Weed Science 2007 55:245–251

Wild Proso Millet (*Panicum miliaceum*) Suppressive Ability among Three Sweet Corn Hybrids

Martin M. Williams II, Rick A. Boydston, and Adam S. Davis*

Due to known variation in canopy properties among sweet corn hybrids, weed suppressive ability (WSA), the crop's ability to reduce weed fitness, may not be uniform among hybrids. This hypothesis was tested using a range of wild proso millet densities subjected to four canopy treatments (three hybrids + weedy monoculture) under irrigated conditions in Washington and primarily rainfed conditions in Illinois. Parameter estimates for responses of weed growth and seed rain to wild proso millet density were used to quantify variation in WSA among hybrids. The same parameter estimates were used in a correlation analysis to identify associations between weed response and sweet corn canopy properties. Weed suppressive ability, as measured by wild proso millet shoot biomass and seed rain, varied among canopy treatments. Hybrid GH2547 was 25 to 31% more suppressive of wild proso millet than hybrid Spirit in Washington and 70 to 91% more suppressive in Illinois. Weed fitness was negatively correlated with leaf area index (LAI) after crop anthesis (−0.48 to −0.63), intercepted photosynthetically active radiation (PAR) at one of two harvest times (−0.51 to −0.56), and LAI at the 120- to 150-cm height (−0.51 to −0.55). Information on WSA may be useful in breeding programs; however, even near-term use of this knowledge offers modest but cumulative improvements to weed management systems in sweet corn.

Nomenclature: Wild proso millet, *Panicum miliaceum* L. PANMI; sweet corn, *Zea mays* L. 'GH2547,' 'Spirit,' 'WHT2801.'

Key words: Competition, fecundity, integrated weed management, weed density.

Crop interference with weed growth is a fundamental method of nonchemical weed management in many cropping systems (Jordan 1993; Regnier and Janke 1990). WSA refers to the crop's ability to reduce weed emergence, growth, or fecundity. WSA is differentiated from crop tolerance, which is defined as the ability of the crop to endure competitive stress from the weed without substantial yield reduction (Jannink et al. 2000; Jordan 1993). The long-term benefit of improvements in WSA is expected to be a reduction in weed seedbank size (Jannink et al. 2000; Jordan 1993; Lindquist and Mortensen 1998).

Crop cultivars vary in WSA and Callaway (1992) provides a summary for many crops. More recent work in corn has identified factors influencing WSA among hybrids, including leaf angle (Sankula et al. 2004), LAI and intercepted light (Lindquist and Mortensen 1998), and crop maturity (Begna et al. 2001). Others have observed inconsistent differences in WSA among corn hybrids (Ford and Pleasant 1994; Roggenkamp et al. 2000). Variation in WSA among cultivars has served as a basis for enhancing WSA through crop breeding and management (Jannink et al. 2000; Jordan 1993).

Sweet corn is one of the most popular vegetables in the United States, exceeding $800 million in farm value (Anonymous 2006). Sweet corn is consumed as a fresh and processed vegetable. Two-thirds of sweet corn acreage in the United States is grown for processing, and Illinois, Minnesota, Washington, and Wisconsin account for 80% of processing acreage (Anonymous 2006). Sweet corn is differentiated from dent corn by expression of genes influencing plant growth and endosperm composition (Azanza et al. 1996; Tracy 2001) and by cultural practices such as planting density and harvest timing. Weed interference reduces quality of many ear traits including filled ear length and kernel depth, and in some cases, results in nearly complete yield loss (Williams 2006; Williams and Masiunas 2006).

Weed management is a primary concern within the food processing industry and wild proso millet is one of the most challenging weeds to manage in sweet corn (Anonymous 2003; Williams and Harvey 2000). Wild proso millet is a weedy race of domesticated proso millet first documented in the 1970s in Minnesota and Wisconsin (Harvey 1979; Strand and Behrens 1981). Within two decades, wild proso millet had spread over 400,000 ha of the Pacific Northwest, north-central United States, and southeastern Canada (Colosi and Schaal 1997). In addition to lowering sweet corn yield, wild proso millet seed contaminates processed sweet corn and is difficult to remove. Wild proso millet has natural tolerance to most herbicides used in sweet corn, high competitive ability, and prolific seed production prior to crop harvest.

Sweet corn hybrids differ in canopy properties, however little is known about the implications of this variation on light competition and weed management. Pataky (1992) reported total leaf area ranged from 2,540 to 4,660 cm^2 per plant among 11 sweet corn hybrids. Makus (2000) showed differences in height and light interception between early-season and midseason hybrids. At common plant population densities, the effect of sweet corn hybrid was more important than row spacing for intercepting light (Bisikwa 2001). Williams et al. (2006a) reported differences in similar canopy properties among three sweet corn hybrids and hypothesized the hybrids also vary in WSA. Therefore, the objectives of this work were to determine the significance of sweet corn canopy variation on WSA and quantify associations between crop canopy properties and WSA.

Materials and Methods

Experimental Methodology. *Site Description.* Field experiments were conducted in 2004 and 2005 at the University of Illinois Crop Sciences Research and Education Center near

DOI: 10.1614/WS-06-123.1

* U.S. Department of Agriculture, Agricultural Research Service, Invasive Weed Management Research, University of Illinois, 1102 S. Goodwin Avenue, Urbana, IL 61801; U.S. Department of Agriculture, Agricultural Research Service, Vegetable and Forage Crops Research, 24106 N. Bunn Road, Prosser, WA 99350; U.S. Department of Agriculture, Agricultural Research Service, Invasive Weed Management Research, University of Illinois, 1102 S. Goodwin Avenue, Urbana, IL 61801. Corresponding author's E-mail: mmwillms@uiuc.edu

Urbana, IL, and the Washington State University Roza Unit near Prosser, WA. The soil at Illinois was a Flanagan silt loam (fine, smectitic, mesic Aquic Argiudoll) with 3.6% organic matter and pH of 6.4 and the soil at Washington was a Warden sandy loam (coarse-silty, mixed, superactive, mesic Xeric Haplocambid) with 0.9% organic matter and pH of 6.5. Experiments were located in different fields in each year. The previous crop was alfalfa (*Medicago sativa* L.) (2004 field) and soybean [*Glycine max* (L.) Merr.] (2005 field) at Illinois and dent corn at Washington (both years). Fields in Illinois received 52 kg N ha^{-1}, 46 kg P ha^{-1}, and 54 kg K ha^{-1} on March 23, 2004, and 52 kg N ha^{-1}, 52 kg P ha^{-1}, and 67 kg K ha^{-1} on March 16, 2005. Fields in Washington received 319 kg N ha^{-1}, 79 kg P ha^{-1}, and 168 kg K ha^{-1} on May 10, 2004, and 224 kg N ha^{-1}, 59 kg P ha^{-1}, and 186 kg K ha^{-1} on May 2, 2005. The experimental area was chisel plowed in the fall or spring, followed by one pass each of a disk harrow and a field cultivator prior to planting.

Experimental Approach. The experimental design was a split plot with four replications. Sweet corn canopy was the main plot factor, including Spirit, WHT2801, GH2547, and a weedy monoculture (absence of crop). All hybrids were *sugary1* endosperm mutants, however Spirit is an earlier-maturing hybrid compared to WHT2801 and GH2547. Four-row main plots were planted on a 76-cm row spacing at 70,400 seeds ha^{-1} in Illinois and 77,800 seeds ha^{-1} in Washington using a seeding depth of 3.2 to 3.8 cm. As needed, sweet corn was thinned to achieve similar density. Four target densities of wild proso millet (0, 13, 39, 132 plants m^{-2}) were assigned to subplots measuring 12.2 m in length and four rows wide. Wild proso millet was not previously observed at experimental sites, therefore within 3 d of crop planting, wild proso millet was seeded 1.3 cm deep in the center two corn rows of each subplot using a cone planter. Planting dates in 2004 were May 24 and May 19 in Illinois and Washington, respectively. Planting dates in 2005 were May 23 and May 9 in Illinois and Washington, respectively. Abnormally dry conditions resulted in poor crop stand in Illinois, however, and the site was cleared with an application of glyphosate at 1.3 kg ae ha^{-1} plus 2% v/v ammonium sulfate and replanted with seed of sweet corn and wild proso millet on June 20. In 2004 each location used wild proso millet seed from populations found in the region; however, Washington seed was used in Illinois during replanting in 2005.

A preemergence application of 2.2 kg ai ha^{-1} atrazine (Illinois) or 1.12 kg ha^{-1} atrazine (Washington) was applied to the entire study area within a day of planting, while a separate preemergence application of 1.78 kg ai ha^{-1} *S*-metolachlor was made to weed-free plots only. Weeds other than wild proso millet were removed by hand, and lambda-cyhalothrin at 26 g ai ha^{-1} or permethrin at 168 g ai ha^{-1} was applied as needed to control Western corn rootworm (*Diabrotica virgifera virgifera* LeConte) beetles.

Experimental sites in Washington were furrow irrigated on average 44 cm each year. The experimental site in 2005 in Illinois was sprinkler irrigated twice (July 2 and August 8) and each irrigation event totaled 2.5 cm of water to offset abnormally low rainfall.

Data Collection. Initial wild proso millet density was determined by counting the number of seedlings in three 1-m lengths of row per plot 2 to 3 wk after emergence. Using the same sampling pattern at the time of harvest of GH2547, wild proso millet shoot biomass was determined by clipping plants at the soil surface, oven drying at 65 C, and weighing. Seed rain was determined using the plastic cup design described by Forcella et al. (1996). Five or more cups totaling 785 cm^2 (Illinois) or 942 cm^2 (Washington) in area were staked between rows 2 and 3 of each plot prior to seed rain. Cups were retrieved at the time of GH2547 harvest and seed were enumerated.

Sweet corn LAI and intercepted PAR were quantified at four times during the growing season in weed-free plots. Sampling events coincided within 3 d of six leaves (V6) of Spirit, anthesis (R1) of Spirit, harvest (H1) of Spirit, and harvest (H2) of WHT2801 and GH2547. Growth stages were determined by the number of visible leaf collars and appearance of reproductive organs. Two crop plants were harvested, leaves were separated, and green leaf area was measured using an area meter.[1] Plants selected for harvest were located in rows 1 or 4 at V6, and for remaining sampling dates, rows 2 or 3 and at least 1 m from the location of previously harvested plants. LAI at each sampling date was estimated as the product of mean leaf area per plant and number of plants per square meter. Quantity of PAR intercepted by the plant canopy was measured under full-sun conditions at three locations within each plot using a linear ceptometer.[2] Two measurements of incident PAR were taken; one measurement above the crop canopy and one at the soil surface, with the sensor perpendicular to, and centered over, rows 2 or 3. All measurements were taken between 10 A.M. and 2 P.M. and mean intercepted PAR was estimated as unity minus the fraction of the soil-surface to above-canopy measurements. Vertical LAI was determined through a stratified harvest at H1. Two plants per plot were divided into 30-cm intervals from the soil surface to the top of the canopy. Leaves in each interval were separated and measured for leaf area as described above.

Both functional and classical growth analyses (Hunt 1982) were used to quantify sweet corn canopy dynamics (Russelle et al. 1984). An instantaneous value for maximal relative growth rate with respect to leaf area, RGR_{max}, was calculated by fitting a third order polynomial function to LAI over thermal time (Hunt 1982; SYSTAT 2004), and finding the maximum of the first derivative of this function. Three periods of leaf area duration (LAD) were calculated as the integral under the LAI curve across thermal time from the period of emergence to anthesis (LAD_{early}), anthesis to harvest (LAD_{late}), and emergence to harvest (LAD_{total}) (Hunt 1990). Finally, late season change in LAI (LAI_{loss}) was calculated as the magnitude of the change in LAI between the R1 and H2 sampling events.

Statistical Analyses. A rectangular hyperbola equation (Cousens 1985) was fit to wild proso millet biomass and seed rain in each year and location:

$$Y = IN/(1 + IN/A) \qquad [1]$$

where Y is weed response (biomass expressed in grams per square meter, seed rain expressed in number per square meter), N is wild proso millet density (expressed in plants per square meter), I is the linear region of the function's slope as weed density approaches zero, and A is weed response as density approaches infinity. Parameter estimates were de-

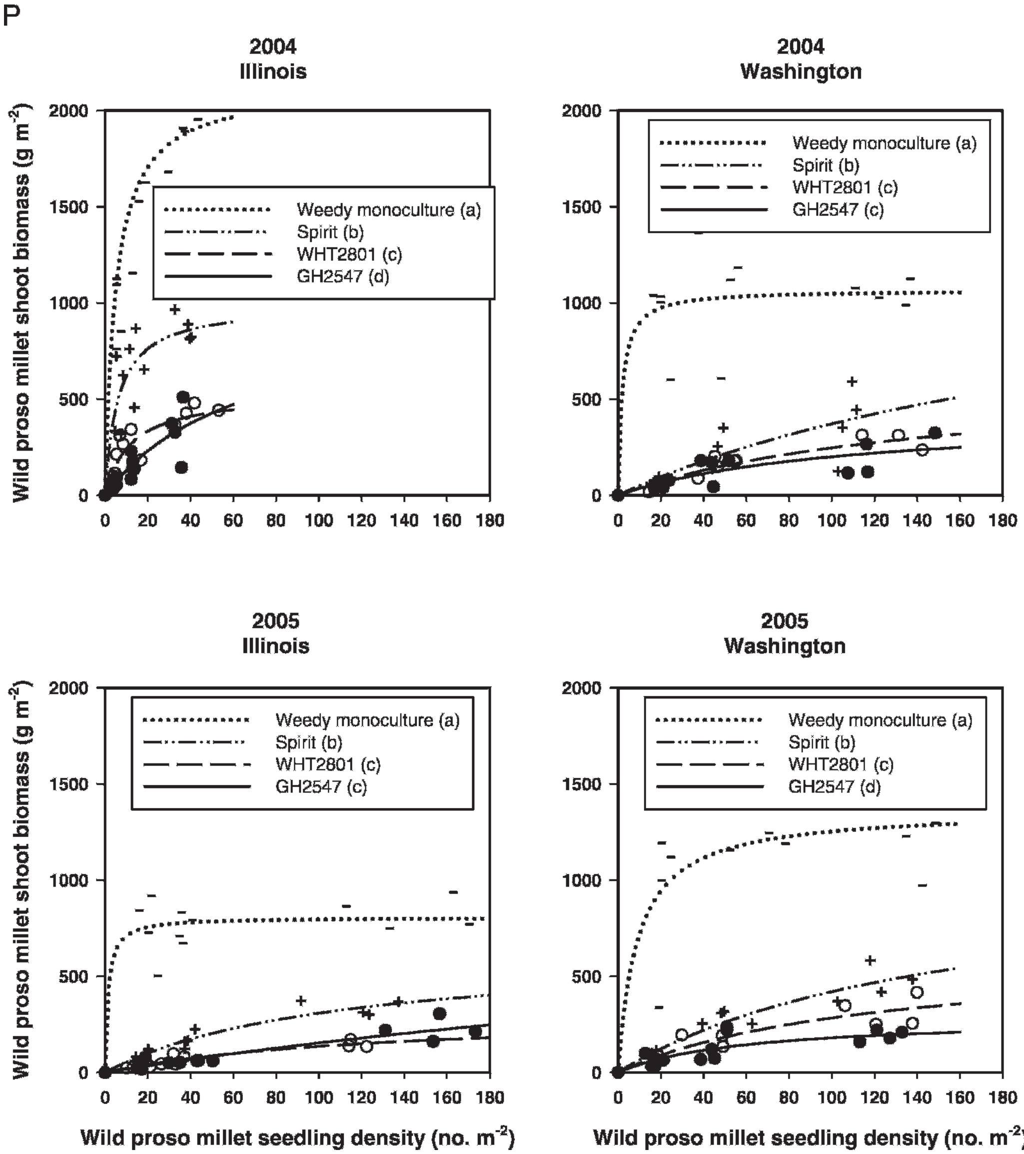

Figure 1. Effect of initial wild proso millet density on weed shoot biomass in field studies conducted in Urbana, IL, and Prosser, WA, in 2004 and 2005. Within each site-year, canopy treatments followed by the same letter (in parentheses) are similar at $P < 0.05$. Symbols for observed values: −, weedy monoculture; +, Spirit; ○, WHT2801; ●, GH2547. Parameter estimates of (Equation 1) are shown in Table 1.

termined using an iterative least-squares procedure (SYSTAT 2004). Lack of fit was assessed by reporting standard errors of parameter estimates, square of the multiple correlation coefficients (R^2), and plotting predicted and observed values. The extra sum of squares principle for nonlinear regression analysis (Ratkowsky 1983) was employed to evaluate the similarity of parameter estimates among locations, years, and canopy treatment. Comparisons were made by calculating a variance ratio of individual and pooled residual sums of squares (Lindquist et al. 1996). Comparisons were tested at a significance level of $\alpha = 0.05$ and differences were identified using letter designations (e.g., a, b, c, and d) in Figures 1 and 2.

Pearson correlations between estimates of I (Equation 1) for wild proso millet shoot biomass, seed rain, and sweet corn canopy properties were conducted on data pooled across hybrids and site-years. Probability values for correlations were calculated using the Bonferroni correction for multiple parameters (Neter et al. 1996).

Results and Discussion

Sweet corn and wild proso millet emergence coincided at each site. Measured within 3 wk of emergence, a range of wild proso millet densities were observed with maximum density as high as 173 seedlings m^{-2} (Figure 1). Wild proso millet recruitment at Illinois in 2004 was notably lower than other site-years; for instance, maximum density was 53 seedlings m^{-2}.

Wild Proso Millet Biomass. Wild proso millet growth varied with canopy treatment. F values indicated weed biomass response to canopy treatment varied among locations and years; therefore data were analyzed and reported by individual site-year. Wild proso millet biomass was greatest in the weedy monoculture, followed by wild proso millet growing in Spirit, then followed by wild proso millet growing in WHT2801 or GH2547 (Figure 1). At Illinois in 2005 and Washington in 2004, weed growth was similar in WHT2801 and GH2547;

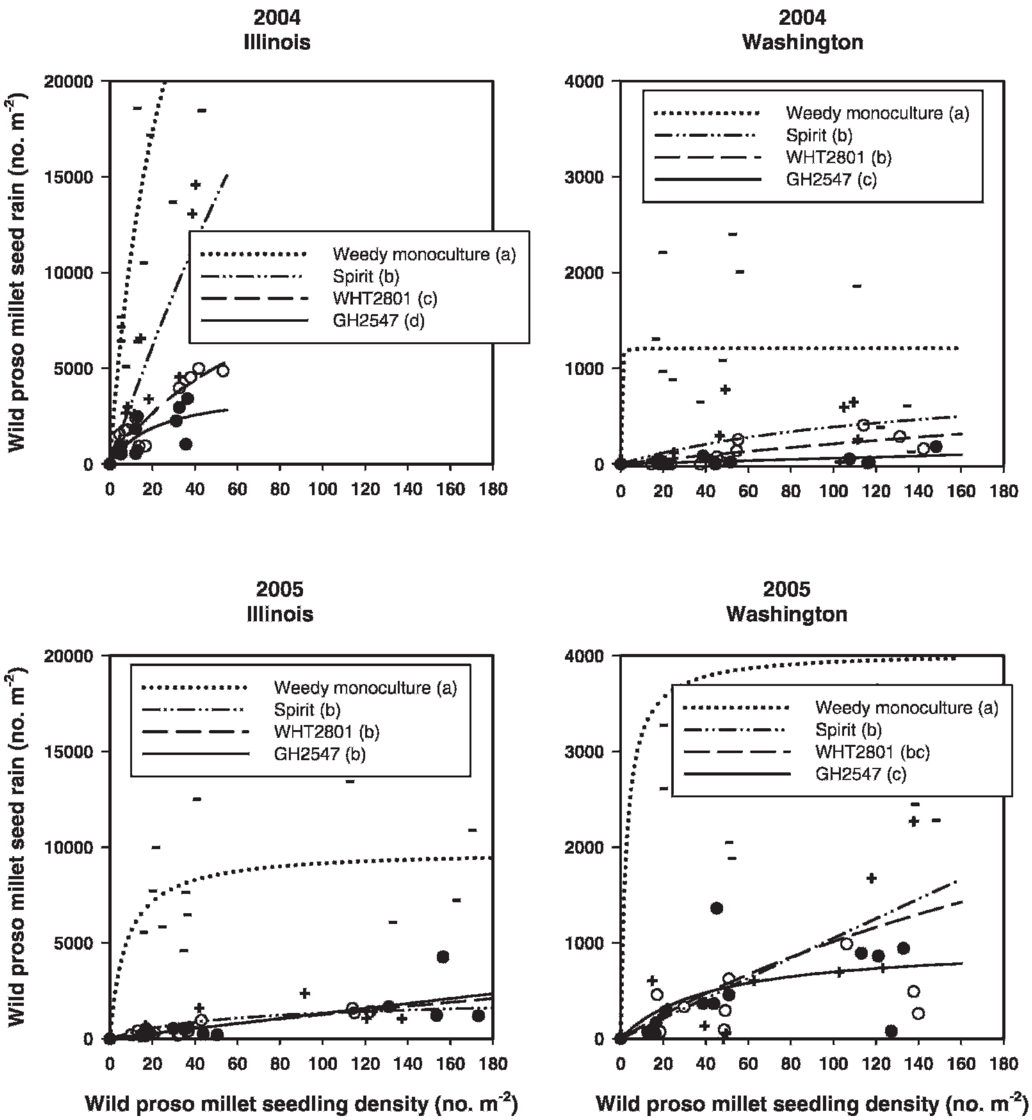

Figure 2. Effect of initial wild proso millet density on weed seed rain in field studies conducted in Urbana, IL, and Prosser, WA, in 2004 and 2005. Within each site-year, canopy treatments followed by the same letter (in parentheses) are similar at $P < 0.05$. Symbols for observed values: −, weedy monoculture; +, Spirit; ○, WHT2801; ●, GH2547. Parameter estimates of (Equation 1) are shown in Table 2.

though GH2547 was more weed suppressive than WHT2801 in the other two site-years.

Weed suppressive ability among canopy treatments is supported further by estimates of the *I* parameter of (Equation 1). The *I* parameter has been used as an index for comparing tolerance to weed interference among crop cultivars (Lindquist and Mortensen 1998), sensitivity of sweet corn ear traits to weed interference (Williams and Masiunas 2006), and the relative competitive abilities among weed species (Swinton et al. 1994). In this work, the *I* parameter quantifies weed growth and seed dispersal at low weed densities (i.e., the linear region of the function), and hence is inversely related to WSA. Estimates of *I* for wild proso millet biomass, ranked numerically from highest to lowest, were weedy monoculture > Spirit > WHT2801 > GH2547 (Table 1), therefore GH2547 and WHT2801 are more suppressive of wild proso millet than Spirit.

Wild Proso Millet Seed Rain. Seed rain in weedy monoculture plots varied widely among site-years and fit of (Equation 1) was often poor. For instance, R^2 was equal to or less than 0.13 in 3 site-years for fit of seed rain data to weed density in weedy monoculture plots (Table 2). Poor fit within site-years is largely explained by the fact that seed rain approached an upper asymptote at the lowest nonzero weed densities in weedy monoculture plots (Figure 2). In the absence of interspecific competition, domesticated proso millet compensates for low plant density by tillering (Agdag et al. 2001). Seed rain in Illinois was several-fold higher than seed rain in Washington (Figure 2). Seed cups only captured dispersed seeds, and in these studies, dispersal was not complete at the time of harvest. An unknown set of environmental conditions in Illinois may have hastened maturation of wild proso millet seed, resulting in earlier seed dispersal at Illinois compared to Washington. For instance, considerably drier conditions were observed in Illinois, as evidenced by Washington accumulating nearly twofold higher water (44 cm average) than in Illinois (24 cm average).

Seed rain of wild proso millet varied with canopy treatment. F values indicated the influence of canopy treatments on seed rain varied among locations and years;

Table 1. Parameter estimates of (Equation 1) for the effect of initial weed density on wild proso millet shoot biomass in four sweet corn canopy treatments for experiments near Urbana, IL, and Prosser, WA, in 2004 and 2005.[a]

Year	Location	Canopy treatment	I	A	R^2
				g m^{-2}	
2004	Illinois	weedy monoculture	428 (115)	2,129 (200)	0.72
		Spirit	164 (54)	991 (119)	0.87
		WHT2801	44.1 (12.4)	534 (84)	0.84
		GH2547	15.0 (5.8)	990 (864)	0.76
	Washington	weedy monoculture	556 (1,011)	1,067 (119)	0.03
		Spirit	5.1 (2.1)	1,365 (1,656)	0.72
		WHT2801	4.1 (0.8)	617 (176)	0.92
		GH2547	3.8 (1.5)	421 (204)	0.71
2005	Illinois	weedy monoculture	601 (1,095)	806 (67)	0.03
		Spirit	5.9 (1.0)	644 (125)	0.94
		WHT2801	2.4 (0.4)	311 (75)	0.93
		GH2547	1.8 (0.5)	1,036 (1,181)	0.89
	Washington	weedy monoculture	152 (83)	1,365 (150)	0.33
		Spirit	6.9 (1.3)	1,071 (330)	0.93
		WHT2801	5.2 (1.4)	623 (198)	0.87
		GH2547	4.8 (1.5)	288	0.82

[a] Standard errors of parameter estimates are in parentheses. I is the linear region of the function's slope as weed density approaches zero, and A is shoot biomass as density approaches infinity.

therefore data were analyzed and reported by individual site-year. Wild proso millet seed rain was greatest in the weedy monoculture, followed by wild proso millet growing in Spirit (Figure 2). Seed rain response was similar between Spirit and WHT2801 in three of four site-years. GH2547 was one of the most suppressive hybrids, except in Illinois in 2005 when all sweet corn hybrids had similar seed rain. Conceivably, wild proso millet seed production and seed rain increases with duration of wild proso millet plant growth. Wild proso millet seed production and dispersal may be lower at the time of harvest in much earlier maturing sweet corn hybrids.

Associations to Crop Canopy Properties. Sweet corn canopy properties varied among hybrids. For complete details of crop canopy development and light environment among Spirit, WHT2801, and GH2547, see Williams et al. (2006a). After the V6 growth stage, LAI and intercepted PAR were typically highest for GH2547, lowest for Spirit, and WHT2801 was intermediate (Williams et al. 2006a). As an example, average LAI at the R1 sampling time was 2.8, 4.1, and 4.7 for Spirit, WHT2801, and GH2547, respectively. Moreover, WHT2801 and GH2547 had leaf area distributed higher in the canopy than Spirit, with largest differences in vertical LAI among hybrids above 60 and 150 cm in Illinois and Washington, respectively (Williams et al. 2006a).

Wild proso millet growth and seed rain were associated with several sweet corn canopy properties. Both wild proso millet shoot biomass and seed rain were negatively correlated (−0.48 to −0.63) with total crop LAI for sampling dates after V6 (Table 3). Sweet corn intercepted PAR was negatively correlated with seed rain (−0.51) at the H1 sampling date and wild proso millet biomass (−0.56) at the H2 sampling date. Significant negative correlations to wild proso millet biomass and seed rain were also observed with sweet corn LAD_{late} and LAD_{total}. Weed suppressive ability of the hybrids also depended upon the height at which crop leaf area occurred. Sweet corn LAI at the 120- to 150-cm height was the only level with significant correlation to wild proso millet shoot biomass (−0.55) and seed rain (−0.51) (data not

Table 2. Parameter estimates of (Equation 1) for the effect of initial weed density on wild proso millet seed rain in four sweet corn canopy treatments for experiments near Urbana, IL, and Prosser, WA, in 2004 and 2005.[a]

Year	Location	Canopy treatment	I	A	R^2
				no. m^{-2}	
2004	Illinois	weedy monoculture	1,492 (594)	41,300 (17,000)	0.66
		Spirit	329 (120)	90,000 (262,000)	0.83
		WHT2801	167 (38)	12,800 (5,940)	0.89
		GH2547	178 (80)	3,970 (1,670)	0.68
	Washington	weedy monoculture	19,600 (285,000)	1,210 (370)	0.05
		Spirit	6.6 (5.8)	934 (1,350)	0.38
		WHT2801	2.4 (1.1)	1,700 (4,820)	0.67
		GH2547	0.6 (0.5)	65,000 (488,000)	0.41
2005	Illinois	weedy monoculture	1,310 (1,160)	9,840 (1,800)	0.13
		Spirit	36.3 (16.9)	2,120 (760)	0.66
		WHT2801	14.0 (3.2)	12,400 (23,300)	0.92
		GH2547	13.4 (9.7)	90,000 (290,000)	0.59
	Washington	weedy monoculture	1,490 (4,750)	4,040 (990)	0.10
		Spirit	10.6 (5.5)	90,000 (341,000)	0.67
		WHT2801	13.2 (14.6)	4,380 (14,200)	0.31
		GH2547	23.2 (16.8)	995 (435)	0.49

[a] Standard errors of parameter estimates are in parentheses. I is the linear region of the function's slope as weed density approaches zero and A is seed rain as density approaches infinity.

Table 3. Correlation matrix of sweet corn canopy properties and wild proso millet model parameter estimates.[a]

Weed response variable (n=43)	Sweet corn canopy properties[b]												
	Total LAI				Intercepted PAR								
	V6	R1	H1	H2	V6	R1	H1	H2	RGR_{max}	LAD_{early}	LAD_{late}	LAD_{total}	LAI_{loss}
Shoot biomass	−0.13	−0.48*	−0.56*	−0.55*	−0.27	−0.35	−0.47	−0.56*	−0.22	−0.45	−0.51*	−0.53*	0.12
Seed rain	−0.31	−0.56*	−0.63*	−0.53*	−0.41	−0.38	−0.51*	−0.46	0.03	−0.60*	−0.54*	−0.61*	0.11

[a] *I* from (Equation 1) was determined using nonlinear regression analysis of season-end weed biomass or seed rain response to initial wild proso millet density in three sweet corn hybrids. Correlation analysis was conducted on data pooled across hybrids for field studies in Urbana, IL, and Prosser, WA, in 2004 and 2005.

[b] LAI, leaf area index; PAR, photosynthetically active radiation; RGR_{max}, maximal relative growth rate determined as a function of leaf area index; LAD_{early}, leaf area duration measured as the integral of the LAI from emergence to anthesis; LAD_{late}, leaf area duration, measured as the integral of the LAI from anthesis to harvest; LAD_{total}, leaf area duration measured as the integral of the LAI from emergence to harvest; LAI_{loss}, magnitude of the change in LAI from R1 to H2 sampling events; V6, the point in time when hybrid Spirit had six leaves; R1, the point in time when Spirit was at anthesis; H1, the point in time when Spirit was harvested; H2, the point in time when WHT2801 and GH2547 were harvested.

* Correlation coefficient significant at $P < 0.05$.

shown). These associations make sense in that they describe increases in the size, location, and duration of the crop canopy, which would reduce light available for wild proso millet. Dent corn canopy properties responsible for suppression of velvetleaf (*Abutilon theophrasti* Medik.) growth and fecundity include maximum crop LAI, rate of canopy closure, and vertical leaf area distribution (Lindquist and Mortensen 1998; Lindquist et al. 1998).

Implications for Weed Management. Regardless of the agricultural management system in dent corn, some weed species routinely evade control despite decades of extensive use of herbicides and tillage (Davis et al. 2005; Menalled et al. 2001). Similar outcomes are likely in sweet corn since only a subset of herbicides registered in dent corn are used in sweet corn and surveys found most fields have numerous species present at the time of sweet corn harvest (Williams et al. 2006b). A growing consensus calls for an integrated approach to weed management that includes using ecological processes advantageously (Buhler et al. 2000; Liebman and Gallandt 1997; Mortensen et al. 2000), such as enhancing the crop's ability to preempt resources (Jordan 1993). Improving WSA of sweet corn, through either genetic or cultural approaches, would target long-term management of weed populations by reducing seedbank size.

The extent to which sweet corn suppresses wild proso millet depends in part on crop hybrid, location, and year. By comparing the *I* parameter estimates (Equation 1) for weed growth on wild proso millet density, GH2547 was 25 to 31% more suppressive than Spirit under irrigated conditions in Washington and 70 to 91% more suppressive under rainfed conditions in Illinois (Table 1). Higher LAI from anthesis to harvest conferred greater weed suppression, and sweet corn LAI at the 120- to 150-cm height was negatively correlated to wild proso millet growth and fecundity. While WSA will rarely kill weeds outright, results from this study suggests WSA of hybrids acts reliably within each sweet corn production region. Greater variation in WSA among hybrids in Illinois suggests competitive sweet corn hybrids may contribute more to weed management in the north-central United States than the Pacific Northwest. Within the array of tactics for integrated weed management, the competitive suppression of weeds by crops can make several small but cumulative contributions of reduced growth and fecundity (Jannink et al. 2000; Liebman and Gallandt 1997) which may reduce herbicide use (Christensen 1994; Lemerle et al. 1996), the number of cultivation passes, or improve weed suppression.

Information on WSA may be useful in several different ways. Direct or indirect selection for WSA traits in breeding programs would lead to genetic improvements for integrated weed management systems (Callaway 1992; Jannink et al. 2000). Nonetheless, cultivars are rarely developed specifically for WSA. Pester et al. (1999) proposed that effectiveness of herbicides in agronomic crops and lack of easily identifiable crop characteristics indicative of WSA have limited such genetic improvements. Alternatively, knowledge of WSA among cultivars could lead to cultural improvements for weed management. As an example, fields with a particularly troublesome weed population would benefit from the use of cultivars with a greater competitive edge. Moreover, competitive cultivars can function independently of weather conditions that might hinder the application of other management practices. Finally, timely postharvest weed management may be more critical following poorly competitive cultivars to minimize seed or propagule production.

Sources of Materials

[1] LI-3100C Area Meter, LI-COR, 4421 Superior Street, Lincoln, NE 68504-0425.

[2] AccuPAR Linear Par Ceptometer PAR-80, Decagon Devices, Inc., 950 NE Nelson Court, Pullman, WA 99163.

Acknowledgments

The authors greatly appreciate the technical assistance of John Frihauf, Ryan Hasty, Brian Philiben, Dallas Spellman, and Yim So. We would also like to recognize Jerald ''Snook'' Pataky for his advice in pursuing this research. Rogers Brand Vegetable Seed provided sweet corn seed.

Literature Cited

Agdag, M., L. Nelson, D. Baltensperger, D. Lyon, and S. Kachman. 2001. Row spacing affects grain yield and other agronomic characters of proso millet. Commun. Soil Sci. Plant Anal. 32:2021–2032.

Anonymous. 2003. Sweet Corn Pest Management Strategic Plan. http://pestdata.ncsu.edu/pmsp/pdf/NCSweetcorn.pdf.

Anonymous. 2006. Vegetables 2005 Summary. Washington, DC: U.S. Government Printing Office. Pp. 17–69.

Azanza, F., A. Bar-Zur, and J.A. Juvik. 1996. Variation in sweet corn kernel characteristics associated with stand establishment and eating quality. Euphytica 87:7–18.

Begna, S.H., R.I. Hamilton, L.M. Dwyer, D.W. Stewart, D. Cloutier, L. Assemat, K. Foroutan-pour, and D.L. Smith. 2001. Morphology and yield response to weed pressure by corn hybrids differing in canopy architecture. Eur. J. Agron. 14:293–302.

Bisikwa, J. 2001. Effects of canopy density on growth and development of wild proso millet and giant foxtail. M.S. thesis. St. Paul, MN: University of Minnesota.
Buhler, D.D., M. Liebman, and J.J. Obrycki. 2000. Theoretical and practical challenges to an IPM approach to weed management. Weed Sci. 48:274–280.
Callaway, M.B. 1992. Compendium of crop varietal tolerance to weeds. Am. J. Alt. Agric. 7:169–180.
Christensen, S. 1994. Crop weed competition and herbicide performance in cereal species and varieties. Weed Res. 34:29–36.
Colosi, J.C. and B.A. Schaal. 1997. Wild proso millet (*Panicum miliaceum*) is genetically variable and distinct from crop varieties of proso millet. Weed Sci. 45:509–518.
Cousens, R. 1985. A simple model relating yield loss to weed density. Ann. Appl. Biol. 107:239–252.
Davis, A.S., K.A. Renner, and K.L. Gross. 2005. Weed seedbank and community shifts in a long-term cropping systems experiment. Weed Sci. 53:296–306.
Forcella, F., D.H. Peterson, and J.C. Barbour. 1996. Timing and measurement of weed seed shed in corn (*Zea mays*). Weed Technol. 10:535–543.
Ford, G.T. and J.M. Pleasant. 1994. Competitive abilities of six corn (*Zea mays* L.) hybrids with four weed control practices. Weed Technol. 8:124–128.
Harvey, R.G. 1979. Serious new weed threat: wild-proso millet. Crops Soils Mag. 27:10–13.
Hunt, R. 1982. Plant Growth Curves: The Functional Approach to Growth Analysis. London: Edward Arnold Publishers.
Hunt, R. 1990. Basic Growth Analysis. London: Unwin Hyman.
Jannink, J.L., J.H. Orf, N.R. Jordan, and R.G. Shaw. 2000. Index selection for weed suppressive ability in soybean. Crop Sci. 40:1087–1094.
Jordan, N. 1993. Prospects for weed control through crop interference. Ecol. Appl. 3:84–91.
Lemerle, D., B. Verbeek, and N.E. Coombes. 1996. Interaction between wheat (*Triticum aestivum*) and diclofop to reduce the cost of annual ryegrass (*Lolium rigidum*) control. Weed Sci. 44:634–639.
Liebman, M. and E. Gallandt. 1997. Many little hammers: Ecological approaches for management of crop-weed interactions. Pages 291–343 *in* L.E. Jackson, ed. Ecology in Agriculture. San Diego, CA: Academic.
Lindquist, J.L. and D.A. Mortensen. 1998. Tolerance and velvetleaf (*Abutilon theophrasti*) suppressive ability of two old and two modern corn (*Zea mays*) hybrids. Weed Sci. 46:569–574.
Lindquist, J.L., D.A. Mortensen, S.A. Clay, R. Schmenk, J.J. Kells, K. Howatt, and P. Westra. 1996. Stability of corn (*Zea mays*)–velvetleaf (*Abutilon theophrasti*) interference relationships. Weed Sci. 44:309–313.
Lindquist, J.L., D.A. Mortensen, and B.E. Johnson. 1998. Mechanisms of corn tolerance and velvetleaf suppressive ability. Agron. J. 90:787–792.
Makus, D.J. 2000. Performance of two sweet corn cultivars grown under conservation tillage and with-in-row weed pressure. Subtrop. Plant Sci. 52:18–22.
Menalled, F.D., K.L. Gross, and M. Hammond. 2001. Weed aboveground and seedbank community responses to agricultural management systems. Ecol. Appl. 11:1586–1601.
Mortensen, D.A., L. Bastiaans, and M. Sattin. 2000. The role of ecology in the development of weed management systems: an outlook. Weed Res. 40:49–62.
Neter, J., M.H. Kutner, C.J. Nachtsheim, and W. Wasserman. 1996. Applied Linear Statistical Models. Chicago: Irwin. 1408 p.
Pataky, J.K. 1992. Relationships between yield of sweet corn and northern leaf blight caused by *Exserohilum turcicum*. Phytopathology 82:370–375.
Pester, T.A., O.C. Burnside, and J.H. Orf. 1999. Increasing crop competitiveness to weeds through crop breeding. Pages 59–76 *in* D.D. Buhler, ed. Expanding the Context of Weed Management. Binghamton, NY: Food Products.
Ratkowsky, D.A. 1983. Nonlinear Regression Modeling: A Unified Practical Approach. New York: Marcel Dekker. Pp. 135–153.
Regnier, E.E. and R.R. Janke. 1990. Evolving strategies for managing weeds. Pages 174–202 *in* C.A. Edwards, R. Lal, P. Madden, R.H. Miller, and G. House, eds. Sustainable Agricultural Systems. Ankeny, IA: Soil and Water Conservation Society.
Roggenkamp, G.J., S.C. Mason, and A.R. Martin. 2000. Velvetleaf and green foxtail response to corn hybrid. Weed Technol. 14:304–311.
Russelle, M.P., W.W. Wilhelm, R.A. Olson, and J.F. Power. 1984. Growth analysis based on degree days. Crop Sci. 24:28–32.
Sankula, S., M.J. VanGessel, and R.R. Mulford. 2004. Corn leaf architecture as a tool for weed management in two corn production systems. Weed Sci. 52:1026–1033.
Strand, O.E. and R. Behrens. 1981. Identification of Wild Proso Millet. Minneapolis, MN: University of Minnesota Agronomy Fact Sheet No. 35. 2 p.
Swinton, S.M., D.D. Buhler, F. Forcella, J.L. Gunsolus, and R.P. King. 1994. Estimation of crop yield loss due to interference by multiple weed species. Weed Sci. 42:103–109.
SYSTAT. 2004. SYSTAT 11.0. Richmond, CA: SYSTAT.
Tracy, W.F. 2001. Sweet corn. Pages 155–197 *in* A.R. Hallauer, ed. Specialty Corns. 2nd ed. Boca Raton, FL: CRC.
Williams, B.J. and R.G. Harvey. 2000. Effect of nicosulfuron timing on wild proso millet (*Panicum miliaceum*) control in sweet corn (*Zea mays*). Weed Technol. 14:377–382.
Williams, M.M., II. 2006. Planting date influences critical period of weed control in sweet corn. Weed Sci. 54:928–933.
Williams, M.M., II., R.A. Boydston, and A.S. Davis. 2006a. Canopy variation among three sweet corn hybrids and implications for light competition. HortScience 41:1–6.
Williams, M.M., II. and J.B. Masiunas. 2006. Functional relationships between giant ragweed (*Ambrosia trifida*) interference and sweet corn yield and ear traits. Weed Sci. 54:948–953.
Williams, M.M., II., T.L. Rabaey, C.L. Boerboom, and A.S. Davis. 2006b. Survey of weeds and weed management in sweet corn grown for processing. Proc. N. Cent. Weed Sci. Soc. 61:83.

Received July 19, 2006, and approved January 12, 2007.