with the crop because the late weeds avoided control tactics.

Reducing corn row spacing allows the crop to fill interrow spaces earlier in the growing season. Early canopy closure may reduce weed interference by increasing the amount of light intercepted by the crop canopy. Research has shown that within the range of corn plant densities used in corn production, density has little effect on photosynthetically active radiation (PAR) interception, but row spacing does affect PAR interception (Tharp and Kells 2001). Farnham (2001) reported that optimum corn yield was attained at the same planting density (79,100 plants ha^{-1}) in both 38- and 76-cm rows.

Table 1. Site characteristics, planting dates, and relative times of emergence for corn and common waterhemp.

					Corn		Waterhemp	
Location	Year	Soil type	pH	Percent OM[a]	Planting date	Emergence date	Emergence date	Corn leaf stage[b]
Hinds	2001	Spillville loam	6.0	3.2	May 1	May 10	May 15	VE
							May 29	V3
							June 11	V5
							July 4	V8
Stratford	2001	Marna silty clay loam	6.7	4.0	May 9	May 15	May 20	VE
							June 5	V3
							June 15	V5
							July 15	V8
Hinds	2002	Spillville loam	6.0	3.2	May 7	May 20	May 22	VE
							May 29	V3
							June 12	V5
							June 26	V8
Curtiss	2002	Clarion loam	6.5	4.0	May 7	May 20	May 22	VE
							May 29	V3
							June 12	V5
							June 26	V8

[a] Abbreviation: OM, organic matter.
[b] Corn leaf stage at the time of common waterhemp emergence.

The use of narrow-row spacing has proven effective in improving weed control in soybean (Legere and Schreiber 1989; Norris et al. 2002; Young et al. 2001). However, most growers have been reluctant to adopt narrow-row spacing in corn because of conflicting results in the yield response to row spacing (Alessi and Power 1974; Farnham 2001; Johnson et al. 1998; Lutz et al. 1971; Murphy et al. 1996; Nunez and Kamprath 1969; Ottman and Welch 1989; Porter et al. 1997; Westgate et al. 1997). The potential yield increase also must be weighed against the cost of purchasing or modifying equipment.

Many weeds, such as redroot pigweed (McLachlan et al. 1993), common lambsquarters (*Chenopodium album* L.) (Tharp and Kells 2001), velvetleaf (Bello et al. 1995; Lindquist et al. 1998; Teasdale 1998), and foxtail species (*Setaria* spp.) (Nieto and Staniforth 1961), have decreased biomass and fecundity when grown in the light-limiting environment under a crop canopy. Palmer amaranth biomass was reduced by 15%, and corn yield loss associated with Palmer amaranth interference was reduced 13% with the use of narrow rows (Murphy et al. 1996). Johnson et al. (1998), however, found no effect of corn row spacing on giant foxtail and little effect on common ragweed (*Ambrosia artemisiifolia* L.).

Table 2. Weekly rainfall in Ames, IA, for 2001 and 2002.

Month	Dates	2001	2002
		cm	
April	1–7	0.7	0.3
	8–14	4.9	1.7
	15–21	0.3	2.4
	22–30	2.7	5.4
May	1–7	6.4	1.4
	8–14	3.8	6.6
	15–21	4.5	0.8
	22–31	4.3	2.5
June	1–7	1.2	1.4
	8–14	2.9	5.7
	15–21	0.8	0.1
	22–30	0.0	0.0
July	1–7	0.1	4.2
	8–14	1.1	8.0
	15–21	1.1	0.0
	22–31	2.5	1.2
August	1–7	2.8	10.9
	8–14	0.0	0.3
	15–21	3.1	2.7
	22–31	1.8	0.3

Integrated weed management systems have been proposed as a way of reducing the effect of weed management practices on the environment (Swanton and Weise 1991). The success of integrated weed management is dependent on understanding weed population dynamics and then developing appropriate control tactics based on this knowledge (Buhler and Hartzler 2001). An understanding of common waterhemp responses to corn management practices will aid in creating an environment unfavorable for weed growth while maintaining crop competitiveness. The objective of this research was to evaluate the effect of common waterhemp emergence time and row spacing on common waterhemp growth and reproduction parameters in corn. The hypothesis was that corn planted in narrow (38 cm) rows would provide greater suppression of late-emerging common waterhemp than corn planted in conventional (76 cm) rows.

Materials and Methods

Four experiments were conducted during 2001 and 2002 at the Iowa State University Hinds and Curtiss Farms near Ames and at a private farm near Stratford, 64 km northwest of Ames. Similar protocols were used in all experiments, and specific information pertaining to each location is presented in Table 1. All fields were planted to soybean the season before the experiment. Experimental areas were chisel plowed in the fall and field cultivated before planting. Urea was applied preplant in the spring of 2001 and 2002 to all locations at 336 kg N ha^{-1}. Weekly rainfall amounts and average daily temperature from the Iowa State University Ag

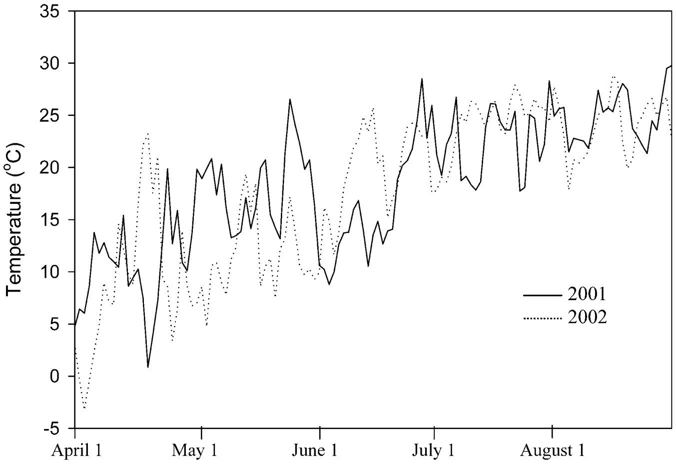

FIGURE 1. Average daily air temperature in 2001 and 2002 at Ames, IA (May through August).

Climate Station, Ames, IA, are presented in Table 2 and Figure 1. Rainfall and temperature data are relevant to the Hinds and Curtis locations; no weather data were recorded at the Stratford site.

A randomized complete block with a split-plot arrangement with four replications was used. Main plots (40 by 140 m) were crop row spacings and consisted of glyphosate-resistant corn ('Golden Harvest H8194') planted in 38- and 76-cm rows at a population of 79,100 seed ha^{-1}. Subplot treatments were waterhemp emergence cohorts that corresponded to corn developmental stages VE, V3, V5, and V8. Each cohort comprised 30 waterhemp plants arbitrarily selected from natural infestation or seedlings between corn rows in a 20- by 35-m subplot area. Plants growing directly in the corn row were avoided. Seed for the artificial plantings were collected the previous fall and stored at 4 C until 2 wk before planting. At this time, water was added and seed were returned to 4 C. Common waterhemp seed were planted 7 to 10 d before the appropriate corn stage by suspending the seed in Laponite RD gel[1] and injecting them 1 to 2 cm below the soil surface. Common waterhemp seed were watered approximately every 4 d until emergence.

Common waterhemp plants that emerged at the appropriate time were selected at the cotyledon stage, and their locations were marked using aluminum tags inserted in the ground adjacent to the plant. Plants that were at least 0.5 m from other targeted waterhemp plants were selected. Weed control was achieved with hand weeding and one to two applications of 0.85 kg ae ha^{-1} of the isopropylamine salt of glyphosate. Tagged waterhemp plants were covered with plastic cups to prevent contact with glyphosate.

In 2001, height and survival of tagged common waterhemp plants were recorded 1 wk after the V8 corn stage and before harvest. In 2002, height and survival of plants were taken biweekly from the V3 to V13 corn stages. At the initiation of common waterhemp senescence, on or about September 20, final height measurements were taken, and plants were cut at the soil surface and placed in paper bags. Plants were dried in an oven for 5 d at 35 C and weighed. Seed production was based on plant dry weight using a linear regression equation by Hartzler et al. (2003). To validate this method, seed were separated from 20 female waterhemp plants using sieves and an air column separator. Seed production from these plants was similar (greater than 95% accuracy) to the predicted value and determined adequate; therefore, seed production is based on plant dry weight. Corn yields were not taken because emergence time effects of common waterhemp on corn yield would have been confounded by differential common waterhemp spacing and density among treatments.

Common waterhemp height, shoot dry weight, and seed production were log transformed for data analysis because of unequal variances. The relationship between corn row spacing and common waterhemp date of emergence was analyzed separately for each growth parameter using analysis of variance in SAS.[2] Back-transformed means are presented. The proportion of common waterhemp plants that died was transformed using the arcsine transformation (Kuehl 2000) and analyzed using analysis of variance in SAS. The back-transformed means of common waterhemp mortality are presented. No location by treatment interaction was observed with any common waterhemp growth parameter; thus, the data from the four experiments were pooled.

Results and Discussion

Delays in common waterhemp emergence relative to corn emergence increased premature mortality of common waterhemp (Table 3). Corn row spacing did not affect mortality at any emergence time. Common waterhemp emerging at the VE stage of corn averaged 20% mortality, whereas plants emerging at the V3 and V5 stages averaged 56 and 97% mortality, respectively. More than 99% of plants emerging at the V8 stage did not survive to maturity. The majority of mortality events for the V5 and V8 cohorts occurred in late June in 2002 (Figure 2). In contrast, mortality with the early cohorts was more evenly distributed from July until the end of the growing season.

Most studies examining the effect of delayed emergence on weed growth and competitiveness have not reported the influence of emergence date on weed survival (Knezevic and Horak 1998; Knezevic et al. 2001; Massinga et al. 2001; McLachlan et al. 1993). Late-emerging weeds in sweet corn had a higher survival rate than early-emerging weeds because of the lack of exposure to control measures (tillage and herbicide application) (Mohler and Calloway 1992). However, in the absence of control tactics, Lindquist et al. (1995) found that velvetleaf survival decreased significantly with delayed emergence in soybean. The low survival rates of plants emerging after the V5 corn stage should be considered when evaluating the need for implementing control tactics for late-emerging waterhemp.

The height of common waterhemp that emerged at the VE corn stage averaged 140 cm. Plant height decreased approximately 40, 80, and 95% with each successive delay in emergence (Table 3). Corn row spacing did not affect common waterhemp height. The variability in height increased as emergence was delayed. Many plants that emerged at the VE corn stage became etiolated, and the plants either lodged or relied on neighboring corn plants for support. Later-emerging plants rarely grew above ear height of the corn plant (1 m).

Biomass accumulation of common waterhemp declined more rapidly with delays in emergence than plant height (Table 3). Plants emerging with VE corn weighed an average

TABLE 3. Common waterhemp survival, height, shoot dry weight, and seed production as affected by TOE and corn row spacing.[a]

Growth parameter[b]	Corn row spacing	Corn stage at the time of cohort emergence				TOE[c]
		VE	V3	V5	V8	
	cm					
Mortality (%)	38	24 (3) a[d]	60 (3) a	97 (3) a	100 (3) a	**
	76	16 (3) a	52 (3) a	96 (3) a	99 (3) a	
Height (cm)	38	142 (3) a	83 (5) a	17 (28) a	0 a	**
	76	139 (3) a	77 (4) a	32 (16) a	9 (44) a	
Shoot dry weight (g plant^{-1})	38	25.1 (1.7) a	6.0 (2.5) a	0.2 (13.8) a	0 a	**
	76	31.3 (1.6) b	5.0 (2.2) a	1.1 (7.7) a	0.1 (21.8) a	
Seed production (thousand seed plant^{-1})	38	39.4 (3.7) a	9.0 (5.6) a	0.6 (32.1) a	0 a	**
	76	48.4 (3.2) b	9.0 (4.9) a	1.3 (20.3) a	0 a	

[a] Abbreviation: TOE, time of emergence.
[b] Means are pooled over location and year; standard error is in parentheses.
[c] Main effect of TOE presented for each growth parameter pooled over row spacing. Significance: ** = significant at P = 0.01.
[d] Means followed by the same letter within a TOE and parameter does not differ between row spacings as determined by analysis of variance (P = 0.05).

of 28 g, whereas plants emerging at V8 weighed less than 1 g. Narrow-row corn decreased the shoot dry weight of plants at the VE corn stage by 20% compared with plants grown in wide rows (Table 3). Biomass of plants that emerged after VE corn stage was not affected by row spacing; however, each successive delay in emergence accounted for 80, 95, and 99% reductions in biomass compared with plants that emerged with corn (Table 3).

Seed production by female common waterhemp plants emerging at the VE corn stage was greater in wide rows than in narrow rows (Table 3). Plants in wide rows averaged 48,400 seed plant^{-1}, whereas plants in narrow rows only produced around 39,400 seed plant^{-1}. Row spacing did not affect the V3 to V8 cohorts, but delays in emergence did decrease seed production to approximately 9,000 and 950 seed plants^{-1} of those emerging at the V3 and V5 corn stages, respectively (Table 3). Plants that emerged at the V8 corn stage did not produce seed.

Common waterhemp biomass accumulation and seed production in corn were much lower than reported by Hartzler et al. (2003) in soybean. Average seed production of plants emerging with soybean was 309,000 seed plant^{-1}, six times greater than plants emerging with corn. Redroot pigweed seed production in monoculture produced up to 400,000 seed plant^{-1} but was reduced to 80,000 seed plant^{-1} when grown in competition with sorghum (Knezevic and Horak 1998). Palmer amaranth fecundity decreased from 140,000 to 1,800 seed m^{-2} with delayed emergence in corn (Massinga et al. 2001). Knezevic et al. (1994) reported redroot pigweed grown in competition with corn produced 32,000 seed plant^{-1} when emerging before the V4 corn stage and 1,500 seed plant^{-1} when emerging between V4 and V7. Although fecundity of common waterhemp declines dramatically with delayed emergence, later-emerging plants can reproduce and add significantly to the seed bank.

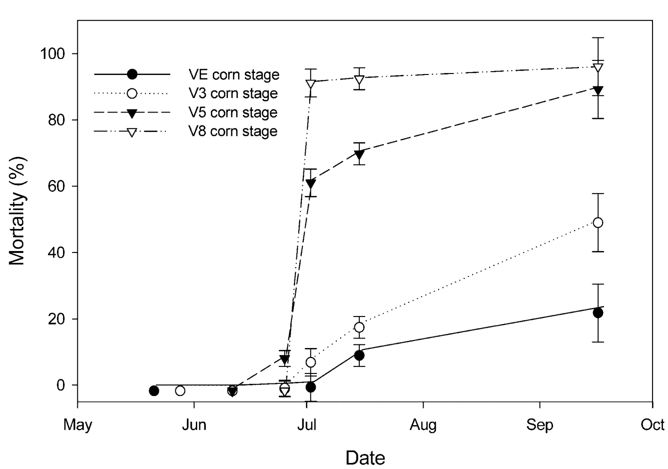

FIGURE 2. Effect of weed emergence time relative to corn growth stage on common waterhemp mortality during the 2002 growing season. Error bars indicate the standard error of treatment means.

Results from this study show that emergence time was more influential than row spacing on common waterhemp growth and survival in corn. Common waterhemp plants produced an average of 1,000 seed when emerging at the V5 corn stage; however, when combined with only 3% survival, these plants would likely have such low economic effect as to not warrant further control measures under most scenarios. Planting corn as early as possible would take advantage of the late emergence of common waterhemp and thus suppress or possibly eliminate competition and fecundity from plants emerging later than V5. More information is needed on waterhemp seed survival and longevity before long-term economic thresholds can be developed. The lack of interaction among experiments suggests that common waterhemp growth in response to emergence time is not highly weather sensitive, despite differences in average temperatures between 2001 and 2002 for the first two cohorts (VE and V3). Knezevic et al. (1994) suggested that higher temperatures may increase redroot pigweed growth and seed production; whereas Wright et al. (1999) found that Palmer amaranth height and dry matter accumulation were directly related to temperature. Narrow-row spacing was only effective in reducing biomass and seed production of the first cohort and not the later-emerging weeds. This rejects the hypothesis that reducing row spacing would reduce the effect of late-emerging weeds.

Sources of Materials

[1] Southern Clay Products Inc., 1212 Church Street, Gonzales, TX 78629.

[2] SAS 8, SAS Institute, SAS Circle, Box 8000, Cary, NC 27512-8000.

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