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Within-Season Changes in the Residual Weed Community and Crop Tolerance to Interference over the Long Planting Season of Sweet Corn

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Sweet corn is planted over a long season to temporally extend the perishable supply of ears for fresh and processing markets. Most growers' fields have weeds persisting to harvest (hereafter called residual weeds), and evidence suggests the crop's ability to endure competitive stress from residual weeds (i.e., crop tolerance) is not constant over the planting season. Field studies were conducted to characterize changes in the residual weed community over the long planting season and determine the extent to which planting date influences crop tolerance to weed interference in growth and yield traits. Total weed density at harvest was similar across five planting dates from mid-April to early-July; however, some changes in composition of species common to the midwestern United States were observed. Production of viable weed seed within the relatively short growth period of individual sweet corn plantings showed weed seedbank additions are influenced by species and planting date. Crop tolerances in growth and yield were variable in the mid-April and both May plantings, and the crop was least affected by weed interference in the mid-June and early-July planting dates. As the planting season progressed from late-May to early-July, sweet corn accounted for a great proportion of the total crop–weed biomass. Based on results from Illinois, a risk management perspective to weeds should recognize the significance of planting date on sweet corn competitive ability. This work suggests risk of yield loss from weed control failure is lower in late-season sweet corn plantings (June and July) than earlier plantings (April and May).

Nomenclature: Corn, *Zea mays* L.

Key words: competitive ability, integrated weed management, planting date, risk management.

Weeds often escape control in sweet corn and yield losses due to weed interference are prevalent. More herbicides are used in sweet corn compared to 40 yr ago, which is associated with fewer weeds present at crop harvest (hereafter called residual weeds) (Williams et al. 2008b). However, over one half of fields continue to suffer yield loss due to weed interference. Poor weed control in sweet corn may exacerbate weed problems in rotational vegetable crops, which have comparatively fewer herbicides registered for use (Fennimore and Doohan 2008). Moreover, weeds are a serious challenge to hybrid seed production and represent the most difficult pests to manage in sweet corn grown for an expanding organic market (R. Teyker, Del Monte Foods, personal communication).

Crop competitive ability consists of two aspects: the crop's ability to suppress weed growth and seed production (weed suppressive ability [WSA]), and the ability of the crop to endure or avoid competitive stress from weeds without substantial reduction in growth or yield (crop tolerance [CT]). Historically, crop competitive ability has been a fundamental component of weed management. Except in cropping systems where culinary issues are paramount and handweeding is economically practical (e.g., weeds in lettuce), CT and WSA continue to be important components of weed management. Crop competitive ability is often examined in terms of cultivar tolerance, in particular, the feasibility of breeding more competitive cultivars (Jannink et al. 2001; Lemerle et al. 2006; Zhao et al. 2006). However, several production practices (e.g., fertility source and cultivar selection) may be manipulated to enhance crop competitive ability (Davis and Liebman 2001; Williams et al. 2008a). Optimizing crop competitive ability does not necessarily have the impediments facing other types of nonchemical weed management tactics, such as fuel use for tillage (Clements et al. 1995) and additional demands on growers' time (Gunsolus and Buhler 1999).

Planting sweet corn over a range of dates, which extends the harvest period, is the primary approach to providing an appropriate supply of ears for processing and fresh markets. Unlike dent corn, in which a narrow planting window is targeted to maximize grain yield, sweet corn harvest timing drives other agronomic decisions such as planting date. In the midwestern United States, sweet corn is often planted from mid-April to early-July. Day length, solar energy, and air and soil temperatures change greatly with planting date in the temperate climate of the midwestern United States.

The long planting season may affect the residual weed community due to changing abiotic conditions over the period. Differences exist in emergence patterns among weed species common to the midwestern United States (Forcella et al. 1992; Hartzler et al. 1999; Stoller and Wax 1973). For example, Eastern black nightshade (*Solanum ptychanthum* Dunal) was the most abundant residual weed species observed in late-planted sweet corn fields (Williams et al. 2008b), consistent with delayed peak emergence of the weed reported by Ogg and Dawson (1984).

Among emerged seedlings, environmental conditions brought about by the long planting season also may influence other aspects of weed population dynamics, including growth rate and length of vegetative period. For example, the relatively short time of sweet corn growth to harvest is insufficient for some annual weed species to produce abundant viable seed (Williams et al. 2008b). The extent to which the long planting window of sweet corn influences seed viability of residual weed species is poorly known. Finally, the long planting season affects crop growth traits important to competitive ability, such as crop height, leaf appearance rate, and shoot biomass partitioning (Williams 2008; Williams and Lindquist 2007).

Sweet corn tolerance to weed interference may not be uniform across the long planting season. If so, such knowledge is valuable in managing risk in integrated weed management systems (Gunsolus and Buhler 1999; Swanton et al. 2008).

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Gunsolus (1990) suggested that mechanical weed management may work best in late-planted field corn or soybean [*Glycine max* (L.) Merr.] because of lower weed density, relative to earlier plantings. Weed control by two rotary hoeings in field corn was less than banded application of atrazine plus metolachlor, but improved with later planting (Mulder and Doll 1994). Colquhoun et al. (1999) speculated later-planted sweet corn may be more competitive with weeds and also that tillage may have greater effectiveness for weed control. Indeed, May planted sweet corn suffered greater maximum yield loss due to weeds (85%) compared with June planted sweet corn (15%) (Williams 2006).

Considering the entire planting season of sweet corn in a temperate climate, is the crop affected more by weed interference at certain planting times? To what extent does the residual weed community change during the planting season? Therefore, the objectives were to (1) characterize within-season changes in the residual weed community across the long planting season of sweet corn, and (2) determine the extent to which the planting season influences CT in growth and yield traits.

Materials and Methods

Site Description. Field experiments were conducted on a Flanagan silt loam (fine, smectitic, mesic Aquic Argiudoll) in 2006 and 2007 at the University of Illinois Vegetable Crop Research Farm near Urbana, IL. Experiments were located in different fields each year and the previous crop was soybean. Fields received N at 129 kg ha^{-1}, P at 113 kg ha^{-1}, and K at 135 kg ha^{-1} on 12 April 2006 and 10 April 2007. The entire experimental area was chisel plowed in the fall and field cultivated after fertilization in the spring. A second field cultivation occurred immediately prior to planting dates identified below.

Experimental Approach. The experimental design was a split plot with four replications. Main plots consisted of five planting date treatments: mid-April (April 12, 2006, and April 20, 2007), early-May (May 8, 2006, and May 3, 2007), late-May (May 30, 2006, and May 23, 2007), mid-June (June 14, 2006, and June 13, 2007), and early-July (July 3, 2006 and 2007). After the mid-April planting date, succeeding treatments were planted when the previously planted sweet corn had two visible leaf collars. 'BC0805'[1] is a main-season (82 d) augmented sugar enhanced endosperm type and has been among the most popular selling fresh market hybrids in recent years (D. Kriegel, Rispen Seeds, personal communication). 'BC0805' was planted in 76-cm rows with a four-row planter at a seeding rate of 83,300 seeds ha^{-1}. Main plot size was 12.2 m long by 6.0 m wide. Subplots measuring 12.2 m long by 3.0 m wide consisted of two treatments: naturally occurring weed populations or weed-free. The weed-free treatment was maintained by a preemergence application of *S*-metolachlor at 1.78 kg a.i. ha^{-1} and atrazine at 2.2 kg a.i. ha^{-1}, followed by handweeding as needed. To avoid nutrient uptake from weeds and weed seed production in unplanted main plots, postemergence applications of 0.47 kg ha^{-1} glufosinate plus 5% (v/v) ammonium sulfate were made as needed prior to planting. Tefluthrin was applied as an in-furrow treatment at planting at a rate of 14 g a.i. 100 m^{-1} of row to control Western corn rootworm (*Diabrotica virgifera* LeConte) larvae. Bifenthrin at 53 g a.i. ha^{-1} was applied as needed during silking to control Japanese beetle (*Popillia japonica* Newman) and Western corn rootworm beetle. The experimental sites were sprinkler irrigated three times in 2006 and four times in 2007 to ensure crop and weed growth.

Data Collection. Crop data were collected from the center two rows of subplots and the timing of data collection was based on crop development in the weed-free treatment. Crop stand was evaluated 3 to 4 wk after planting, hereafter called "early stand count," and the day of harvest, hereafter called "harvest stand count." Within 3 d after silk emergence, two sweet corn plants per subplot were cut at the soil surface and separated into leaf, stalk, and reproductive tissues. Leaf area per plant was measured using an area meter[2] and all biomass components were weighed after oven drying at 65 C. Leaf area index at each sampling date was estimated as the product of mean leaf area per plant and number of plants per square meter at harvest. An indexed metric of chlorophyll content (CC) of the primary ear leaf of five plants per plot was measured within 3 d of silking using a chlorophyll meter.[3]

Marketable ears were hand-picked near commercial maturity from 6.1 m of the center two rows. Ears were considered marketable if 90% of kernels were full and had a gravimetric moisture content of 75 $\pm$ 3%. Ears (including silks and husks) meeting these criteria exceeded 4.4 cm in diameter for the first four planting dates, and 3.8 cm in diameter for the final planting date. From earliest to latest planting date, harvest dates were July 17, August 1, August 10, August 23, and September 14 in 2006 and July 11, July 24, August 6, August 24, and September 10 in 2007. Total number and mass, hereafter called "green mass yield," of marketable ears were recorded. Number of ears per unit area was converted to boxes of ears based on 50 ears per box. Fresh ears were immediately husked with a husking bed[4] and kernels were removed from the cob with an industry-grade corn cutter.[5] Husked mass yield and kernel mass yield were recorded. A 20-g sample of fresh kernels from each plot was immediately ground with a mortar and pestle and gently squeezed through 0.5-mm nylon mesh. A digital refractometer[6] was used to determine soluble solids concentration of the extract.

Within 2 d prior to crop harvest, weeds were sampled from within four 0.25-m^2 quadrats per plot. Quadrats were placed within 25 cm of center crop rows and $\geq$ 2.5 m from adjacent alleyways. Height of the primary weed canopy was measured, then weeds were clipped at the soil surface, sorted by species, counted, and weighed after oven drying at 65 C. An additional 5 to 10 plants of each species were collected from the weedy treatment, allowed to dry at room temperature for 3 wk, and hand-threshed to remove seed, if present. Thirty seeds (in 2006) or 50 seeds (in 2007) per species were tested for viability using the tetrazolium assay (Peters 2000). Weed seed dispersal within plots was minimal at sweet corn harvest; therefore, viability tests were conducted only on nondispersed seed. Soils in main plots were sampled to a depth of 10 cm on each planting date and submitted for analysis for N, P, and K concentration.[7] Daily minimum and maximum air temperatures and precipitation were accessed from a weather station located within 1 km of experimental plots.[8]

Table 1. Monthly water supply (rainfall and irrigation) and minimum, maximum, and mean average daily temperatures for the months of April through September in 2006 and 2007. Departure from 30-yr average water supply and mean air temperature for these months in Urbana, IL, are included for reference.

		Water supply		Average daily temperature			Departure from average	
Year	Month	Rainfall	Irrigation	Min	Max	Mean	Water supply	Temperature
		mm		C			mm	C
2006	April	112	0	7.3	20.1	13.7	7	2.8
	May	78	25	11.0	22.4	16.7	−19	−0.3
	June	42	25	15.8	28.0	21.9	−40	−0.2
	July	199	25	19.0	30.8	24.9	106	1.0
	August	76	0	18.4	28.3	23.3	−35	0.6
	September	34	0	11.6	23.7	17.7	−48	−1.3
2007	April	62	0	4.1	16.2	10.2	−44	−0.7
	May	41	45	13.0	27.1	20.1	−36	3.0
	June	138	25	16.9	29.1	23.1	56	1.0
	July	87	0	17.0	28.4	22.7	−31	−1.2
	August	38	25	19.7	31.6	25.7	−48	2.9
	September	52	0	14.2	28.9	21.6	−29	2.6

Statistical Analyses. Planting date CT to weed interference was calculated as

$$CT = 100(V_{WDY}/V_{WF}) \quad [1]$$

where V_{WDY} is the response variable (e.g., biomass or yield) in the weedy subplot and V_{WF} is the response variable in the weed-free subplot. For each year, planting date CT values were calculated for early stand count, harvest stand count, leaf mass, stem mass, reproductive mass, total mass, per plant leaf area, LAI, chlorophyll content, box yield, green mass yield, husked mass yield, kernel mass yield, and soluble solids concentration. In addition, net primary productivity (NPP) was calculated as the sum of total weed biomass and crop biomass in weedy subplots.

Prior to analysis, all data were examined for homogeneity of variances using the modified Levene's test (Neter et al. 1996). Variances were found to be nonhomogeneous between years; therefore, analyses were performed within each year. Diagnostic tests of residuals indicated data complied with ANOVA assumptions of homogeneity of variance and normality, therefore data were not transformed. To evaluate the effect of planting date on total weed density, weed biomass, weed height, crop biomass, CT values, NPP, and soil nutrient concentration, data were subjected to ANOVA to determine planting date effects and compute least squares means (SYSTAT 2004). Means were compared using protected, Bonferroni-corrected multiple comparisons at $\alpha = 0.05$ (Neter et al. 1996).

Results and Discussion

Both years were warmer and drier than the 30-yr average; however, conditions in 2007 were more extreme than 2006 as evidenced by higher temperatures and greater rainfall shortages (Table 1). Temperatures in April and May were cooler than June, July, and August, followed by temperatures cooling in September. While irrigation partially offset rainfall shortages, water supply still was near or below the 30-yr average for all months except July of 2006 and June of 2007, which experienced water supply 106 and 56 mm above average, respectively. Water supply from emergence to harvest exceeded 300 mm for planting date treatments, with the exceptions in 2007 of the mid-April (275 mm), mid-June (270 mm), and early-July (192 mm) treatments. Furthermore, soil fertility at planting was largely consistent across planting dates. Concentrations of N, P, and K averaged 70, 61, and 233 ppmv, respectively in 2006 and results were similar in 2007 (data not shown).

Residual Weed Community. Seedlings of the residual weed community began emerging within 2 d of crop emergence, and species were representative of common weeds of the midwestern United States. Velvetleaf (*Abutilon theophrasti* Medik.), redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] were observed in all planting dates (Table 2). By the time of crop harvest, redroot pigweed accounted for 37 to 85% of the total weed biomass in 8 of 10 cases. Early-emerging broadleaf weeds such as velvetleaf and common lambsquarters were most abundant within the first or second planting dates (up to 33% of total weed density), whereas late-emerging large crabgrass accounted for a greater portion of the weed community in the latter half of the planting season. Barnyardgrass was most abundant during May planting dates, but was a minor portion of the weed community in later planting dates ($\leq$ 4% of total weed biomass). Though common purslane (*Portulaca oleracea* L.) was frequently observed, it accounted for $\leq$ 3% of the total weed biomass. Fall panicum (*Panicum dichotomiflorum* Michx.) contributed to the weed community the first two planting dates in 2007, but was not observed in 2006.

By harvest, high weed density was observed in all treatments, with total weed density being similar ($P \geq 0.200$) across planting dates and averaging 181 plants m^{-2} in 2006 and 391 plants m^{-2} in 2007. Unlike weed density, total weed biomass varied with planting date. Weed biomass decreased as the planting season progressed ($P \leq 0.001$). Weed biomass in mid-June and early-July plantings were consistently lower than weed biomass in one or more earlier treatments (Figure 1). Weed canopy height averaged 162 cm in 2006, yet varied ($P < 0.008$) with planting date in 2007, with a taller weed community in late May (227 cm) than earlier planting dates (177 cm) (data not shown). A reduction in weed biomass over the sweet corn planting season, despite constant weed density, has been observed previously. Weed community biomass, dominated by barnyardgrass, common lambsquarters, green foxtail [*Setaria viridis* (L.) Beauv.],

Table 2. Weed species composition at the time of sweet corn harvest across five planting dates in Urbana, IL.[a]

Year	Planting date	ABUTH	AMARE	CHEAL	DIGSA	ECHCG	PANDI	POROL
		species-specific contribution to weed density (% of total)						
2006	Mid-April	7	39	30	3	15	0	3
	Early-May	3	20	33	0	39	0	6
	Late-May	1	69	4	11	1	0	13
	Mid-June	0	48	10	38	2	0	0
	Early-July	0	47	22	12	1	0	16
2007	Mid-April	5	2	27	0	0	65	0
	Early-May	1	2	30	12	5	46	4
	Late-May	1	13	4	24	43	0	15
	Mid-June	1	9	6	61	1	10	5
	Early-July	1	14	1	48	0	0	20
		species-specific contribution to weed biomass (% of total)						
2006	Mid-April	34	40	23	0	2	0	0
	Early-May	3	37	40	0	19	0	0
	Late-May	7	85	4	2	1	0	1
	Mid-June	4	72	4	12	3	0	0
	Early-July	3	84	5	4	1	0	1
2007	Mid-April	15	4	66	0	0	15	0
	Early-May	8	6	57	3	6	19	0
	Late-May	12	51	11	5	19	0	1
	Mid-June	3	70	1	17	4	3	1
	Early-July	6	63	0	24	0	1	3

[a] Weed species identified by Bayer codes: ABUTH, *Abutilon theophrasti* Medik.; AMARE, *Amaranthus retroflexus* L.; CHEAL, *Chenopodium album* L.; DIGSA, *Digitaria sanguinalis* (L.) Scop.; ECHCG, *Echinochloa crus-galli* (L.) Beauv.; PANDI, *Panicum dichotomiflorum* Michx.; POROL, *Portulaca oleracea* L.

redroot pigweed, and velvetleaf, decreased 82% or more over a 6-wk planting window of sweet corn (Williams 2006).

Which weed species produced viable seed by the time of sweet corn harvest, and did planting date influence percentage of viable seed? Seed viability tests were conducted on samples of velvetleaf, redroot pigweed, common lambsquarters, large crabgrass, and barnyardgrass, since these species were observed in all planting dates. For all planting dates, redroot pigweed and barnyardgrass produced viable seed, averaging 91 and 58% viability, respectively, across years (Table 3). While large crabgrass was observed in all treatments, it produced viable seed (average 49% viability) only in the late May and later planting dates.

Velvetleaf seed viability exceeded 80% in 8 of 10 cases, while common lambsquarters produced viable seed in only the last planting date of 2006. Many commercial sweet corn hybrids have a shorter vegetative period than the main-season hybrid used in this research; therefore, weed seed viability reported here may be a ''worst case scenario'' in relation to some production fields. Nonetheless, results show seedbank additions would be more likely for some species (e.g., velvetleaf and redroot pigweed) than others (e.g., common lambsquarters) in sweet corn, indicating the relative seedbank replenishment of species, and perhaps primary weed problems for rotational crops.

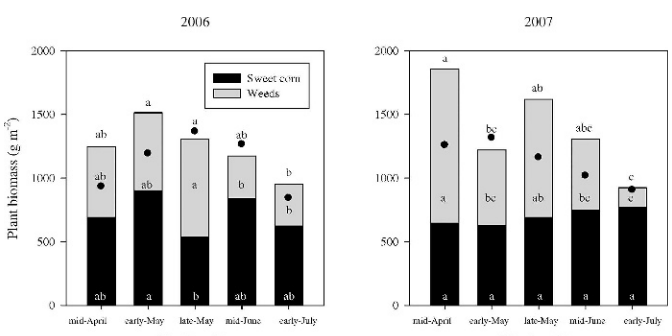

Figure 1. Plant biomass of weed community and sweet corn grown in competition across five planting dates in 2006 and 2007. Within a year and plant type, columns overlaid with the same letter are not significantly different at $P < 0.05$ based on protected, Bonferroni-corrected multiple comparisons. Net primary productivity is crop + weed biomass. Means separation of net primary productivity is identified in the same manner above each column. Weed-free sweet corn biomass (•) is included for reference.

Tolerance in Crop Growth. Early and harvest crop stand counts were not different than the weed-free control over planting dates (data not shown), indicating the residual weed community did not prevent crop emergence or induce crop mortality.

Crop growth generally was most affected by weeds in the late-May planting, and least affected in the mid-June and later planting dates. Sweet corn in the late-May planting had the lowest CT values for leaf mass in both years, stem mass in 2006, and leaf area in 2007 (Table 4).

Weed interference had a consistent effect on LAI across planting dates in 2006, but reduced LAI most in the first three planting dates of 2007 as evidenced by low CT values ($P < 0.001$). These results are consistent with Williams and Lindquist (2007), whereby weed interference reduced canopy growth of May-planted sweet corn to a greater extent than a June planting. Furthermore, additional planting dates studied here show that sweet corn growth in the early-July planting is also resilient to weed interference, and crop growth suppression by weeds is more likely in early-season (April and May) planting dates.

Tolerance in Crop Yield. Crop yield traits were least affected by weed interference in the late-season (June and July) plantings. For example, CT values for box yield, green mass yield, husked mass yield, and kernel mass yield were highest in the mid-June and early-July planting dates, and often lowest in one or more of the early planting dates (Table 4). While most yield traits of the mid-April planting were comparable to mid-June and early-July plantings in 2006, mid-April plantings in 2007 suffered complete yield loss. Differences between years in CT of mid-April plantings may be the result

Table 3. Weed seed viability at time of sweet corn harvest of the five most abundant species observed across five planting dates in Urbana, IL.[a]

Year	Planting date	ABUTH	AMARE	CHEAL	DIGSA	ECHCG
		viability (%)				
2006	Mid-April	97	97	0	0	60
	Early-May	0	97	0	0	93
	Late-May	0	90	0	73	90
	Mid-June	80	93	0	70	97
	Early-July	93	90	40	43	90
	Mean	54	93	8	37	86
	SE	22	2	8	16	7
2007	Mid-April	94	88	0	0	34
	Early-May	84	82	0	0	30
	Late-May	90	96	0	50	18
	Mid-June	98	92	0	56	42
	Early-July	92	88	0	0	20
	Mean	92	89	0	21	29
	SE	2	2	0	13	4

[a] Weed species identified by Bayer code; ABUTH, *Abutilon theophrasti* Medik.; AMARE, *Amaranthus retroflexus* L.; CHEAL, *Chenopodium album* L.; DIGSA, *Digitaria sanguinalis* (L.) Scop.; ECHCG, *Echinochloa crus-galli* (L.) Beauv.

of the level of competition from the weed community, where conditions in 2007 favored 118% more weed biomass compared to 2006 (Figure 1). Also, the early-May planting was affected relatively more by weeds in 2006 than in 2007. Unusually cool, wet conditions immediately after the early-May planting in 2006 delayed crop emergence 1 wk, and may have influenced the crop's ability to compete later in the season. For instance, reduction in emergence and seedling vigor of high-sugar endosperm sweet corn types from cool, moist conditions are driven by complex interactions (Tracy 2001), while sweet corn seedling traits have been implicated in crop competitive ability against wild-proso millet (*Panicum miliaceum* L.) (So et al. 2009). Overall, crop yield tolerance to weed interference is higher, and more stable, near the end of the planting season, compared to plantings prior to June. Williams (2006) observed weed interference in a May planted sweet corn resulted in more yield loss potential and a longer critical period of weed control, relative to a June planting.

These experiments test crop tolerance to a relatively high level of weed interference. With the exception of preplant tillage done just prior to each planting date, no direct intervention for weed control was made. As a result, density and vigor of the residual weed community in this study was likely higher than expected in production fields. The purpose of this work was to characterize how the long planting season influences the residual weed community and CT. Results show the crop tolerates weeds best when planted late in the season, though caution should be exercised when relating the magnitude of CT values in this work to growers' fields. More detailed study of growers' fields in the midwestern United States is reported by Williams et al. (2008b).

Net Primary Productivity. The crop having a greater competitive edge in late-season plantings, compared to earlier in the season, is further evidenced by biomass data of the crop–weed community. Net primary productivity decreased from late-May through early-July plantings (Figure 1). Sweet corn biomass in the presence of weeds was constant over this period, whereas weed biomass steadily decreased. What caused the weed community to decline over time, but not the crop in the presence of weeds? Weed density was relatively high and constant across plantings, indicating the declining weed community was not constrained by low population density late in the season. However, a shift in the species composition was observed over the long planting season, and there may have been differences in the weed species' ability to compete. For instance, early-emerging species such as common lambsquarters dominated the weed community biomass in the earliest plantings, outcompeting later emerging seedlings. Redroot pigweed has a long emergence pattern, and while it

Table 4. Values for sweet corn tolerance to weed interference across five planting dates in Urbana, IL.[a]

Year	Planting date	Leaf mass	Stem mass	Repro mass	Total Shoot mass	Leaf area per plant	LAI	CC	Box yield	Green mass yield	Husked mass yield	Kernel mass yield	SSC
		% of weed-free											
2006	Mid-April	86.4 ab	99.0 a	53.8	73.6	85.6	85.7	80.9 ab	39.4 ab	26.0 b	30.3 ab	36.6 ab	97.0
	Early-May	91.9 a	103.1 a	63.1	78.5	90.8	89.7	84.4 ab	6.3 b	5.0 b	4.5 b	4.7 bc	97.2
	Late-May	53.8 b	65.4 b	29.5	45.0	56.7	50.8	61.7 b	8.9 b	5.7 b	4.3 b	1.3 c	92.2
	Mid-June	81.2 ab	96.0 ab	65.8	77.0	72.9	67.8	87.8 a	52.5 a	48.3 a	46.6 a	45.5 a	95.0
	Early-July	88.0 ab	96.1 ab	69.4	81.3	84.9	79.2	92.6 a	111.2 a	94.0 a	95.8 a	79.2 a	105.2
	Mean	80.3	91.9	56.3	71.1	78.2	74.6	81.5	43.7	35.8	36.3	33.5	97.3
	P-value	0.035	0.011	0.197	0.069	0.243	0.068	0.012	0.002	0.001	0.000	0.000	0.137
2007	Mid-April	67.6 ab	64.5	38.5 b	57.8	72.4 ab	64.6 b	85.9	0.0 b	0.0 b	0.0 b	0.0 b	.
	Early-May	77.7 ab	78.6	47.5 ab	62.2	84.0 a	63.3 b	86.6	65.3 a	42.2 a	39.1 a	34.9 a	82.2 b
	Late-May	54.7 b	72.7	71.1 ab	68.5	43.5 b	39.1 b	78.8	4.5 b	3.1 b	2.9 b	1.8 b	94.2 a
	Mid-June	80.9 ab	81.5	58.4 ab	69.9	84.9 a	90.8 a	91.0	25.2 ab	20.4 ab	19.6 ab	17.9 ab	99.4 a
	Early-July	90.9 a	86.7	74.3 a	82.3	97.5 a	101.2 a	85.2	65.8 a	60.7 a	60.7 a	62.4 a	99.2 a
	Mean	74.4	76.8	58.0	68.1	76.5	71.8	85.5	32.2	25.3	24.5	23.4	93.8
	P-value	0.022	0.315	0.047	0.224	0.000	0.000	0.465	0.000	0.000	0.000	0.008	0.000

[a] Within a year, means followed by the same letter within a column are not significantly different at $P \leq 0.05$ based on protected, Bonferroni-corrected multiple comparisons. Abbreviations: Repro mass, reproductive biomass; CC, chlorophyll content; SSC, soluble solids concentration.

was a primary species in later plantings, the final redroot pigweed population may have been composed of cohorts emerging after crop dominance had been established. Alternatively, weed growth rate may have declined as the season progressed. Oliver (1979) attributed loss of velvetleaf competitiveness over time with photoperiodicity and changing day length. Williams (2006) observed declines in weed biomass over two sweet corn plantings dates, which was attributed in part to the role of air temperature on efficiency of different photosynthetic pathways (C3 weed vs. C4 crop). Indeed, sweet corn planted late in the season appeared to have greater stress tolerance than the early planted crop. In the presence of common weeds of the Midwest, June-planted sweet corn partitioned more biomass to stem and reproductive tissues and had greater resiliency in silk emergence relative to May-planted sweet corn (Williams and Lindquist 2007). The effects of the long planting season on crop–weed contributions to NPP also may have been the result of environment-induced changes in both crop and weed growth. These results are consistent with field surveys of 175 grower's fields in Illinois, Minnesota, and Wisconsin, whereby mean level of weed interference was lower in fields harvested in September, compared with August (Williams et al. 2008b).

Implications. Though of secondary importance to harvest timing, optimizing sweet corn yield within each planting remains desirable. The fact that delayed planting of full-season dent corn hybrids reduced yield potential is well known (Benson 1990; Darby and Lauer 2002; Lauer et al. 1999; Swanson and Wilhelm 1996). Sweet corn hybrids generally have shorter periods of growth than dent corn in the midwestern United States, and significance of planting date on crop yield, even under weed-free conditions, is poorly known. Early planting of sweet corn into cold or wet soils can compromise field emergence, lower yields, and result in nonuniform maturity (Tracy 2001). Per plant yield of sweet corn was unaffected by planting dates separated by 4 wk in Newfoundland (Kwabiah 2004). In contrast, decreases in weed-free yield with June or July planting dates, relative to May plantings, have been observed in Illinois (Williams 2006, 2008). Compared with earlier plantings, later plantings can be subjected to more diseases and insects. For example, inherently poorer growing conditions or viral infection could not be separated as the mechanism for sweet corn yield decline in an early-July planting (Williams 2008). Regardless of whether yield potential is non-uniform from mid-April to early-July plantings, the need for marketable ears for processing and fresh market necessitates a long planting season.

Thorough knowledge of crop and weed community responses to planting date, including crop tolerance to weed interference, offers new opportunities for improving weed management. Late-season sweet corn planting in Illinois alters the critical period of weed control such that early-season plantings require timely and highly effective management, in contrast to late-season plantings where less herbicide could be used, reducing risk of herbicide carryover to sensitive rotational crops (Williams 2006). Crop tolerance does not kill weeds outright; however, knowledge of factors improving CT benefits weed management systems relying on multiple tactics. Depleted weed biomass from late planting may improve effectiveness of soil tillage for weed control (Gunsolus 1990; Mulder and Doll 1994). Although the present research did not find an influence of planting date on total weed density, enhanced crop tolerance later in the planting season was observed, as proposed by Colquhoun et al. (1999). Enhanced CT coupled with poor late-season weed growth may improve the efficacy of postemergence weed control tactics, such as tillage and postemergence herbicide applications. Moreover, because weed communities of late season plantings are less competitive compared with early-season plantings, risk of yield loss from weed control failure is lower than early-season plantings.

In conclusion, sweet corn tolerance to weed interference was consistently highest in the latter half of the planting season in Illinois. Crop growth and yield traits were most affected by weed interference in the April and May plantings, and least affected in the June and July plantings. From late-May to the end of the planting season, sweet corn biomass in the presence of weeds was constant, whereas weed biomass in the presence of sweet corn steadily decreased. While subtle changes in the weed species composition were observed over the planting season, total weed density remained high (e.g. $\geq 181\ m^{-2}$). The five residual species observed throughout the study varied in their ability to produce viable seed by the time of crop harvest, whereby common lambsquarters and large crabgrass failed to produce viable seed until late-May or later plantings. The extent to which these phenomena apply to other environments (e.g., locations, weather patterns, soil types) is unknown. Within the context of the conditions of these studies, the within-season changes in sweet corn tolerance to weed interference could prove useful in managing risk associated with weeds.

Sources of Materials

[1] Sweet corn seed, Rogers Seeds, Nampa, ID.

[2] LI-3100 Area Meter, LI-COR, Inc., Lincoln, NE.

[3] Chlorophyll meter SPAD-502, Spectrum Technologies Inc., Plainfield, IL.

[4] Four-lane husking bed, A&K Development Company, Eugene, OR.

[5] Power corn cutter, A&K Development Company, Eugene, OR.

[6] AR200 Digital Refractometer, Leica Microsystems Inc., Buffalo, NY.

[7] A&L Great Lakes Laboratories, Inc., Fort Wayne, IN.

[8] Illinois State Water Survey, Champaign, IL.

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