

**Effect of tillage and corn row spacing on
common waterhemp growth and fecundity**

by

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GENERAL INTRODUCTION

Common waterhemp (*Amaranthus rudis* Sauer) is a dioecious *Amaranthus* species native to Iowa. Problems with common waterhemp increased greatly during the late 1980's and early 1990's due to several factors including the adoption of reduced tillage systems, selection of herbicide resistant biotypes, and simplification of weed management systems. An improved understanding of factors influencing the growth and survival of waterhemp is essential to develop economical and environmentally benign weed management systems.

Integrated weed management (IWM) is an ecological approach to weed control that reduces dependence on herbicides (Swanton and Weise 1991). IWM involves the use of several weed control measures including but not limited to cultural, chemical, and biological methods. In order to successfully incorporate these methods, an increased understanding of the biological characteristics of weed populations is needed, particularly in the areas of crop-weed interactions and weed population dynamics.

Thesis organization

A literature review precedes the two papers that are presented in a journal format. The first paper documents the impact of corn (*Zea mays*) row spacing and time of waterhemp emergence on waterhemp growth and seed production. The second paper documents the impact of tillage on waterhemp emergence, persistence, and distribution in the seedbank. General conclusions, literature review citations, and acknowledgements will then follow.

LITERATURE REVIEW

Common waterhemp (*Amaranthus rudis* Sauer) is member of the pigweed (Amaranthaceae) family native to the Midwest region of the United States (Pammel 1913). It is found throughout the majority of the United States (Gleason and Cronquist 1991). This dioecious annual exhibits prolific seed production, with individual plants capable of producing over five million seeds (Hartzler et al. 2003).

Common waterhemp can range in height from 0.1- to 3.5 m. Leaves are glossy, hairless, elongated or lanceolate and are positioned alternately on the stem. Stem and leaf color tend to be shades of green, but may vary to red. Vegetative characteristics are identical to that of tall waterhemp (*Amaranthus tuberculatus*), and the two species can only be distinguished by the presence and absence of sepals. The identification of common waterhemp and tall waterhemp has been so confounding that researchers suggested they be classified as a single species (Pratt and Clark 2001).

Many factors have contributed to the problems associated with common waterhemp in today's crop production practices. Continuous use of the same or similar herbicides increases the selection pressure for resistance more than if multiple modes of action are used (Jasieniuk et al. 1996). The reliance on acetolactate synthase-inhibiting, triazine, and protoporphyrinogen oxidase-inhibiting herbicides have selected resistant biotypes of common waterhemp that are now present throughout many Midwest states (Anderson et al. 1996, Foes et al. 1998, Hinz and Owen 1997, Patzoldt et al. 2002).

A decrease in tillage over the past two decades has favored waterhemp and other small-seeded weeds. Less intensive tillage allows the seed to remain near the soil surface where it is more likely to encounter favorable conditions for germination and establishment (Buhler 1992). In a study examining redroot pigweed (*Amaranthus retroflexus*) requirements for emergence, optimum germination occurred between air temperature of 35° and 40°C (Ghorbani et al. 1999). Minimum temperature requirement for germination was above 5°C. Soil moisture had an additive effect on emergence when temperature was between 25° and 35°C. Optimum depth for emergence was 0.5 to 3 cm, with sandy soil types preferred over heavy soils for establishment.

In central Iowa common waterhemp typically initiates emergence in mid- to late May and then continues for six to eight weeks with peak emergence occurring in mid-June (Hartzler et al. 1999). Other common annual weeds such as velvetleaf (*Abutilon theophrasti*), woolly cupgrass (*Eriochloa villosa*), and giant foxtail (*Setaria faberi*), begin to emerge around late April and early May and have shorter durations of emergence than common waterhemp. The initial time of emergence for these four annuals varied among years, but the emergence sequence was consistent with common waterhemp initiating emergence 5 to 25 days after velvetleaf.

Reduced tillage, including the absence of inter-row cultivation and the reduction of residual and pre-emergence herbicides in corn (*Zea mays*) and soybean (*Glycine max*) production also favors weeds with a prolonged emergence pattern (Hager et al. 1997, Hartzler et al. 1999). Soil-applied herbicides do not have adequate residual activity for late flushes of common waterhemp emergence, and

most post-emergence herbicides are applied prior to peak common waterhemp emergence to control earlier emerging weeds. Although delayed emergence may favor survival in row crops, late-emerging plants are at a competitive disadvantage with the crop due to the previously established crop canopy.

The effect of several *Amaranthus* species on crop yields has been reported. Smooth pigweed (*Amaranthus hybridus*) consistently reduced soybean yields 55% over a three year period (Moolani et al. 1964). Shurtleff and Coble (1985) found that soybean yields were reduced 22% because of competition with redroot pigweed. Increases in Palmer amaranth (*Amaranthus Palmeri*) density decreased soybean yield 17- to 68% with increasing soybean density (Klingaman and Oliver 1994). Common waterhemp decreased soybean yield 43% after 10 weeks of competition (Hager et al. 2002). Sorghum (*Sorghum bicolor*) yield also decreased as the duration of competition with tall waterhemp increased (Feltner et al. 1968).

Most research examining the time of weed emergence focuses on the influence of weeds on crop yield. Late-emerging downy brome (*Bromus tectorum*) reduced winter wheat (*Triticum aestivum*) biomass and yield up to five times more when it emerged within three weeks of wheat than six weeks after wheat or in the spring (Blackshaw 1993). Palmer amaranth emerging with corn decreased corn yield 15% more compared to plants emerging at the four- to six-leaf corn stage (Massinga et al. 2001). Knezevic et al. (1994) found that redroot pigweed emerging after the V7 stage of corn development did not affect corn yield. Common waterhemp emerging between V4 and V6 corn stages had little effect on corn yield (Murphy et al. 1996, Steckel and Sprague 2002). A review of weed interference in

soybean found that yield loss associated with weed competition declined rapidly as weed emergence was delayed at least three weeks after soybean emergence (Stoller et al. 1987).

Delays in weed emergence may lessen the impact that the weeds have on crop yield, but late-emerging plants may interfere with harvest, reduce crop quality and contribute to the weed seed bank. Dry matter and seed production of redroot pigweed was greater when it emerged at or before the three-leaf stage than on or after the five-leaf stage of sorghum (Knezevic and Horak 1998). The delay in redroot pigweed emergence in sorghum resulted in more dry matter allocation for leaves and stems rather than reproductive structures (Knezevic et al. 2001). Redroot pigweed exhibited less branching and an increase in the proportion of dry matter allocated toward the upper portion of the plant canopy compared to plants grown in full sunlight. These differences were attributed to a decline in canopy transmitted PPFD (McLachlan et al. 1993). Palmer amaranth that emerged with corn produced 140,000 seed m^{-2} ; however, plants that emerged with V4 to V7 corn produced only 1,800 seed m^{-2} (Massinga et al. 2001). Common waterhemp seed production decreased from 300,000 to 3,000 seeds with delayed emergence in soybeans (Hartzler et al. 2003).

The effect of delayed emergence on plant survival has rarely been noted. Common waterhemp that emerged at the VE soybean stage of development had 91% survival, whereas only 19% of waterhemp that emerged at V6 survived (Hartzler et al. 2003). In New York, the presence of sweet corn had little effect on redroot pigweed survival, although late-emerging weeds had a better chance of

reaching maturity by not being exposed to early-season control tactics such as herbicides and cultivation (Mohler and Calloway 1992).

A decrease in corn row spacing alters the spacing of plants between and within rows, which in turn influences canopy characteristics. Phytochrome mediated responses such as narrow leaves, long stems, and decreased root mass can occur when seedlings are grown in close proximity (Kasperbauer and Karlen 1994). Corn planted in an equidistant spacing pattern increased biomass and leaf area index (LAI) compared to that grown in a conventional pattern (Bullock et al. 1988). Changes in the spatial pattern of corn then affect the architecture and light dynamics of a corn canopy. Rapid canopy closure may reduce weed interference by increasing the amount of light intercepted by the crop canopy. Early canopy closure and increased LAI and increased incident PAR are achieved with narrower row spacing (Flenet et al. 1996, Forcella et al. 1992a, Teasdale 1995, Tharp and Kells 2001, Westgate et al. 1997). Other methods of manipulating the crop canopy include planting at higher densities, or selecting varieties with rapid growth or canopy characteristics that are more efficient at intercepting light.

Many corn growers remain reluctant to adapt narrow row spacing because of conflicting results on corn yield (Alessi and Power 1974, 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 must be weighed against the cost of new or modifications to equipment, including the planter, combine, and tractor tire spacing and size.

The effect of row spacing on weed management has been studied more in soybean than in corn since narrow row spacing in soybean is a common practice. Narrow rows have consistently improved weed control in soybeans. Legere and Schreiber (1989) reported increased soybean leaf area and reduced redroot pigweed biomass in narrow row (25 cm) soybean. Narrow rows also decreased the amount of weed resurgence after herbicide application in soybean. Weed biomass and density decreased linearly with decreasing soybean row spacing in North Carolina (Yelverton and Coble 1991). Reduced rates of herbicides have also been documented to be more effective in controlling weeds in narrow row than wide row soybean (Ateh and Harvey 1999, Mickelson and Renner 1997).

Numerous other studies have also documented decreased biomass and fecundity of weed species such as redroot pigweed (McLachlan et al. 1993), common lambsquarters (*Chenopodium album*) (Tharp and Kells 2001), velvetleaf (Bello et al. 1995, Lindquist et al. 1998, Teasdale 1998), and foxtail (*Setaria* spp.) (Nieto and Staniforth 1961) in response to the limiting light environment under a crop canopy. Palmer amaranth grown in 50 cm corn rows exhibited a 15% decrease in biomass compared to plants grown in 76 cm rows. Corn yield loss associated with Palmer amaranth competition was reduced from 15% to a 2% loss (Murphy et al. 1996). However, narrow row spacing has not always resulted in reduced weed biomass. Johnson et al. (1998) found no effect of corn row spacing on giant foxtail and little effect on common ragweed (*Ambrosia artemisiifolia*) biomass. Burcucumber (*Sicyos angulatus*) emergence and biomass were also not affected by decreased corn row spacing (Esbenshade et al. 2001).

No-till is defined as a system with soil disturbance limited to that created by the planting operation. Advantages and disadvantages of a no-till system have been debated over three decades. Advantages include reduced soil erosion, decreased fuel and labor costs, and improved soil moisture and tilth (Doran and Linn 1994, Frye 1984, Triplett and VanDoren 1977). The disadvantages associated with no-till include decreased soil temperature early in the season, increase in disease occurrence, and an increased reliance on herbicides to replace the role of tillage in weed control (Buhler 1992, Forcella et al. 1994, Johnson and Lowery 1985).

Weed control is often identified as the limiting factor in adoption of conservation tillage systems such as no-till (Koskinen and McWhorter 1996). A lack of understanding how tillage affects weed population dynamics makes weed management in no-till difficult. For effective control to be attained, weed response to tillage practices must be better understood.

Tillage influences vertical distribution, abundance, and longevity of seed in the seedbank (Cousens and Moss 1990, Roberts and Feast 1973). The most significant change in weed seed density and placement due to tillage occurs in the top 0 to 2.5 cm depth (Schreiber 1992). Non-inversion tillage, such as chisel till and no-till, tends to leave a higher proportion of seed near the soil surface (Ball 1992). After five years in a no-till system, 67% of all weed seed were located in the upper 1 cm of the soil with very few seed located below 10 cm. In a chisel till system, 32% of the weed seed were in the top 1 cm, with seed concentration decreasing linearly with increasing soil depth (Yenish et al. 1992). Pareja et al. (1985) found 85% of all weed seed in the upper 5 cm of soil in a reduced tillage system, whereas only 28%

were in the same zone under conventional tillage. Soil type also influences seed depth within tillage systems. This is especially true in no till, where soils that are prone to crusting may retain seed at the surface more than those with a high shrink-swell capacity (Cardina et al. 1991).

Differences in seed burial depth affect weed community composition because species whose seed survive, germinate, and emerge near the soil surface tend to increase under reduced tillage conditions (Buhler 1995). The fate of weed seed (germination, dormancy, or loss of viability) is dependent upon internal physiological conditions and environmental conditions encountered in the soil (Harper et al. 1965).

The greatest amount of germination of a specific seed lot tends to occur during the first growing season following seed dispersal (Egley and Williams 1991). Forcella et al. (1997) noted first-year *Amaranthus* spp. emergence ranged from 0.2 to 13% and averaged 3.3% across a 22 experiments. Annual emergence of common waterhemp rarely exceeded 7% of the initial seedbank, with approximately 15% cumulative emergence over a four-year period (Buhler and Hartzler 2001). In another experiment, Hartzler et al. (1999) found 15% cumulative waterhemp emergence over three years, with the majority of emergence occurring the first two years. An increase in the amount of crop residue on the soil surface, like that found in no-till, prolonged the emergence of several annual weeds when compared to bare soil (Buhler et al. 1996). Redroot pigweed had increased emergence and survival was significantly higher in no-till than chisel tillage (Buhler et al. 1996, Mohler and Calloway 1992).

Seed buried in the soil from previous tillage practices may persist for several years and remain a continuing source of infestation in a no-till system (Lueschen and Andersen 1980, Yenish et al. 1992). Research examining the persistence of common waterhemp seed found 12% of the initial seedbank remained after four years of burial with 95% of the seed viable (Buhler and Hartzler 2001). The viability of seed found in a no-till system was 74% compared to 59% in chisel plow (Mulugeta and Stoltenberg 1997).

Ogg and Dawson (1984) reported that weed seed that had been present in the seedbank more than one year emerged later than seed that had only overwintered one time. Other studies have found no difference in emergence pattern as influenced by the age of seed in the seedbank (Roberts 1964, Roberts and Feast 1970).

Densities of weeds have responded inconsistently to changes in tillage system. Tillage buries the seed, so it would be expected that decreased densities would exist with increasing tillage. No-till and chisel plow did not affect pigweed (Buhler 1992), foxtail, and common lambsquarters (Johnson et al. 1989) populations. In another study, giant foxtail and velvetleaf densities increased in no-till systems compared to a conventional chisel-till system (Buhler and Daniel 1988). Interactions between tillage and the effectiveness of control tactics also influence weed response to tillage (Buhler 2002).

Research Objectives

The acceptance of integrated weed management programs has been hindered by a lack of information on crop-weed interactions. By understanding

these interactions, development and application of timely, efficient, and effective management options can occur. The objectives of this research project were to:

- A) Evaluate the response of common waterhemp growth parameters to corn row spacing and date of common waterhemp emergence, and
- B) Evaluate the influence of tillage on common waterhemp seedbank behavior.

Common waterhemp has tremendous reproduction potential, which aids in the establishment and spread to previously uninfested land. Information on the effect of common waterhemp on corn yield has been documented, but information concerning the effect of corn on common waterhemp growth parameters is lacking. It is important to understand how crop yield is affected by weeds, but it is equally important to understand the effects of crops on the weeds and to develop cropping systems that suppress weed growth and survival.

Knowledge of weed seedbank behavior is critical in planning effective weed management systems (Buhler et al. 1997, Forcella et al. 1992b). The prediction of potential weed emergence would prove beneficial in developing integrated weed management strategies and aid in the conversion from conventional to a reduced tillage system. An understanding of the persistence and location of seed within the seedbank will aid in determining multi-year responses to management techniques.

INFLUENCE OF CORN ON COMMON WATERHEMP GROWTH AND FECUNDITY

A paper to be submitted to Weed Science

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Four experiments were conducted in central Iowa during 2001 and 2002 to determine the effect of common waterhemp (*Amaranthus rudis* Sauer) emergence timing in corn (*Zea mays*) planted in 38 and 76 cm rows on common waterhemp growth and fecundity. Four common waterhemp emergence cohorts were established in each experiment corresponding to the VE, V3, V5, and V8 stages of corn (*Zea mays*) development. Delayed emergence of common waterhemp in corn significantly affected all growth parameters of common waterhemp. Common waterhemp survival averaged 80, 44, 3, and 1% survival for the first, second, third and fourth cohorts respectively. Mature common waterhemp height for the first cohort was 140 cm, whereas plants emerging at the V8 corn stage were only 5 cm. Row spacing significantly affected biomass and fecundity of the first cohort, but later cohorts were not affected by row spacing. For example, biomass of the first cohort was 20% less in 38 cm rows than in 76 cm rows. Biomass and seed production of waterhemp emerging at the V3, V5, and V8 corn stages decreased 80, 97 and 99%, respectively in comparison to the first cohort.

Introduction

Integrated weed management systems have been proposed as a way of reducing the impact of weed management on the environment (Swanton and Weise 1991) . The development and acceptance of these systems can only occur after the biology and ecology of weeds in various cropping systems is understood.

Common waterhemp (*Amaranthus rudis* Sauer) is native to the Midwest, although it has only developed into a serious problem in corn (*Zea mays*) and soybean (*Glycine max*) in the last 15 years due to changes in production practices (Hager et al. 1997, Pammel 1913). The repeated use of triazine (Anderson et al. 1996), acetolactate synthase-inhibiting (Foes et al. 1998, Hinz and Owen 1997), and protoporphyrinogen oxidase-inhibiting (Patzoldt et al. 2002) herbicides has selected resistant biotypes of common waterhemp. A decrease in the use of tillage allows common waterhemp seed to remain at or near the soil surface, therefore providing optimum conditions for germination (Buhler 1992). Research in Iowa has found common waterhemp to initiate emergence in mid-May, whereas other important annual weeds such as velvetleaf (*Abutilon theophrasti*), giant foxtail (*Setaria faberi*), and woolly cupgrass (*Eriochloa villosa*) begin emerging in the latter part of April (Hartzler et al. 1999). The delayed emergence pattern of common waterhemp allows it to escape many control tactics, but places the plant at a competitive disadvantage with the previously established crop.

As weed emergence is delayed relative to the crop, less crop yield loss occurs. Corn yield is only slightly affected by redroot pigweed (*Amaranthus retroflexus*) (Knezevic et al. 1994) and common waterhemp (Murphy et al. 1996, Steckel and Sprague 2002) that emerge after the V5 stage of corn development. Although late emerging weeds may not affect yield they are still capable of interfering with harvest, reducing crop quality, and contributing to the future weed seedbank.

Biomass and seed production of common waterhemp rapidly decreased with delayed emergence in soybeans (Hartzler et al. 2003). Biomass of redroot pigweed also decreased with delayed emergence in sorghum (*Sorghum bicolor*) (Knezevic and Horak 1998). Redroot pigweed had less branching and an increased proportion of dry matter allocated to the upper portion of the plant canopy when compared to those plants grown in full sunlight (McLachlan et al. 1993). The reproductive capacity of plants also decreases with delays in emergence. Delayed redroot pigweed emergence in sorghum resulted in decreased allocation of dry matter to reproductive structures (Knezevic et al. 2001). Knezevic et al. (1994) reported that redroot pigweed seed production was reduced by 81% if emergence was delayed from the V3 to the V5 stage of corn development. Palmer amaranth (*Amaranthus palmeri*) 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 stage of corn (Massinga et al. 2001). Delaying emergence of common waterhemp in soybeans from VE to V6 decreased common waterhemp seed production 99% (Hartzler et al. 2003). The effect of delayed emergence on weed plant survival has rarely been noted. 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). Mohler and Calloway (1992) found that late emerging weeds in sweet corn had a better chance at survival by avoiding control tactics.

Narrowing corn row spacing allows the crop to fill inter-row spaces earlier in the growing season. Rapid 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 PAR interception, but that row spacing does affect PAR interception (Tharp and Kells 2001). Farnham (2001) found that optimum corn yield was attained at the same planting density (79,100 plants ha⁻¹) in both 38 and 76 cm rows.

The use of narrow row spacing has proven effective in improving weed control in soybeans (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 due to 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*)(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 limiting light environment of 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*).

The success of integrated weed management programs is based on the understanding of weed population dynamics and then developing appropriate control

tactics based on this knowledge (Buhler and Hartzler 2001). An understanding of common waterhemp responses to the corn crop will aid in creating an environment unfavorable for weed growth, while maintaining crop competitiveness. The objective of this research was to evaluate the impact 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 (38cm) rows would suppress growth of late emerging common waterhemp more than corn planted in conventional (76 cm) rows.

Materials and Methods

Four experiments were conducted during 2001 and 2002 in central Iowa at the Iowa State University Hinds and Curtiss Farms near Ames, Iowa and at a private farm near Stratford, Iowa, 64 kilometers 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 soybeans in the season prior to the experiment. Experimental areas were chisel plowed in the fall and field cultivated prior to planting. Urea was applied pre-plant in the spring of 2001 and 2002 to all locations at 336 kg of N ha⁻¹. Weekly rainfall amounts and average daily temperature from the Ames, Iowa ISU Ag Climate station are presented in Table 2 and Figure 1.

A randomized complete block with a split plot arrangement with four replications was utilized. Main plots were glyphosate-resistant corn (Golden Harvest H8194) planted in 38 and 76 cm rows at a population of 79,100 seed ha⁻¹ and sub plots were waterhemp emergence cohorts. Four waterhemp emergence cohorts

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

Location	Year	Soil type	pH	% OM ¹	Corn		Waterhemp	
					Planting Date	Emergence date	Emergence date	Corn leaf stage ²
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

¹ Abbreviation: OM, organic matter.

² Corn leaf stage at time of common waterhemp emergence.

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

Month	Days	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

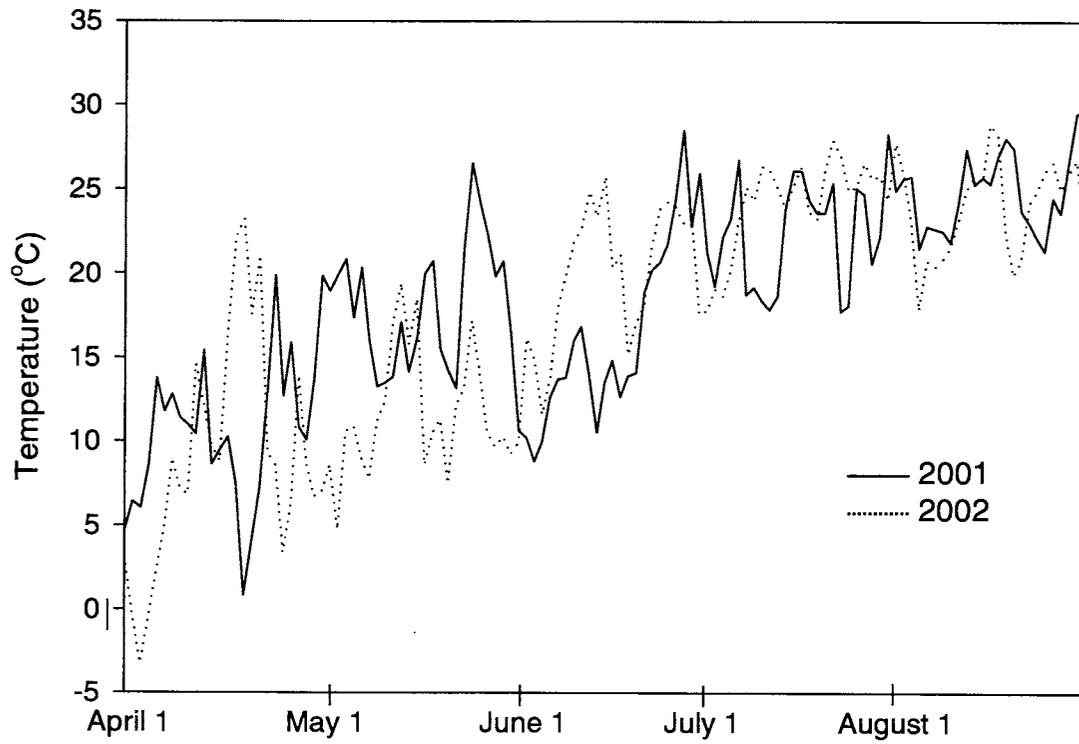


Figure 1. Average daily air temperature in 2001 and 2002 at Ames, Iowa (April through August).

were selected in relation to corn development (VE, V3, V5 and V8). Each cohort was comprised of 30 waterhemp plants selected from natural infestation or seedings between rows in a 65 m² area. Seed for the artificial planting was collected the prior fall and stored at 4° C until two weeks prior to planting. At this time, water was added and seed was returned to 4° C. Common waterhemp seed was planted 7 to 10 days prior to the appropriate corn stage by suspending the seed in Laponite RD gel¹ and injecting them 1 to 2 cm below the soil surface. Common waterhemp seed was watered approximately every four days until emergence. Common waterhemp plants that emerged at the appropriate time were selected at the cotyledon stage and their location marked using aluminum tags inserted in the ground adjacent to the plant. Plants were selected that were at least 0.5 m from other targeted waterhemp plants. Weed control was achieved with hand weeding and one to two applications of 0.85 kg ae ha⁻¹ glyphosate. Tagged waterhemp plants were covered with plastic cups to prevent contact with glyphosate.

Height and survival of tagged waterhemp plants were recorded throughout the growing season. At the initiation of common waterhemp senescence, 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 five days at 35°C and weighed. Seed production was based on plant dry weight using a linear regression equation determined by Hartzler et al. (2003). To validate this method, seed was separated from 20 female waterhemp plants using sieves and an air column separator.

¹ Southern Clay Products, Inc., 1212 Church Street, Gonzales, Texas, 78629, USA.

Correlation between seed production of these plants and the previous research was greater than 95% and determined adequate; therefore, seed production is based on plant dry weight. Corn yields were not taken due to differential mortality among treatments and variation in common waterhemp densities.

Common waterhemp height, shoot dry weight, and seed production were log transformed. The regression analyses for the growth parameters were completed using SigmaPlot². The relationship between corn row spacing and common waterhemp date of emergence were analyzed separately for each growth parameter using analysis of variance in SAS. The PROC GLM procedure was used in SAS because sample size differed among treatments. Untransformed means are presented. The proportion of common waterhemp plants that survived was transformed using the arcsin transformation (Kuehl 2000). Transformed percentages were analyzed using analysis of variance in SAS. The untransformed means of common waterhemp survival 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 waterhemp emergence relative to corn emergence reduced the survival of common waterhemp plants (Table 3). Corn row spacing did not affect survival rate at any emergence time. Common waterhemp emerging at the VE stage of corn averaged 80% survival to maturity, whereas plants emerging at the V3

² SPSS Inc., Jandel Scientific, San Rafael, CA, USA.

Table 3. Common waterhemp survival, height, shoot dry weight, and seed production per plant as affected by time of emergence (TOE) and corn row spacing.

Growth parameter ¹	Corn row spacing	Corn stage at time of emergence ³				TOE ²
		VE	V3	V5	V8	
		----- % -----				
Survival	38 cm	76	40	3	0	**
	76 cm	84	48	4	1	
		----- cm -----				
Height	38 cm	142	83	17	0	**
	76 cm	139	77	32	9	
		----- g -----				
Shoot dry weight	38 cm	25.1*	6.0	0.2	0.0	**
	76 cm	31.3*	5.0	1.1	0.1	
		----- no. plant ⁻¹ -----				
Seed production	38 cm	39,450*	9,000	580	0	**
	76 cm	48,400*	9,050	1,300	0	

¹ Means are pooled over location and year.

² Main effect of TOE presented for each growth parameter pooled over row spacing as determined by ANOVA. Significance: * = significant at $P = 0.05$, ** = significant at $P = 0.01$.

³ Means followed by an asterisk within a TOE and parameters differ in significance between row spacing as determined by ANOVA ($P = 0.01$).

and V5 stages averaged 44% and 3% survival, respectively. Less than 1% of plants emerging at the V8 time survived. Waterhemp mortality occurred throughout the growing season, rather than a single event resulting in a majority of the deaths (data not presented).

Most studies examining the effect of delayed emergence on weed growth and competitiveness do not report survival rates of late-emerging plants (Knezevic and Horak 1998, Knezevic et al. 2001, Massinga et al. 2001, McLachlan et al. 1993). Late-emerging weeds in sweet corn had higher survival than early-emerging weeds due to 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 and decreased approximately 40, 80 and 95% with each successive delay relative to corn emergence (Table 3). Emergence delays in relation to corn emergence and row spacing resulted in a linear decrease in log-transformed common waterhemp height (Figure 2). Corn row spacing did not affect common waterhemp height. The distributions of plant heights are presented in Figure 3. The variability in height increased as emergence was delayed. Heights of first cohort common waterhemp ranged from 60 to 240 cm. Many plants that emerged at the VE corn stage became etiolated and the plants either fell down or

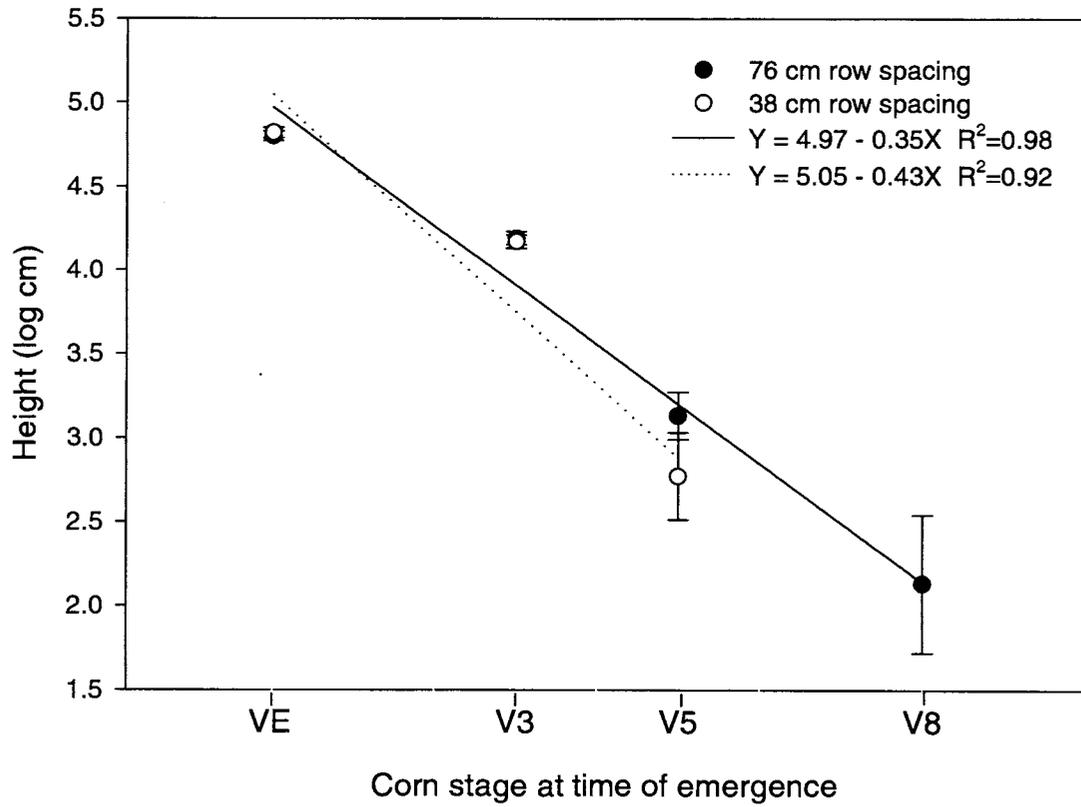


Figure 2. Height of common waterhemp as affected by emergence delays in relation to corn stage. Bars represent standard error of means.

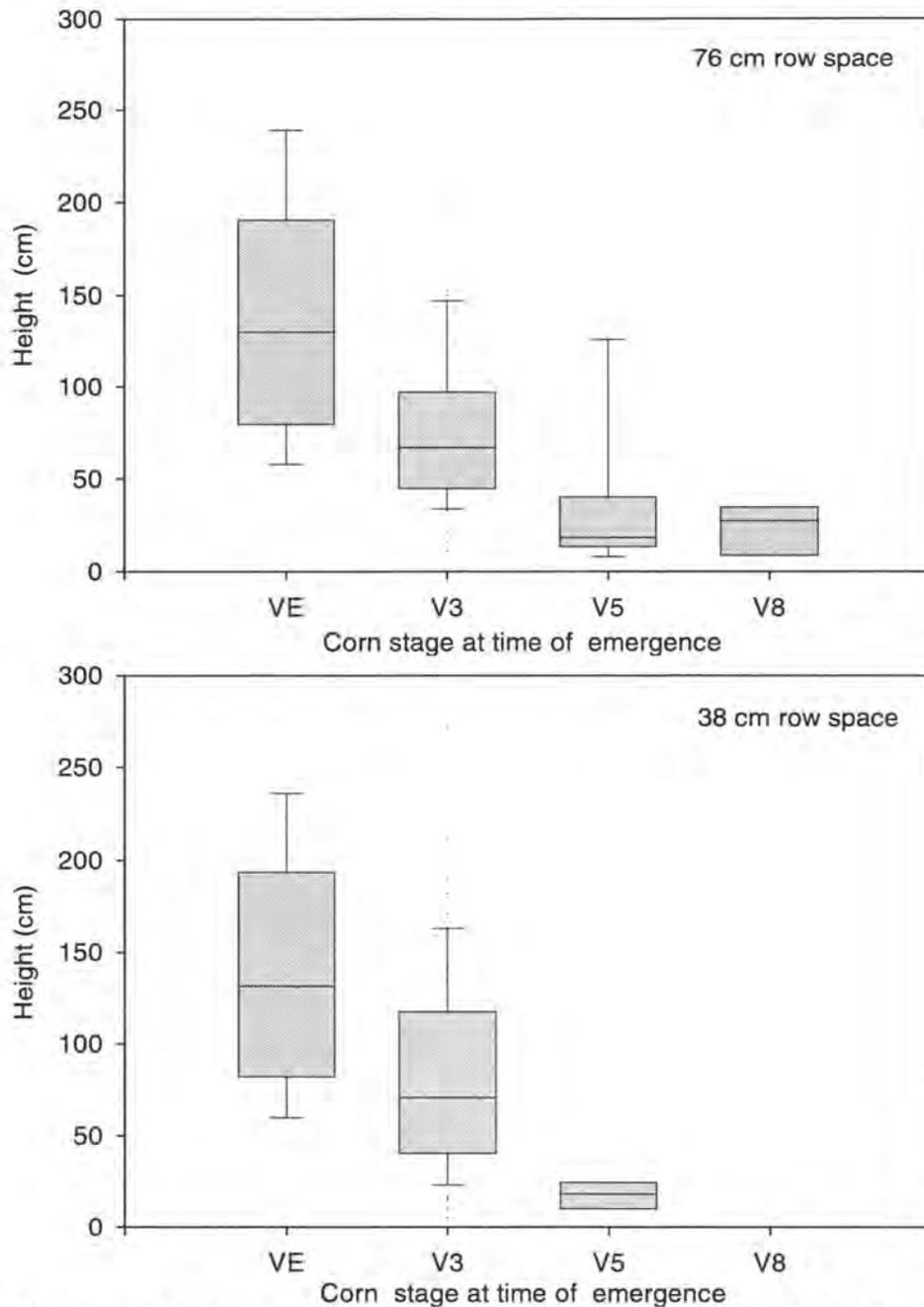


Figure 3. Height distribution of common waterhemp as affected by emergence delays in 76 cm and 38 cm corn row spacing. The ends of each bar mark the 10th and 90th percentiles; the top and bottom of each shaded box denote the 25th and 75th percentiles, respectively. The horizontal line within each box denotes the median.

relied on neighboring corn plants for support. Very few plants reached above the corn canopy (2.5 m). Later emerging plants rarely grew above ear height on the corn plant (1 m).

Biomass accumulation (Figure 4) of common waterhemp declined more rapidly in response to delays in emergence than did plant height (Figures 3). The majority of plants emerging at VE corn stage weighed less than 40 g and 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 to that grown in wide rows (Table 3). Plants that emerged after VE corn stage were not affected by row spacing (Figure 5); however, each delay in emergence accounted for 80, 95 and 99% reductions in biomass compared to plants that emerged with corn (Table 3).

Redroot pigweed growing in competition with corn (McLachlan et al. 1993) and sorghum (Knezevic et al. 2001) altered the allocation of dry matter compared to those growing in absence of competition. Late-emerging redroot pigweed had increased allocation of dry matter in the main stem components and less from branch components in the presence of corn (McLachlan et al. 1993). Vertical distribution was also altered, with more dry matter allocated to the upper portion of the canopy than lower portions.

Seed production by female common waterhemp plants emerging at the VE corn stage was greater in wide rows than narrow rows (Table 3). Plants in wide rows averaged over 48,000 seeds per plant, whereas plants in narrow rows only produced around 39,000 seeds per plant. Row spacing did not affect later emergence cohorts, but delays in emergence did decrease seed production to

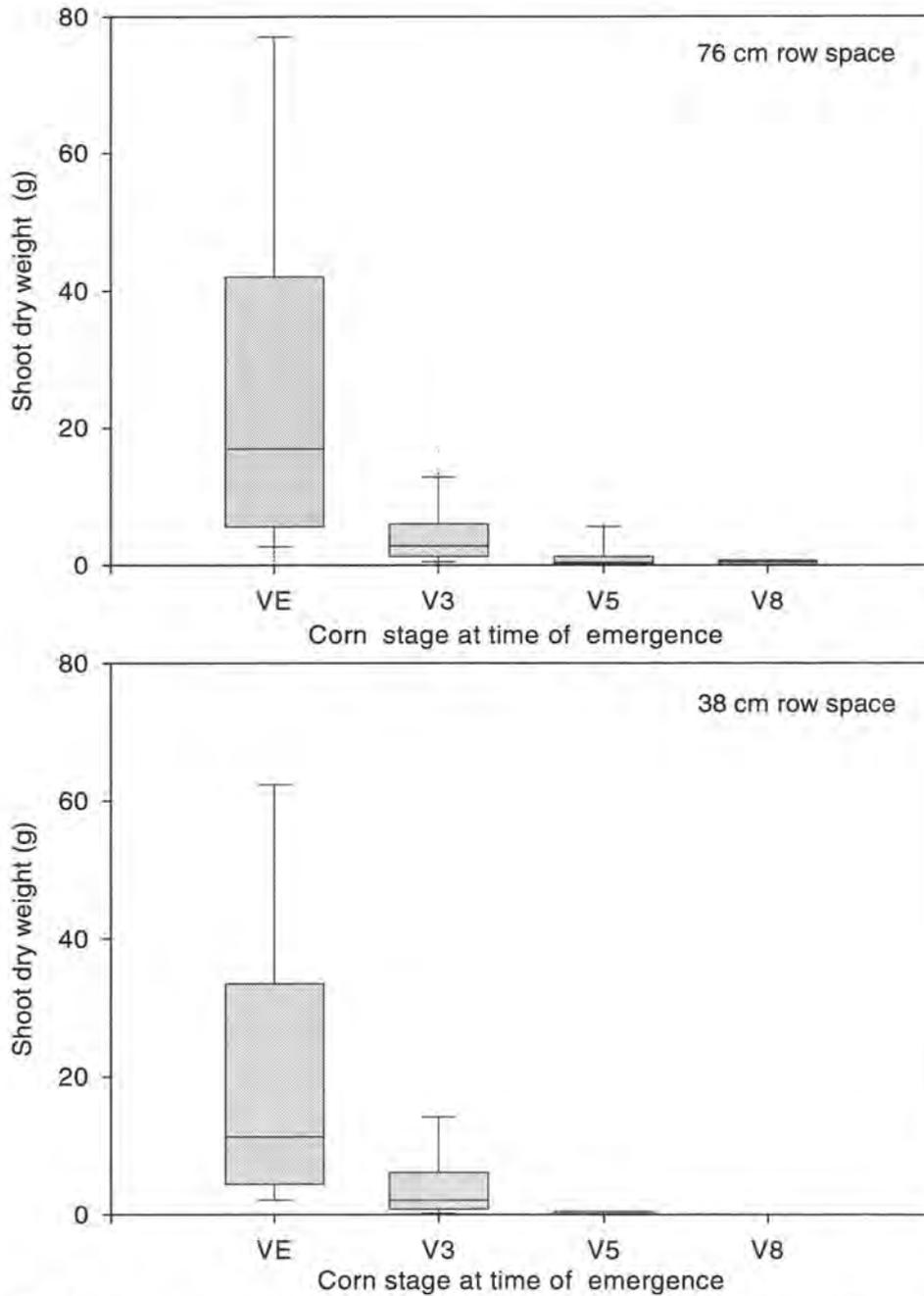


Figure 4. Shoot dry weight distribution of common waterhemp as affected by emergence delays in 76 cm and 38 cm corn row spacing. The ends of each bar mark the 10th and 90th percentiles; the top and bottom of each shaded box denote the 25th and 75th percentiles, respectively. The horizontal line within each box denotes the median.

approximately 9000 and 950 seeds when 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 this study with corn was much less than reported by Hartzler et al. (2001) in soybean. Average seed production of plants emerging with soybeans was 309,000 seeds per plant, six times greater than that of plants emerging with corn. Redroot pigweed seed production in monoculture produced up to 400,000 seeds per plant, but was reduced to 80,000 seeds per plant when grown in competition with sorghum (Knezevic and Horak 1998). Palmer amaranth fecundity decreased from 140,000 seeds m^{-2} to 1800 seeds 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 seeds per plant when emerging before the V4 corn stage and 1500 seeds per plant when emerging between V4 and V7. The fecundity of common waterhemp tapers off dramatically with delayed emergence; even so, the later emerging plants are still capable of producing a large enough quantity of seeds to recharge the seedbank.

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 seeds when emerging at the V5 corn stage; however, when combined with only a 3% chance of survival, these plants would likely have such low economic value as to not warrant further control measures under most scenarios. Narrow row spacing was only effective in reducing

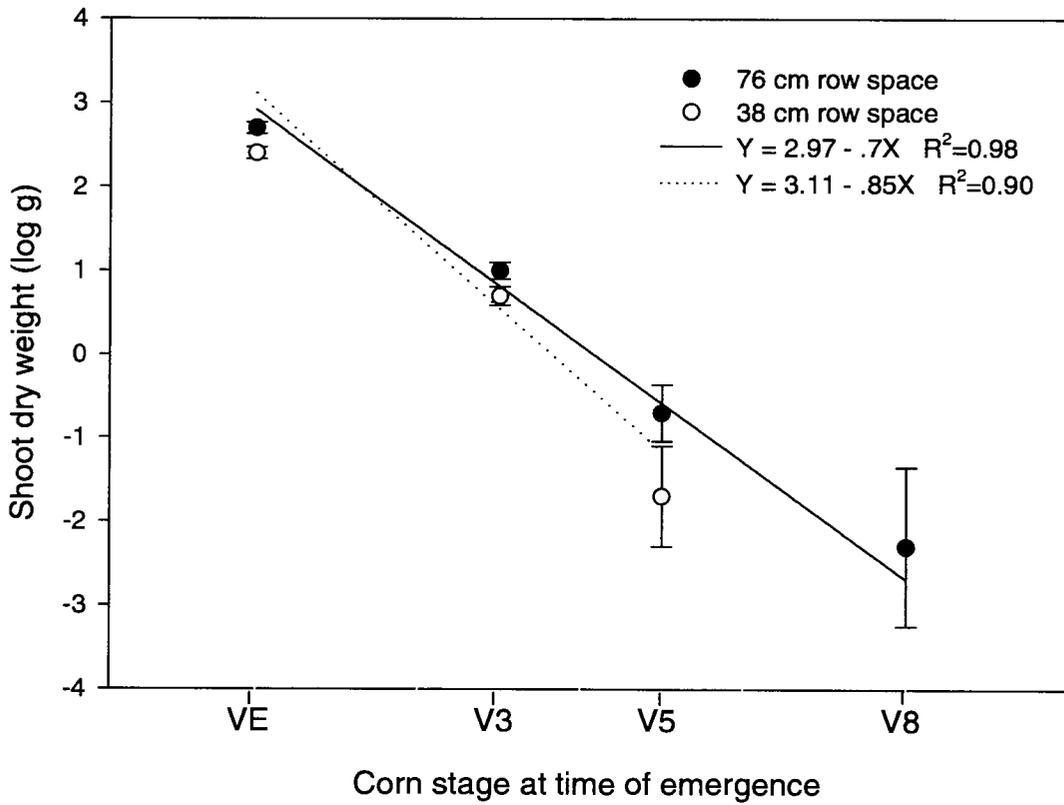


Figure 5. Shoot dry weight of common waterhemp as affected by emergence delays in relation to corn stage. Bars represent standard error of means.

the biomass and seed production of the first cohort, not the later emerging weeds.

This rejects the hypothesis that narrow rows would reduce the impact of late emerging weeds more than conventional row spacing. Decreasing row spacing will increase the amount of light intercepted by crop through faster canopy closure, leaving less light available for weed germination and growth earlier in the season. The use of narrow row spacing could also decrease the chance of leaving gaps that occur between planter passes in wide rows where weeds may appear.

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EFFECT OF TILLAGE ON COMMON WATERHEMP EMERGENCE AND VERTICAL DISTRIBUTION OF SEED IN THE SOIL

A paper to be submitted to Weed Science

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Field studies were conducted in 2001 and 2002 to determine the effects of tillage on the behavior of common waterhemp (*Amaranthus rudis* Sauer) in the soil seed bank. Emergence of common waterhemp was greater in no-till than chisel till. Tillage did not affect the initial time of emergence; however, the time to 50% emergence was longer in no-till than chisel till. Duration of emergence did not differ among tillage systems. Common waterhemp seed was concentrated near the soil surface in no-till, whereas seed in the chisel till were primarily found between 9 and 15 cm. The delayed and increased emergence in no-till contributes to the problems in managing common waterhemp in this system.

Introduction

The prolific seed production of common waterhemp has played a role in helping it become a major pest in crop fields. Plants have been reported to produce over five million seeds per plant (Hartzler et al. 2001). One of the most important factors in effectively managing a weed is to understand its germination and emergence characteristics. Germination and emergence patterns of waterhemp are characteristics that contribute significantly to management problems. In central Iowa, common waterhemp plants typically begin emerging in mid to late May (Hartzler et al. 1999). While peak emergence of most summer annual weeds generally occurs during the early portion of the growing season, common waterhemp

emergence can easily extend from the middle to late portions of the growing season (Hartzler et al. 1999).

The advantages and disadvantages of no-till have been debated over decades. Reduced soil erosion, improved soil moisture and tilth, and decreased fuel and labor costs are commonly highlighted as advantages of no-till (Doran and Linn 1994, Frye 1984, Triplett and VanDoren 1977). Disadvantages include decreased early season soil temperature, greater incidence of disease, and increased reliance on herbicides to replace tillage (Buhler 1992, Forcella et al. 1994, Johnson and Lowery 1985). However, weed control is often identified as the limiting factor in adopting conservation tillage systems (Koskinen and McWhorter 1996). A lack of understanding of the effects of tillage on the behavior of common waterhemp in regards to emergence, persistence, and location in the seed bank makes weed management even more difficult.

Annual emergence of common waterhemp has been reported to rarely exceed 7% of the initial seed bank, with cumulative emergence averaging approximately 15% over three year (Hartzler et al. 1999) and four year period (Buhler and Hartzler 2001). Research examining the persistence of common waterhemp seed found 12% of the initial seed bank had 95% viability after four years of burial (Buhler and Hartzler 2001).

The presence or absence of tillage has been cited as influencing many aspects of the seed bank. Crop residue remaining on the surface in no-till practices may prolong and increase the amount of emergence and survival for redroot pigweed (Buhler et al. 1996, Mohler and Calloway 1992). The viability of weed seed

found in a no-till and chisel till system averaged 74% and 59%, respectively (Mulugeta and Stoltenberg 1997).

The vertical distribution of seed and longevity are strongly influenced by tillage (Cousens and Moss 1990, Roberts and Feast 1973). The fraction of seed found in the upper 5 cm of the soil surface is 70 to 85% in no-till and approximately 30% in chisel till (Pareja et al. 1985, Yenish et al. 1992). Less intensive tillage allows the seed to remain near the soil surface where it is more likely to encounter favorable conditions for germination and establishment (Buhler 1992). In a study examining redroot pigweed (*Amaranthus retroflexus*) requirements for emergence, optimum germination occurred between 35° to 40°C and at a depth of 0.5 to 3 cm (Ghorbani et al. 1999). Cardina et al. (2002) reported that densities of small seeded broadleaves were higher in no-till compared to chisel tillage and that this is reflective of the high density of seed located near the soil surface. Giant foxtail (*Setaria faberi*) emergence was three times greater in no-till than chisel till (Schreiber 1992). Buhler and Mester (1991) found at least 40% of *Setaria* spp. emerged from the upper 1 cm of soil in no-till compared to 25% in chisel tillage, with emergence from depths greater than 4 cm averaging 5% in no-till and 10% in chisel tillage.

Information related to the effects of production practices on common waterhemp will aid in developing more efficient approaches to manage this weed and aid growers in the conversion from a conventional to a no-till system. Therefore, the objectives of this research were to evaluate the emergence, persistence, and vertical distribution of common waterhemp seed as affected by an established no-till or chisel till system.

Materials and Methods

Seed Collection and Preparation

Common waterhemp seed was collected from one mature female plant in the fall of 2000 and one in the fall of 2001 in Story County, Iowa. Common waterhemp seed from each year was divided into 16 lots of 10,000 based on weight. Seed was stored at room temperature in paper bags until plot establishment.

Plot Description and Installation

Experiments were conducted in Field 63 in 2001 and in Field 70 in 2002 at the Agriculture and Biosystems Engineering Research Center near Ames, Iowa. Both fields were maintained in a long-term tillage study prior to the initiation of this study. Neither field had prior serious problems with common waterhemp in the years preceding initiation of the experiments. The chisel tillage system in both fields included fall chisel tillage after harvest and disc and field cultivation prior to planting in the spring. Weekly rainfall amounts and average daily temperature from the Ames, Iowa ISU Ag Climate station are presented in Table 2 and Figure 1.

Field 63 was a randomized complete block design with four replications. Main plots were no-till and chisel till that have been in place since 1998. The soil type was a Canisteo silty clay loam (Mesic Typic Haplaquoll) with a pH of 7.7 and 6.0% organic matter. The previous crop in 2000 was soybean. Micro-plots were established 3 m from the front of each block in November 2000 to create artificial seed banks prior to fall tillage. Eight micro-plots were created by removing crop residue from a 1 m² area and evenly distributing 10,000 common waterhemp seed over the soil surface and then replacing crop residue. Glyphosate resistant

corn (Dekalb DK545RR) was planted in 76 cm rows at 79,100 seed ha⁻¹ on April 26, 2001. Nitrogen fertilizer (28% UAN) was side-dressed in the plots at a rate of 170 kg ha⁻¹ approximately one month after planting. Glyphosate was applied when weeds were approximately 10 cm tall at a rate of 0.85 kg ae ha⁻¹ on May 29, 2001.

Field 70 was also a randomized complete block design consisting of two tillage treatments in four replications. Continuous corn had been grown in 76 cm rows in the experimental area since 1981. The soil type was a Clarion loam (Mesic Typic Hapludoll) with a pH of 6.6 and 3.5% organic matter. Eight micro-plots were established in November of 2001 using the same protocol as in 2000. Glufosinate resistant corn (Pioneer 35P17) was planted at 70,500 seed ha⁻¹ on April 26, 2002. Nitrogen fertilizer (32% UAN) was knifed into the plots at a rate of 195 kg ha⁻¹ one month after planting. Glufosinate was applied when weeds were approximately 10 cm tall at a rate of 1.9 kg ai ha⁻¹ on June 5, 2002.

Data Collection and Analysis

Seedbank Emergence

Seedlings were counted twice weekly from April to July, after which counts were taken weekly until harvest. Common waterhemp were counted and removed by hand at the cotyledon stage, allowing for an accurate measurement of the emergence from the seed bank and reducing competition for resources.

Initial time of emergence (ITE), days to 25% emergence, days to 50% emergence, days to 90% emergence, duration of emergence, and cumulative emergence were determined for each plot. Plot means for each parameter were then analyzed using analysis of variance in SAS. Data were further analyzed for

tillage effects by year using the TTEST procedure in SAS. Statistical differences in all data were determined at the $P=0.05$ level.

Soil Seed Bank

In 2001 and 2002, soil samples were taken in the spring prior to planting and in the fall after harvest. Sampling consisted of five cores, 5 cm in diameter and 15 cm deep, taken from a 0.09 m² area in the center of each micro plot. A systematic sampling pattern was used to avoid resampling the same areas. Soil cores were then divided into three sections based on depth: 0 to 3 cm, 3 to 6 cm, and 6 to 15 cm. Individual cores were pooled for each micro-plot then placed into capped strainers lined with 0.5 mm stainless steel screens. Strainers were placed in an elutriator for one hour. The elutriator uses water to separate weed seed from clay and silt particles (Wiles et al. 1996). After elutriation, samples were dried at 35°C for 24 hours. All remains within the strainer were emptied into a petri dish for sorting. Common waterhemp seed recovered was only counted if viable. Seed was considered viable if they were firm when pressured by the tip of a forceps (Rothrock et al. 1993).

All data were analyzed for tillage effects by year and sampling date using the TTEST procedure and Tukey's HSD Test in SAS at $P = 0.05$ unless otherwise noted.

Results and Discussion

Seedbank Emergence

Cumulative emergence from the previous fall seed bank ranged from 2% in chisel till to 7% in no-till (Table 2). A higher percentage of seed emerged in 2001 than in 2002 (data not presented). Common waterhemp emergence was previously

reported to be less than 10% emergence in the first year after burial (Hartzler et al. 1999). Research in both Iowa and Wisconsin found that redroot pigweed emergence was greater under no-till conditions than in systems with tillage (Buhler et al. 1996, Mohler and Calloway 1992).

Initial time of emergence was not affected by tillage. Emergence in 2001 began one to two weeks earlier than in 2002 (data not presented). Initial emergence for many weed species is noted to vary among years due to environmental conditions (Buhler and Hartzler 2001, Hartzler et al. 1999). The numbers of days to reach 25% and 50% of annual emergence were significantly affected by tillage. Time to 25% emergence was two times greater in no-till than chisel till. Thirty-five days after initial emergence, common waterhemp in no-till reached 50% emergence, whereas it only took ten days in chisel till. Tillage systems also differed in the number of days to reach 90% emergence. The no-till treatment did not reach 90% emergence until July 3, whereas the chisel till treatment reached 90% on June 19. Duration of common waterhemp emergence was 26 days longer in no-till than chisel till. Plants continued emerging in no-till plots until August in 2001. Tillage effects on emergence may be attributed to differences in soil temperature, precipitation, and the amount of crop residue on the soil surface (Buhler and Daniel 1988, Buhler et al. 1996).

The number of seedlings that occurred at each emergence event in 2001 was much greater in no-till than chisel till (Figure 2). Very little emergence occurred in both the no-till and chisel till for one week after N application (May 29), although emergence in 2002 did not seem affected by N application.

Table 2. Initial time of emergence (ITE), days to 25%, 50%, and 90% of annual emergence, duration of emergence (DOE), and cumulative emergence (CUM) for common waterhemp as affected by tillage.

Tillage	ITE	25%	50%	90%	DOE	CUM
		-----Days-----				% ¹
No-till	May 24 a ²	17 a	35 a	40 a	53 a	7 a
Chisel till	May 26 a	8 b	10 b	26 b	27 b	2 b

¹ Based on percentage of 10,000 seed m⁻² spread on the soil surface in fall 2001 and 2002.

² Means followed by the same letter within year and parameter did not differ as determined by paired t-test ($P < 0.05$).

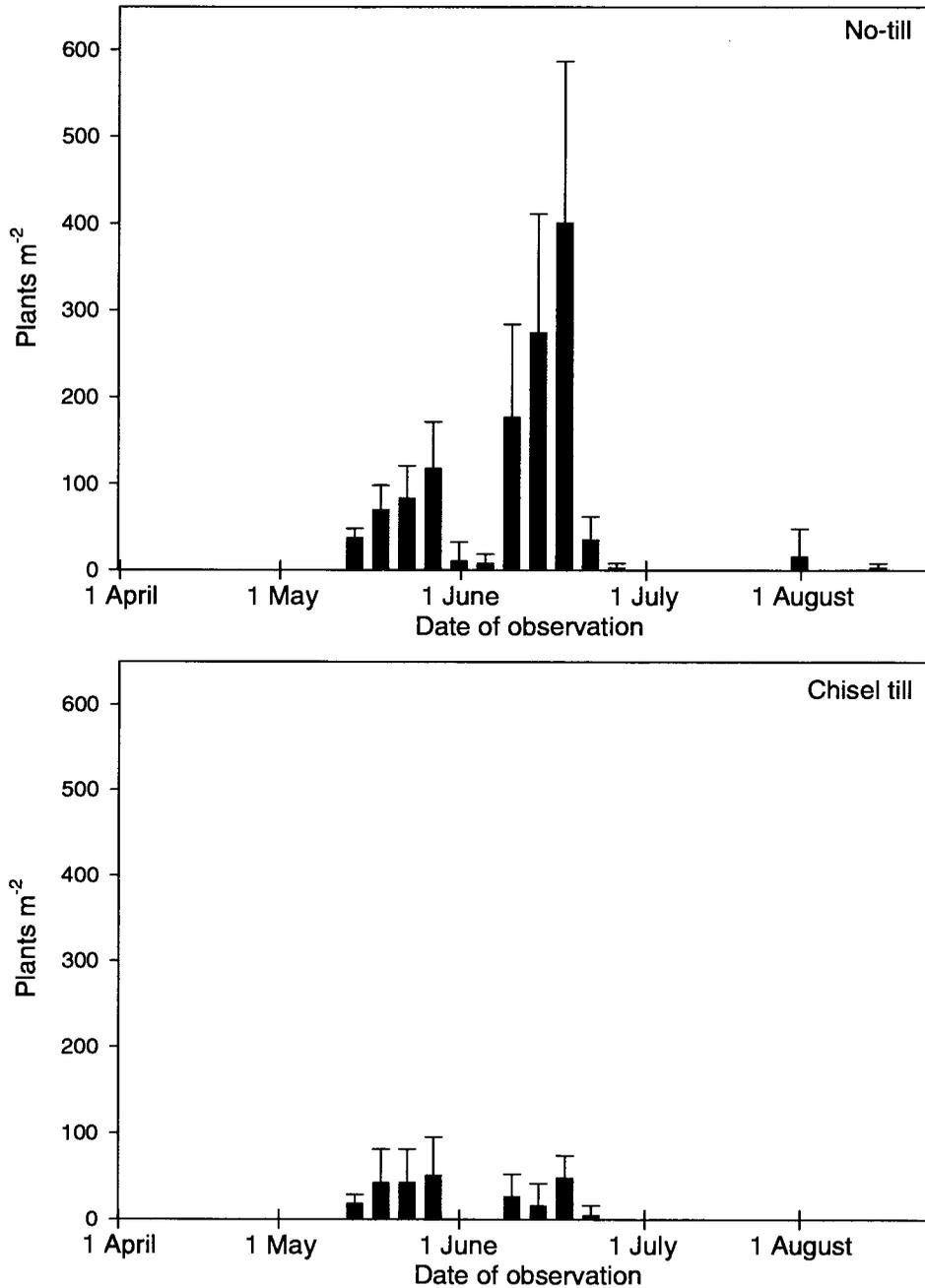


Figure 2. Emergence periodicity of common waterhemp in no-till and chisel till during 2001 following spread of 10,000 seed m⁻² on soil surface in November 2000. Bars represent standard error of means.

application. In 2002, common waterhemp emerged throughout early and mid June, but terminated on June 21. Emergence resumed on July 13 following significant rainfall events between July 4 and 10 (Figure 3).

Vertical Distribution of Seed

Common waterhemp seed were found at a greater density in the upper 3 cm soil zone of no-till than in chisel till for the spring sampling (Table 3). Chisel till had more seed in the lower 9 cm than the 0 to 3 cm sampling depth in three of four sampling times. Viable seed were present in the no-till at the 6 to 15 cm depth after three years without tillage. Previous research by Yenish et al. (1992) and Cardina et al. (2002) found a higher number of seed in no-till near the surface, whereas in chisel till seed were evenly distributed throughout the tilled zone. Distribution and density of seed may have been influenced by post dispersal seed predation which has been cited to act as a filter on the seed rain (Hulme 2002).

Common waterhemp emergence timing and abundance was influenced by tillage. The large number of seed found in the upper portion of the soil profile in no-till correlates to the increased emergence that occurs in that tillage system. Growers switching from chisel tillage to no-till need to emphasize weed control during the transition to prevent weeds from increasing and becoming more difficult to control. The prolific seed production of common waterhemp allows for a rapid increase in the seedbank (Hartzler et al. 2001). Special attention should be made to scout for common waterhemp through canopy closure in corn and soybean fields. The prolonged emergence pattern in no-till compared to chisel till may influence the duration that weed management strategies need to be in place during the growing

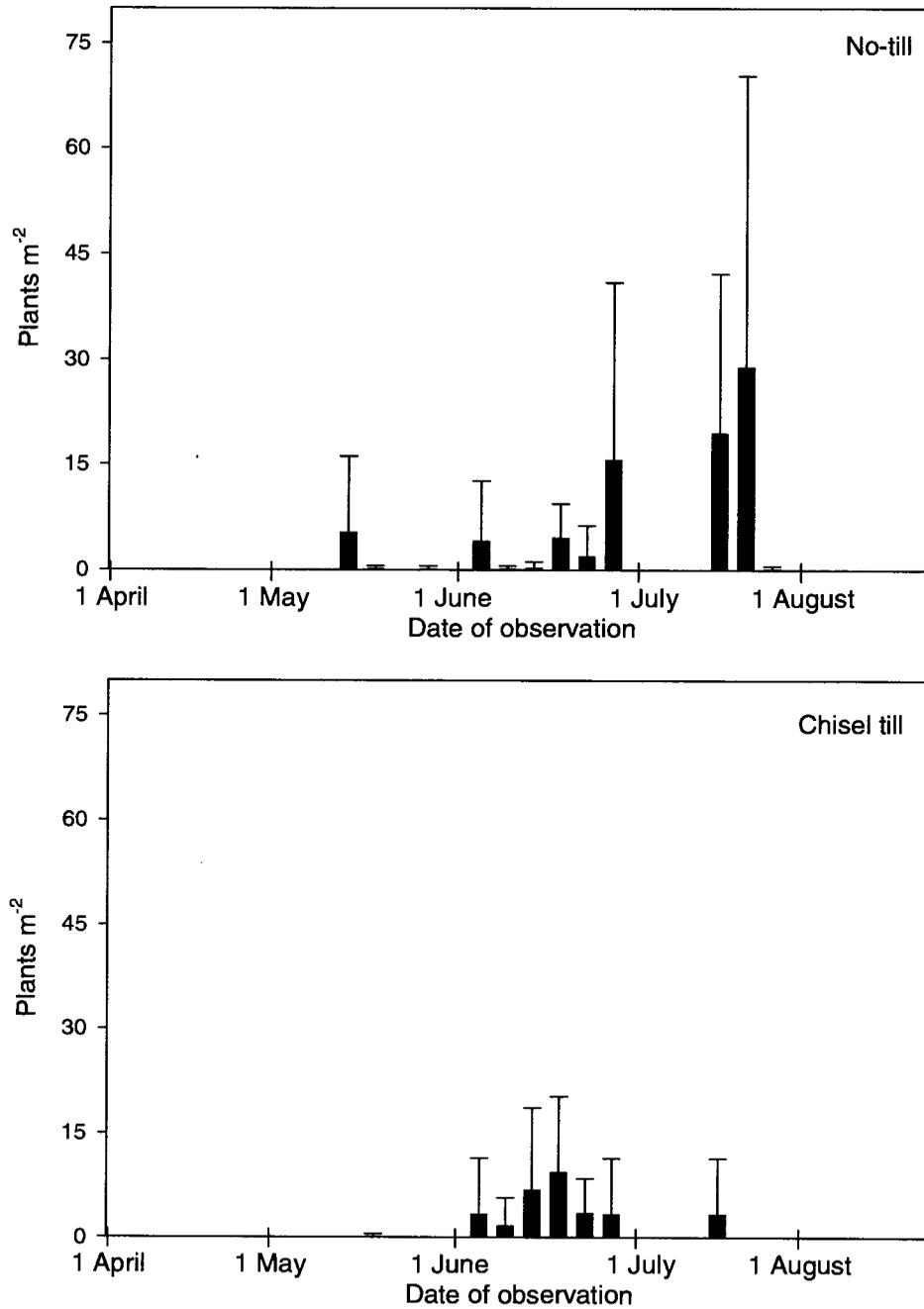


Figure 3. Emergence periodicity of common waterhemp in no-till and chisel till during 2002 following spread of 10,000 seed m⁻² on soil surface in November 2001. Bars represent standard error of means.

Table 3. Distribution of common waterhemp seed by depth as affected by tillage at Ames, IA for 2001 and 2002.

Year	Tillage	Spring			HSD ¹	Fall			HSD
		0–3 cm	3–6 cm	6–15 cm		0–3 cm	3–6 cm	6–15 cm	
		----- seed cm ⁻³ soil-----				----- seed cm ⁻³ soil-----			
2001	No-till	21* ²	17	18	NS	9	1	0	6
	Chisel till	10*	16	19	7	4	3	8	NS
2002	No-till	29*	8	16	12	7	3	3	NS
	Chisel till	1*	10	12	9	1	2	10	5

¹ Tukey's Honestly Significant Difference (at $P < 0.05$) value for comparisons within a row and sampling date.

² Means followed by an asterisk within year, sampling depth, and sampling time differed as determined by paired t-test ($P < 0.05$).

season. The percentage of common waterhemp plants that emerge between control measures and canopy closure may vary among tillage systems. Production practices that decrease the time to canopy closure, increase the amount of light intercepted by the canopy, and use accurate and timely herbicide application will be advantageous in no-till systems to increase crop competition with common waterhemp.

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GENERAL CONCLUSIONS

Delayed emergence of common waterhemp in corn decreased survival, growth and fecundity of plants. The suppression of waterhemp due to interspecific competition with corn was greater than reported with interspecific competition with soybean (Hartzler et al. 2003). Common waterhemp plants that emerged with soybean averaged 220 g shoot dry wt whereas plants that emerged with corn weighed only 10 g. The fecundity of common waterhemp was 44 times greater in soybean than in corn. Less than 1% of common waterhemp emerging at the V8 stage of corn survived to maturity. Decreasing corn row spacing was not effective in suppressing late-emerging waterhemp compared to conventional 76 cm rows.

Percent of seeds emerging and the duration of common waterhemp emergence was influenced by tillage. Initial time of common waterhemp emergence was not affected by tillage, but twice as many plants emerged in no-till as in chisel till throughout the growing season. The duration of emergence was 26 days longer in no-till than chisel till. The prolonged emergence of common waterhemp in no-till increases the need for management strategies that provide effective control until the crop canopy is capable of effectively suppressing common waterhemp seedlings. Production practices that increase light interception by the crop and shorten the time to canopy closure will be beneficial, especially in no-till.

This research has provided insights into the biological characteristics of common waterhemp. This understanding of the competitive ability and emergence pattern of common waterhemp in corn will allow growers to develop and implement accurate and efficient control measures.

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