Influence of Planting Date and Weed Interference on Sweet Corn Growth and Development

Martin M. Williams II* and John L. Lindquist

ABSTRACT

Crop planting date and canopy density influence interactions between weeds and sweet corn (*Zea mays* L.); however, little is known about sweet corn growth response to weed interference. Field studies were conducted in 2004 and 2005 near Urbana, IL, to quantify the influence of planting date and weed interference on growth of sweet corn height, leaf area, aboveground biomass, and phenological development. Crop growth response to weed interference (presence or absence) was determined for sweet corn planted early May (EARLY) and late June (LATE). Dominant weed species included barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], common lambsquarters (*Chenopodium album* L.), common purslane (*Portulaca oleracea* L.), green foxtail [*Setaria viridus* (L.) Beauv.], redroot pigweed (*Amaranthus retroflexus* L.), and velvetleaf (*Abutilon theophrasti* Medicus) at densities ranging from 95 to 256 plants m^{-2}. Weed interference reduced sweet corn's absolute height growth rate, maximum leaf area index (LAI), absolute LAI growth rate, with some of the largest effects on crop growth observed in the EARLY planting date. Silk emergence was delayed by weeds for EARLY planted sweet corn, but not LATE. Moreover, the LATE planting date resulted in 9% taller crop plants with 36% lower maximum LAI. Relative to an EARLY planting date, lower yield losses due to weeds for LATE sweet corn correspond to greater resiliency of crop growth and silk emergence to weed interference.

Managing weed populations through modification of the crop canopy has been investigated as a component of integrated weed management in dent corn (*Zea mays* L.) (e.g., Lindquist and Mortensen, 1998). The overall goal has been to improve the crop's ability to establish dominance over the weed, aimed specifically at preempting resources, enduring competitive stress, or avoiding stress (Jannink et al., 2000; Jordan, 1993). A number of cultural practices have been studied, including alteration in population density (Begna et al., 2001; Nurse and DiTommaso, 2005; Tharp and Kells, 2001), row spacing (Begna et al., 2001; Norsworthy and Oliveira, 2004), or corn leaf orientation (Toler et al., 1999). Moreover, identification of important canopy traits responsible for stress tolerance and weed suppression has provided the basis for directing crop breeding efforts (Jannink et al., 2000; Lemerle et al., 2006; Jordan, 1993; Tollenaar and Wu, 1999).

Variation in canopy properties in sweet corn is large and has practical implications for weed management. For instance, Pataky (1994) reported differences in vertical leaf area distribution among 11 hybrids, with total leaf area ranging from 2540 to 4660 cm^2 per plant. Higher sweet corn maximal leaf area index (LAI) from anthesis to harvest conferred greater suppression of wild proso millet (*Panicum miliaceum* L.), and LAI at the 120- to 150-cm height was negatively correlated to weed growth and fecundity (Williams et al., 2007). With a crop population density of 56 800 plants ha^{-1}, effect of sweet corn hybrid was more important than crop row spacing (51 vs. 76 cm) for intercepting light and influencing growth of wild proso millet and green foxtail (Bisikwa, 2001).

Planting date has a significant effect on crop–weed interactions. Velvetleaf fecundity was reduced by delayed dent corn planting dates (Nurse and DiTommaso, 2005). Delayed planting reduced yield losses due to weeds in soybean [*Glycine max* (L.) Merr.] (Buhler and Gunsolus, 1996) and dent corn (Gower et al., 2002), explained largely by an increase in weed seedling mortality with delayed planting date. Delayed dent corn planting had lower weed densities in 1 of 2 yr, and efficacy of rotary hoeing increased with delayed planting (Mulder and Doll, 1994). Critical period of weed control (CPWC), the phase of the crop growth cycle when weed interference results in unacceptable yield loss, began 500 growing degree days (GDD) earlier in sweet corn planted the first week of May relative to a mid-June planting in Illinois, despite comparable weed species composition and density (Williams, 2006). Factors other than weed density account for differences observed in CPWC, and may include crop growth response to planting date.

The amount of time required to reach sweet corn maturity is influenced by planting date (Kwabiah, 2004), primarily due to variation in temperature environment during growth. However, the extent to which planting date influences sweet corn growth and canopy development is poorly understood. Crop modeling has been used to determine optimal planting dates for dent corn (Anapalli et al., 2005). Nielsen et al. (2002) reported thermal time of silk emergence and grain-fill period decreased as planting was delayed from early May to mid-June. In temperate climates, full-season dent corn hybrids can be exposed to potentially lethal cold temperatures before grain maturation when planting is delayed. Sweet corn hybrids often mature earlier than dent corn in North America and are sown over a range of planting dates to extend availability for fresh market

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Abbreviations: BIO, biomass per unit area; CPWC, critical period of weed control; EARLY, early May planting date; GDD, growing degree days; HT, canopy height; LAI, leaf area index; LATE, late June planting date; SSC, soluble solids concentration.

and processing, spanning 3 mo in the north-central USA (Tracy, 2001). Response of sweet corn to weeds is likely to vary with planting date since the effects of weeds tends to be linked with the growth and competitiveness of the crop. While canopy development has been described among some processing hybrids (Williams et al., 2006), there appear to be no reports on the influence of planting date on sweet corn growth and development. Therefore, the objective of this research was to quantify the influence of planting date and weed interference on growth of sweet corn height, leaf area, aboveground biomass, and phenological development.

MATERIALS AND METHODS

Site Description

Field experiments were conducted in 2004 and 2005 at the University of Illinois, Cruse Tract Vegetable Research Farm near Urbana (40°4′N, 88°12′W). The soil was a Flanagan silt loam (fine, smectitic, mesic Aquic Argiudolls) averaging 3.6 g kg^{-1} organic matter and pH of 6.4. Experiments were located in different fields in each year. Previous crops were alfalfa (*Medicago sativa* L.) and soybean for the 2004 and 2005 experiments, respectively. Fields received a broadcast application of granular fertilizer including 129 kg N ha^{-1}, 113 kg P ha^{-1}, and 135 kg K ha^{-1} on 23 Mar. 2004 and 16 Mar. 2005.

Experimental Approach

The experiment followed a split-plot design with four replications. The main plot factor was planting date, which consisted of seeding sweet corn in the first week of May, hereafter referred to as EARLY, and the third week of June, hereafter referred to as LATE. The experimental area was chisel plowed in the fall or spring, followed by one pass each of a disk harrow and a field cultivator before planting. Glufosinate-tolerant sweet corn (cv. GH0937, a mid-season *sugary1* endosperm mutant) was planted in 0.76-m rows at 70 423 seeds ha^{-1} on 6 May (EARLY) and 21 June (LATE) in 2004 and 2 May (EARLY) and 20 June (LATE) in 2005.

Subplot treatments consisted of presence (weedy) or absence (weed-free) of weed interference, such that weed presence was a random effect over time. Subplots measured 12.2 m in length by 4 rows wide (3.0 m). A preemergence application of 1.78 kg a.i. ha^{-1} *S*-metolachlor (2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide) and 2.2 kg a.i. ha^{-1} atrazine (6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine) was applied to weed-free plots the day of crop planting, and all subsequent emerging weeds were removed by hoe or hand.

The experimental site was irrigated four times in 2005 (7 June, 21 June, 29 June, and 9 August). Each irrigation event totaled 2.5 cm of water to offset abnormally low rainfall. Permethrin (3-phenoxybenzyl(1RS)-*cis*,trans-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate) was applied in both years at 168 g a.i. ha^{-1} to control western corn rootworm (*Diabrotica virgifera virgifera* LeConte) beetles as needed.

Data Collection

Based on growth stage in the weed-free treatment, sweet corn growth was determined in weed-free and weedy subplots at V2, V4, V6, V8, R1 (silk emergence), and R3 (harvest) (Ritchie et al., 2003). Three consecutive corn plants per plot were cut at the soil surface in rows 1 and 4 through the V6 sampling time, then rows 2 and 3 for later sampling times. Crop growth stage and plant height from the plant base to apex were recorded for 10 consecutive plants. Leaves were separated from stems by cutting the lamina at the ligule, while newly emerged leaves were separated at the uppermost visible collar. Leaf area was determined using an area meter (LI-3100C Area Meter, LI-COR, Lincoln, NE) and plant biomass was oven-dried at 65°C for 4 to 6 d.

Within 18 to 21 d after anthesis, marketable ears, including silks and husks, exceeded 4.4 cm in diameter. Harvest dates were 2 August (EARLY) and 11 September (LATE) in 2004 and 27 July (EARLY) and 30 August (LATE) in 2005. Five marketable ears from each weedy and weed-free plot were randomly selected, sealed in plastic bags, and placed on ice. Within 6 h, ears were analyzed for kernel moisture and soluble solids concentration (SSC), indicators of relative maturity (Hale et al., 2005; Ritchie et al., 2003). Kernels were removed from the cob with an electric knife in 2004 and a power corn cutter (Power Corn Cutter, A&K Development Co., Eugene, OR) in 2005. Percent kernel moisture was determined gravimetrically using a 20-g sample of fresh kernels. Another 20-g sample was ground with a mortar and pestle and then gently squeezed through 0.5-mm nylon mesh. A digital refractometer (AR200 Digital Refractometer, Leica Microsystems, Educational and Analytical Division, Buffalo, NY) was used to determine SSC of the extract.

Thermal time accumulated from sweet corn emergence was used as the reference point for growth and development measurements. Thermal time was measured in GDD calculated using minimum and maximum air temperatures obtained from a nearby weather station (Illinois State Water Survey, 2005). A base temperature of 10°C was used as the minimum temperature for corn growth, and 30°C was used as the air temperature associated with maximum growth rate.

Statistical Analyses

Sweet corn growth in canopy height (HT), leaf area index (LAI), and biomass per unit area (BIO) as a function of thermal time were determined for each subplot. The LAI and biomass were determined from leaf area and biomass of harvested plants and total stand density within the subplot. To quantify growth over time as influenced by planting date and weed interference, data were regressed on GDD accumulated from emergence using the Richards function (Hunt, 1982):

$$Y = \frac{Y_{\max}}{[1 + \exp(a - b\text{GDD})]^{1/c}} \qquad [1]$$

where $Y_{\max}$ represents maximum HT, LAI, or BIO, and *a*, *b*, and *c* are shape coefficients. The combination $b/(c + 1)$ represents a weighted mean relative growth rate and $Y_{\max}$ $b/[2(c + 2)]$ is a weighted mean absolute growth rate over the entire growth period (Hunt, 1982). If $c = 1$, the ratio a/b defines the thermal time from emergence when the maximum absolute growth rate occurs (i.e., the inflection point). Some caution is needed when interpreting this ratio because its value also is highly correlated with $Y_{\max}$ (i.e., taller plants will reach a/b later). In fitting Eq. [1] to LAI over thermal time, only LAI from emergence to the R1 growth stage (before 700 GDD) were included in the analysis.

To evaluate the effects of planting date and weed interference on height, LAI, and biomass growth, Eq. [1] was fitted to these data for each subplot using PROC NLIN (SAS Institute, 1990). If the estimate of *c* did not vary from 1.0, its value was set to a constant 1.0 in all subsequent analyses, in which case Eq. [1] reduces to a logistic function. Parameter estimates obtained for each subplot were then subjected to ANOVA to determine treatment effects. ANOVA was con-

Table 1. Monthly rainfall and irrigation amounts and minimum, maximum, and mean average daily temperatures for the months of May, June, July, and August in 2004 and 2005 in Urbana, IL. Departure from 30-yr average precipitation and mean air temperature for these months are included for reference.

	Water supply		Air temp.			Departure avg.	
Month	Rainfall	Irrigation	Min.	Max.	Mean	Rainfall	Temp.
	mm		°C			mm	°C
				2004			
May	116	0	13.0	24.4	18.7	−6	+1.7
June	96	0	15.2	26.6	20.9	−11	−1.2
July	146	0	17.4	27.7	22.6	+27	−1.4
Aug	91	0	14.3	25.9	20.1	−20	−2.7
				2005			
May	25	0	9.1	23.5	16.3	−97	−0.7
June	61	194	17.6	30.1	23.9	−45	+1.8
July	109	0	18.6	30.3	24.5	−9	+0.6
Aug	57	65	18.7	29.9	24.3	−55	+1.6

ducted using the PROC MIXED procedure (Littell et al., 1996) to compute least squares means, standard errors, and treatment differences at the $\alpha = 0.05$ level. Since planting date × weed interference interaction effects were typically significant, Eq. [1] was again fit to HT, LAI, and biomass over thermal time across all replicates within a treatment to obtain a residual mean square error (rmse) and an approximate r^2 (calculated as 1 − residual sums of squares/corrected total sums of squares) for the treatment.

To evaluate the effects of planting date and weed interference on sweet corn development, the number of leaves counted at the V4 and V8 stages of development in each subplot were subjected to ANOVA using PROC MIXED as described above. To determine differences in time of silk emergence, the percentage of 10 plants within each subplot at the R1 stage of development also was compared using ANOVA. Finally, as an estimate of developmental differences at harvest, the percentage moisture and SSC of harvested ears was compared among treatments using ANOVA.

RESULTS AND DISCUSSION

Precipitation, Thermal Units, and Weed Community

Early planted sweet corn received 40% more water than LATE in 2004, but treatments received equivalent water in 2005, primarily due to irrigation in that year (Williams, 2006). Monthly average daily air temperature was cooler in 2004 than 2005 during the months of June, July, and August (Table 1). During these months, average temperatures were 1.8°C cooler than the 30-yr average in 2004, but 1.3°C warmer than the long-term average in 2005. Consistent temperatures throughout the growing season in 2004 resulted in relatively small differences in GDD accumulation between planting date treatments in 2004, where LATE sweet corn accumulated slightly greater heat units between 10 and 50 d after emergence compared with EARLY (Fig. 1). The warm temperatures in late June, July, and August of 2005 resulted in rapid GDD accumulation immediately after LATE planting in 2005, such that large differences in GDD accumulation occurred between planting date treatments in that year.

Weed species common to the U.S. Corn Belt began emerging within 2 d of sweet corn emergence. Dominant species included barnyardgrass, common lambsquarters, common purslane, green foxtail, redroot pigweed, and velvetleaf. Total weed densities in weedy plots were high, ranging from 226 to 300 plants m^{-2} at R1 in 2004 and 95 to 256 plants m^{-2} at R1 in 2005 (data not shown). Despite high weed seedling densities, weed canopy density varied by planting date as evidenced by >70% shorter weed canopy and >80% lower weed biomass LATE compared with EARLY at the time of crop harvest (data not shown). Additional details of weed community characteristics are described in Williams (2006).

Height

Equation [1] explained at least 96% of the variance in sweet corn height in relation to thermal time from emergence (Table 2). Sweet corn hybrid ‘GH0937’ used in this study was 15 to 25% shorter than dent corn at similar stages in Nebraska (Barker et al., 2006). However, sweet corn height varies from 150 to 300 cm among commercial hybrids used in the north-central USA (Bisikwa, 2001; Williams et al., 2006). Averaged over weed interference levels, sweet corn grew 13 to 24 cm taller (HT$_{\max}$) in the LATE compared to EARLY (Fig. 2) treatments in both years and weed interference reduced absolute height growth rate (HT$_{\max}$ $b/6$) by 6 to 12% (Table 2). Hunter et al. (1974) observed increases in corn stem length as temperatures increased from 20

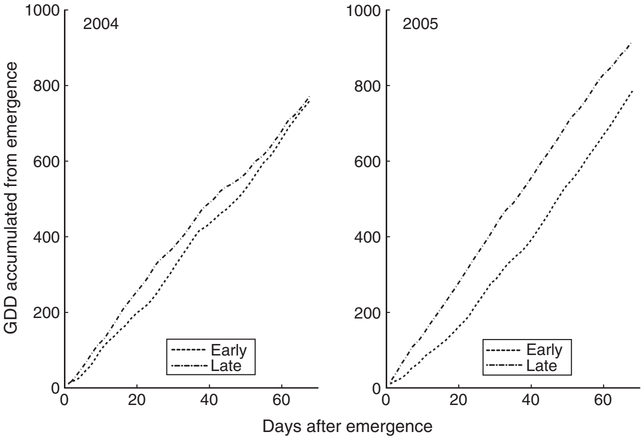

Fig. 1. Growing degree days (GDD) accumulated from emergence in relation to days after emergence for two planting dates in 2004 and 2005 at Urbana, IL. EARLY refers to a planting date the first week of May and LATE refers to a planting date the third week of June.

Table 2. Sweet corn maximum height (HT_{max}), thermal time of maximum absolute growth rate (*a*/*b* from Eq. [1] fitted to HT on GDD), and weighted mean absolute growth rate over the entire growing season (HT_{max} *b*/6, when $c = 1$) as influenced by planting date (PD) and weed interference (INT) in 2004 and 2005. Residual mean square error (rmse) and approximate r^2 ($\sim r^2$) are from the fit of Eq. [1] on HT over GDD across all replicates of each treatment. *P* values from analysis of variance of parameter estimates fitted to each experimental unit shown below means.

PD	INT	HT_{max}	*a*	*b*	*a*/*b*	HT_{max} *b*/6	rmse	$\sim r^2$
		cm			GDD	cm gdd^{-1}		
				2004				
Early	weed-free	213	4.42	0.0115	385	0.408	106.2	0.99
	weedy	195	4.38	0.0114	385	0.372	159.6	0.98
Late	weed-free	220	3.91	0.0105	372	0.385	52.04	0.99
	weedy	213	3.91	0.0107	368	0.377	99.69	0.99
	PD	<0.001	<0.001	<0.001	<0.001	0.05		
	INT	<0.001	0.58	0.95	0.25	<0.001		
	PD × INT	0.006	0.48	0.20	0.20	0.003		
				2005				
Early	weed-free	184	3.90	0.0095	409	0.292	71.72	0.99
	weedy	213	3.57	0.0077	510	0.254	195.7	0.96
Late	weed-free	221	4.66	0.0105	444	0.385	88.83	0.99
	weedy	224	4.36	0.0095	462	0.352	79.35	0.99
	PD	<0.001	<0.001	<0.001	0.71	<0.001		
	INT	0.02	<0.001	<0.001	<0.001	<0.001		
	PD × INT	0.16	0.81	0.16	0.01	0.72		

to 30°C. Therefore, observed differences in height between planting dates appear correlated with temperature, since late-planted sweet corn accumulated thermal time more quickly than the EARLY treatment, especially in 2005 (Fig. 1).

Planting date and weed interference had an interaction effect on sweet corn height growth. Weed interference influenced maximum corn height the most in the EARLY treatment. However, the direction of sweet corn response was inconsistent between years. EARLY weed-free sweet corn (213 cm) was taller than weedy plots (195 cm) in 2004, whereas the inverse was observed in 2005 (184 cm in weed-free and 213 cm in weedy) (Table 2). As evidenced by magnitude of crop yield loss, the effect of weed interference was more severe EARLY compared to LATE (Williams, 2006). Differential effect of weed interference on crop height EARLY suggests conditions in 2004 may have resulted in resource limitations different than in 2005.

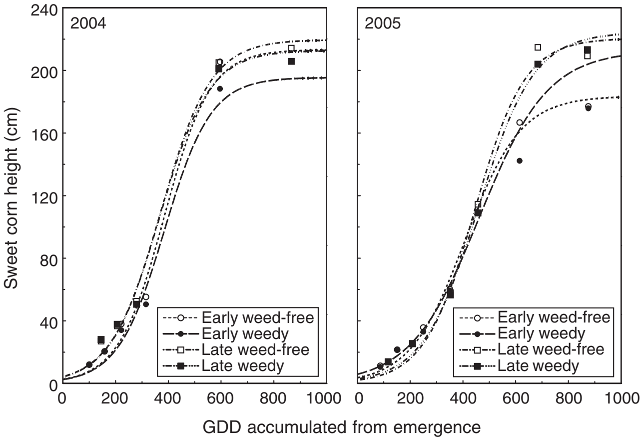

Fig. 2. Sweet corn height in relation to growing degree days (GDD) accumulated from emergence as influenced by planting date and weed interference in 2004 and 2005. Symbols represent the mean of four replicates and lines represent best fit of Eq. [1] on height. EARLY refers to a planting date the first week of May and LATE refers to a planting date the third week of June.

Leaf Area Index

Growth in LAI was strongly affected by planting date and by weed interference (Fig. 3). Equation [1] explained at least 89 and 62% of the variance in sweet corn LAI in relation to thermal time from emergence in 2004 and 2005, respectively (Table 3). Weed interference reduced maximum sweet corn LAI and LAI growth rate. For instance, maximum LAI (LAI_{max}) was reduced 23 to 33% by weed interference EARLY, while absolute LAI growth rate (LAI_{max} *b*/6) was reduced 11 to 40% by weed interference EARLY (Table 3). Though similar reductions due to weed interference were observed LATE in 2005, there was no effect of weed interference on LAI in the LATE treatment in 2004. Hall et al. (1992) and Evans et al. (2003) observed similar leaf area reductions due to weed interference. Eleven to 40% lower absolute LAI growth rate in weedy plots, relative to weed-free (Table 3), indicates reductions in maximum sweet corn leaf area were likely the result of weed interference inhibiting leaf emergence or leaf area expansion, as opposed to accelerating leaf senescence.

Late-planted sweet corn had 27 to 44% less maximum LAI relative to the EARLY treatment. Similar reductions in dent corn LAI and leaf dry matter were observed throughout the growing season near Lincoln, NE, when comparing early May to mid-June planting dates (Swanson and Wilhelm, 1996). Though leaf area was not reported, Hunter et al. (1974) reported no effect of temperature (20–30°C) on total leaf number. However, reducing the photoperiod from 20 to 10 h decreased the number of leaves 22% on average. Photoperiod of the LATE planted sweet corn was steadily declining compared with the EARLY treatment, where photoperiod increased to a maximum near 21 June followed by declining daylength. Differences in photoperiod among treatments may have contributed to the reduced LAI of the LATE treatment. Growth of dent and sweet corn are influenced by interactions between planting date and cultivar (Darby and Lauer, 2002; Kwabiah, 2004; Lauer et al., 1999).

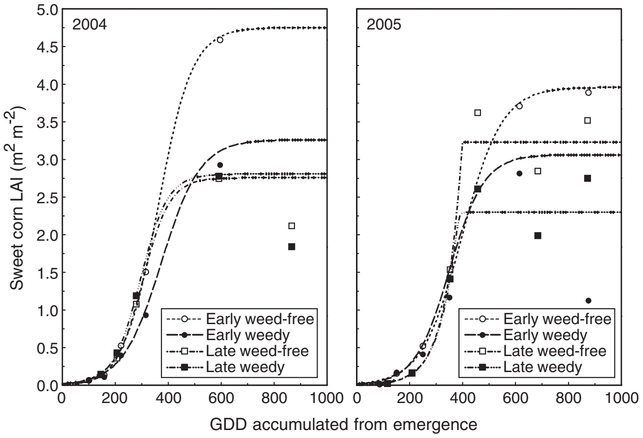

Fig. 3. Sweet corn leaf area index (LAI) in relation to growing degree days (GDD) accumulated from emergence as influenced by planting date and weed interference in 2004 and 2005. Symbols represent the mean of four replicates and lines represent best fit of Eq. [1] on LAI. EARLY refers to a planting date the first week of May and LATE refers to a planting date the third week of June.

Biomass

Growth in biomass was affected by planting date, weed interference, and their interaction in both years (Fig. 4). Equation [1] explained at least 95 and 54% of the variance in sweet corn biomass in relation to thermal time from emergence in 2004 and 2005, respectively (Table 4). Compared to EARLY planting, the LATE planting date resulted in greater maximum crop biomass and lower biomass growth rate, resulting in more thermal time (GDD) required to achieve maximal biomass. For instance, weed-free maximum crop biomass (BIO_{max}) was 1255 and 1902 g m^{-2} LATE in 2004 and 2005, respectively, compared with 973 and 1795 g m^{-2} in EARLY weed-free treatments (Table 4). Similar differences in absolute biomass growth rates (BIO_{max} $b/6$) among weed-free plots resulted in LATE plots requiring an additional 121 and 170 GDD to achieve maximal biomass (a/b) in 2004 and 2005, respectively (Table 4). Contrary to our observations, Darby and Lauer (2002) observed a decline in total crop biomass from an early May to a late-June planting date in Wisconsin.

While parameter estimates obtained from the fit of Eq. [1] on biomass over thermal time do not clearly show the trend, Fig. 4 shows that weed interference always reduced sweet corn biomass by R1 and later. Results at the R1 sampling date show that the reduction in sweet corn biomass owing to weed interference was greatest in the EARLY (31%) compared with the LATE (3%) treatment in 2004 (Fig. 4). Similarly, sweet corn maximum biomass at harvest was reduced 74% by weed interference in the EARLY 2005 treatment but was unaffected in the LATE treatment in that year (Table 4).

Development

Early season weed interference had no effect on leaf emergence, as evidenced by insignificant p values for leaf number at the V4 growth stage of sweet corn (Table 5). By the V8 growth stage, weed interference began to influence leaf number in sweet corn. Weedy treatments EARLY in 2004 had an average of 1.1 fewer leaves than weed-free sweet corn, though planting date did not affect leaf number in 2005 ($p = 0.20$) (Table 5). The cumulative effect of weed interference delayed silk emergence in EARLY weedy plots. As an example, only 2 to 35% of plants had emerged silks in EARLY weedy plots at a time when 83% or more of plants had emerged silks in weed-free plots (Table 5). Delays in dent corn silk emergence due to weed interference have been reported previously, and are influenced by hybrid (Tollenaar et al., 1997) and N level (Tollenaar et al., 1994).

Delay in crop development from weed interference, as evidenced by delayed silk emergence, might result in variable maturity among weed interference treatments. However, only weak effects of weed interference were observed in kernel moisture ($p = 0.07$) and SSC ($p = 0.04$) in 1 of 2 yr (Table 5). Inherent in the design of these experiments was that only fully developed ears (diameter of >4.4 cm) were harvested and analyzed. Fewer ears were harvested from weedy plots, particu-

Table 3. Sweet corn maximum LAI (LAI_{max}), thermal time of maximum absolute growth rate (a/b from Eq. [1] fitted to LAI on GDD, when $c = 1$), and weighted mean absolute growth rate over the entire growing season {LAI_{max} $b/[2(c + 2)]$} as influenced by planting date (PD) and weed interference (INT) in 2004 and 2005. Residual mean square error (rmse) and approximate r^2 ($\sim r^2$) are from the fit of Eq. [1] on LAI over GDD across all replicates of each treatment. P values from analysis of variance of parameter estimates fitted to each experimental unit shown below means.

PD	INT	LAI_{max}	a	b	c	a/b	$LAI_{max} \times b/[2(c + 2)]$	rmse	$\sim r^2$
		m^2 m^{-2}				GDD	m^2 m^{-2} gdd^{-1}		
					2004				
Early	weed-free	4.75	5.62	0.0155	1.0	364	0.0121	0.1446	0.96
	weedy	3.26	5.10	0.0136	1.0	384	0.0072	0.1593	0.89
Late	weed-free	2.76	5.87	0.0194	1.0	303	0.0090	0.0224	0.98
	weedy	2.81	5.74	0.0195	1.0	301	0.0090	0.0475	0.96
	PD	<0.001	<0.001	<0.001		<0.001	0.06		
	INT	<0.001	0.004	0.15		0.26	<0.001		
	PD × INT	<0.001	0.071	0.11		0.18	<0.001		
					2005				
Early	weed-free	3.96	5.26	0.0132	1.0	402	0.0089	0.2005	0.92
	weedy	3.06	5.35	0.0153	1.0	359	0.0079	0.7765	0.62
Late	weed-free	3.23	751.0	1.8816	117.1	N/A	0.0255	0.2138	0.92
	weedy	2.30	93.5	0.2431	15.95	N/A	0.0156	0.1586	0.88
	PD	0.003	<0.001	<0.001		N/A	<0.001		
	INT	<0.001	<0.001	<0.001		<0.001	<0.001		
	PD × INT	0.96	<0.001	<0.001		N/A	<0.001		

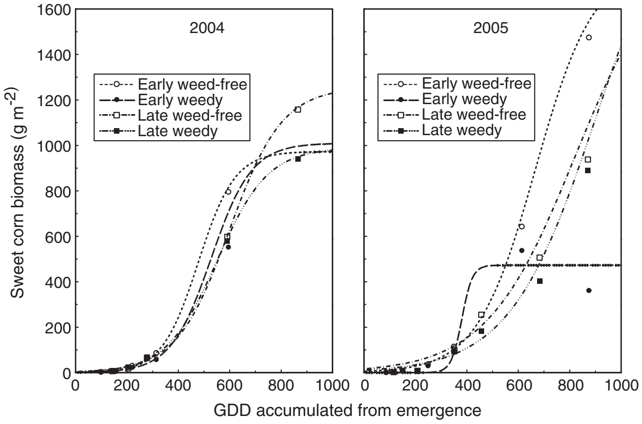

Fig. 4. Sweet corn total aboveground biomass in relation to growing degree days (GDD) accumulated from emergence as influenced by planting date and weed interference in 2004 and 2005. Symbols represent the mean of four replicates and lines represent best fit of Eq. [1] on biomass. EARLY refers to a planting date the first week of May and LATE refers to a planting date the third week of June.

larly in the EARLY treatment (Williams, 2006), indicating weed interference delayed (or ceased) the crop's ability to produce fully developed ears in weedy plots. Therefore, our data on kernel moisture and SSC reflect the effect of weed interference on marketable ears, but underestimate the effect that weed interference had on plants that produced underdeveloped ears.

Though initial weed density (>95 weeds m^{-2}) was high in both years and planting dates, the degree of competition for individual limited resources in each environment is difficult to ascertain. Crop yield data (Williams, 2006) indicated that EARLY planted sweet corn endured an overall greater level of weed interference, as evidenced by 85% maximum yield loss, compared with 15% maximum yield loss LATE. Sweet corn planted LATE may have greater stress tolerance. High weed biomass EARLY reflects resource availability to the weed community, but low weed biomass LATE could be the result of a more suppressive crop, lower weed growth rate, or a combination of the two factors.

Table 5. Sweet corn development as influenced by planting date (PD) and weed interference (INT) in 2004 and 2005. Columns headed with V4 and V8 show the mean number of leaves $plant^{-1}$ in each treatment at a sampling time corresponding to the targeted V4 and V8 leaf stages. The R1 (silk emergence) column reports the mean percentage of 10 consecutive plants $plot^{-1}$ with emerged silks. Moisture and soluble solids concentration (SSC) columns report the mean percent water and SSC of sweet corn kernels at harvest.

PD	INT	V4	V8	R1	Moisture	SSC
		– no. leaves –		%		
			2004			
Early	weed-free	3.88	8.10	82.5	72.5	24.48
	weedy	3.85	7.00	2.5	74.7	22.75
Late	weed-free	3.88	7.85	87.5	66.9	23.65
	weedy	3.93	7.90	95.0	68.1	21.63
	PD	0.61	0.14	<0.001	<0.001	0.24
	INT	0.86	0.03	<0.001	0.07	0.04
	PD × INT	0.61	0.02	<0.001	0.60	0.85
			2005			
Early	weed-free	4.03	7.25	87.5	70.7	24.7
	weedy	3.95	6.93	35.0	70.4	25.6
Late	weed-free	3.68	7.28	100	59.9	23.2
	weedy	3.90	7.03	100	59.6	24.3
	PD	0.08	0.77	0.01	<0.001	0.07
	INT	0.49	0.20	0.06	0.81	0.16
	PD × INT	0.18	0.86	0.06	0.98	0.84

Nonetheless, weed interference consistently reduced sweet corn's absolute height growth rate, maximum LAI, absolute LAI growth rate, with some of the largest effects on crop growth observed in the EARLY planting date. In addition, silk emergence was delayed by weeds for EARLY planted sweet corn, but not LATE. The LATE planting date consistently resulted in taller crop plants with greater shoot biomass, yet with lower maximum LAI, indicating a greater proportion of shoot biomass was partitioned to stems and reproductive tissues relative to the EARLY treatment.

Typical dates for sweet corn planting in the north-central USA influence crop canopy development. This variation in canopy development influences the crop's ability to endure competitive stress and suppress weeds, resulting in interactive effects of planting date and weed

Table 4. Sweet corn maximum total aboveground biomass (BIO_{max}), thermal time of maximum absolute growth rate (*a*/*b* from Eq. [1] fitted to BIO on GDD), and weighted mean absolute growth rate over the entire growing season (BIO_{max} *b*/6, when $c = 1$) as influenced by planting date (PD) and weed interference (INT) in 2004 and 2005. Residual mean square error (rmse) and approximate r^2 ($\sim r^2$) are from the fit of Eq. [1] on BIO over GDD across all replicates of each treatment. *P* values from analysis of variance of parameter estimates fitted to each experimental unit shown below means.

PD	INT	BIO_{max}	*a*	*b*	*a*/*b*	BIO_{max} *b*/6	rmse	$\sim r^2$
		$g\ m^{-2}$			GDD	$g\ m^{-2}\ gdd^{-1}$		
				2004				
Early	weed-free	973	6.74	0.0141	480	2.26	3772	0.97
	weedy	1010	6.71	0.0127	543	2.01	2618	0.95
Late	weed-free	1255	5.81	0.0097	601	2.03	3965	0.98
	weedy	989	5.61	0.0102	555	1.65	3861	0.98
	PD	0.04	<0.001	<0.001	<0.001	0.003		
	INT	0.07	0.02	0.07	0.46	0.002		
	PD × INT	0.02	0.08	<0.001	<0.001	0.52		
				2005				
Early	weed-free	1795	5.88	0.0088	672	2.55	35108	0.90
	weedy	473	18.60	0.0489	449	5.80	37669	0.54
Late	weed-free	1902	4.75	0.0058	842	1.74	5698	0.96
	weedy	2242	5.36	0.0059	918	2.12	2181	0.98
	PD	<0.001	<0.001	<0.001	<0.001	0.005		
	INT	<0.001	0.001	<0.001	<0.001	0.02		
	PD × INT	<0.001	0.003	<0.001	<0.001	0.07		

interference on the crop. Under central Illinois conditions and weeds common to the region, sweet corn growth likely contributes to the crop having a distinct competitive advantage when planted mid-June, compared with early May planting. These results explain, in part, the influence of planting date on CPWC of weed control in sweet corn reported by Williams (2006).

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