Weed Science 2012 60:537–541

Competitive Effects of Volunteer Corn on Hybrid Corn Growth and Yield

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Transgenic volunteer corn is a competitive weed in soybean that decreases soybean yield at densities as low as 0.5 plants m^{-2}, yet the competitive effects of volunteer corn in corn have yet to be quantified in the peer-reviewed literature. In order to quantify competition between volunteer corn and hybrid corn, seed was harvested from transgenic hybrid corn. The seed was then hand-planted at two locations (Lafayette, IN and Wanatah, IN) into 3 by 9 m plots of hybrid corn at five densities: 0 (control), 0.5, 2, 4, and 8 plants m^{-2}. Volunteer corn competition reduced leaf area and biomass of hybrid corn plants. Hybrid corn grain yield at Lafayette, IN, was reduced by 23 and 22% due to competition with volunteer corn growing in densities of 8 plants m^{-2} in 2010 and 2011, respectively, but when volunteer corn grain yield was combined with the hybrid corn grain yield, there was no reduction in total grain yield. This study demonstrates that the competitive effects on the grain yield of the hybrid corn will be offset by the grain yield of the volunteer plants. However, because the unpredictable locations and densities of volunteer corn plants present challenges to machine harvesting, future studies should examine what proportion of the volunteer crop is actually harvestable.

Nomenclature: Glyphosate; corn, *Zea mays* L.; Bt, *Bacillus thuringiensis* Berliner.
Key words: Competition; yield; glyphosate-resistant; Bt.

The adoption of herbicide-resistant (HR) corn and soybean [*Glycine max* (L.) Merr.] in the United States has increased since the introduction of glyphosate-resistant (GR) soybean varieties in 1996 and GR corn hybrids in 1998 (Castle et al. 2006). In 2011, greater than 94% of the soybean and 72% of the corn planted in the United States was HR (USDA-NASS 2011). The widespread and rapid adoption of GR technologies has led to the evolution of weed biotypes resistant to glyphosate due to selection pressure of glyphosate-only herbicide programs (Johnson et al. 2009). GR crop adoption has also been correlated with increased occurrence of volunteer GR crops, such as volunteer corn growing as a weed (Davis et al. 2008).

Volunteer corn growing in soybean can reduce soybean yield by 10% when left uncontrolled and growing at densities of 0.5 plants m^{-2} (Marquardt et al. 2012), yet the impact of volunteer corn growing with hybrid corn is not addressed in the peer-reviewed literature. The literature does address aspects of intraspecific competition in hybrid corn. Liu et al. (2004) showed that uneven emergence of corn stands reduced grain yield due to competition. Approximately 16% of plants with a two- and four-leaf stage delay in emergence reduced grain yield by 4 and 8%, respectively. Steckel et al. (2009) showed that uncontrolled initial corn stands of 2 or more plants m^{-2} that were V3 to V5 (when replanting corn into corn) could reduce replanted grain yield. Volunteer corn may not be as competitive as hybrid corn in replanted corn or in uneven corn emergence situations, but the data from the latter have provided researchers with valuable information that can be used to help assess the possible impacts of volunteer corn in corn.

The competitive effects of common grass weed species such as shattercane [*Sorghum bicolor* (L.) Moench], johnsongrass [*Sorghum halepense* (L.) Pers.], and foxtail (*Setaria* spp.) on hybrid corn growth and yield have been studied. Beckett et al. (1988) found that shattercane is a highly competitive weed when not controlled in hybrid corn, and shattercane densities of 6.6 clumps m^{-1} in 76-cm rows (two to three plants per clump) reduced corn grain yield by 22%. Hans and Johnson (2002) showed that 31-cm-tall shattercane could reduce hybrid corn grain yield, and the yield reductions could be as high as 85%. Johnsongrass growing in densities of 0.4 and 1.2 plants per m^{-1} lowered hybrid corn grain yield by 8.5 and 49.5%, respectively (Ghosheh et al. 1996). Yellow foxtail [*Setaria pumila* (Poir.) Roem. and Schult.] with a biomass of 110 g m^{-2} reduced corn grain yield by 10% when it was not controlled, but the absolute weed density that reduced corn grain yield was not reported (Clay et al. 2006). Giant foxtail (*Setaria faberi* Herrm.) can reduce corn grain yield by 14% at densities of 10 plants m^{-1} when not controlled (Fausey et al. 1997). Volunteer corn could have a similar impact as the above-mentioned weeds on hybrid corn due to the physiological similarities between the grasses, especially shattercane.

Volunteer corn competition in hybrid corn can be viewed from another perspective, namely intraspecific competition. Light interception and plant population have been shown to be very important factors contributing to intraspecific competition in corn (Page et al. 2010b). Many studies have focused on optimizing plant population in corn plantings (Cox 1997; Knapp and Reid 1981; Nafziger 1994; Olson and Sander 1988; Singer et al. 2003; Stanger and Lauer 2006). The presence of volunteer corn effectively increases the total plant population in the field, and the resulting competitive effect could lower the grain yield of the adjacent hybrid corn. Unlike many other weed species, volunteer corn has the ability to produce grain that is not a harvest contaminant. While volunteer corn would compete for resources with hybrid corn, the potential grain yield loss due to the competitive effect of volunteer corn may be at least partially or completely offset by the volunteer corn grain yield (assuming that volunteer plants develop an ear). The objective of this research was to quantify the competitive effect of volunteer corn growing in increasing densities on hybrid corn growth and grain yield.

Materials and Methods

Corn seed was hand-harvested from GR corn, Dekalb 63-42 in 2009 and Dekalb 61-19 in 2010 (Monsanto Company, St. Louis, MO) for use in establishing volunteer corn in 2010 and 2011, respectively. Field research was conducted at two

DOI: 10.1614/WS-D-11-00219.1

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Table 1. Mean monthly temperature and precipitation at the Throckmorton Purdue Agricultural Center (TPAC) and the Pinney Purdue Agricultural Center (PPAC) in 2010 and 2011.

	TPAC				PPAC			
	Temperature		Precipitation		Temperature		Precipitation	
	2010	2011	2010	2011	2010	2011	2010	2011
Month	C		cm		C		cm	
April	15	12	7.4	15.2	10	9	3.3	10.4
May	18	17	6.2	11.4	17	15	9.8	11.9
June	23	23	10.6	9.4	22	21	16.3	10.4
July	24	26	6.5	4.8	23	24	10.7	13
August	24	23	4.4	2.6	23	21	4.8	6.1
September	20	18	2.4	7.1	18	16	6.3	8.5
Mean	20	19	—	—	18	17	—	—
Total	—	—	38.7	50.5	—	—	51.2	60.3

locations (Throckmorton Purdue Agricultural Center [TPAC], Lafayette, IN, and Pinney Purdue Agricultural Center [PPAC], Wanatah, IN) in 2010 and 2011. The soil type at TPAC was a Toronto-Milbrook silty loam (fine-silty, mixed, superactive, mesic Udollic Endoaqualf) with a pH of 6.2 and 2.9% organic matter. The soil type at PPAC was a Hanna sandy loam (coarse-loamy, mixed, active, mesic Aquultic Hapludalf) with a pH of 6.5 and 2% organic matter. The sites were fall chisel plowed and field cultivated in the spring, a Purdue University–recommended practice when planting continuous corn (Erickson and Lowenberg-DeBoer 2005). The fields were fertilized according to Purdue University Extension recommendations (Camberato et al. 2011). Nitrogen fertilizer application timing was different between the sites. TPAC was fertilized prior to planting, while at PPAC nitrogen fertilizer was sidedressed when the hybrid corn was at the V3 corn growth stage. Temperature and weather data for TPAC and PPAC are shown in Table 1. A Dekalb 61-19 hybrid corn was planted in 76-cm rows at a rate of 79,000 seeds ha^{-1} at TPAC (April 20, 2010, and May 20, 2011) and 79,000 seeds ha^{-1} at PPAC (May 4, 2010, and May 9, 2011). The corn area was divided into plots (3 m by 9 m), and five targeted-densities (a small percentage of seeds did not emerge or were killed by glyphosate applications) of volunteer corn (0 [control], 0.5, 2, 4, and 8 seeds m^{-2}) were hand-planted using a spike planter (Hand Jab Planter, Almaco, Nevada, IA) in a randomized complete-block design with six replications. Volunteer corn seed was randomly planted in the plot area to simulate the true variability of volunteer corn emergence in relation to hybrid corn rows. The previous crop at both locations was corn, and any naturally occurring volunteer plants were removed by hand from the control treatments. The density of naturally occurring volunteer corn was less than one plant per control treatment, which is equal to a density of 0.03 plants m^{-2}. We were not able to differentiate between the volunteer plants we planted and the naturally occurring population in treatments other than the control, but we concluded that the low density of the naturally occurring volunteer corn did not significantly impact our targeted densities. Two volunteer corn planting dates were used (at corn planting: EARLY, at V4 hybrid corn stage: LATE). The experimental plots were treated with a premixture (Lexar®, Syngenta Crop Protection, Inc., Greensboro, NC) of 1.46 kg ai ha^{-1} of *s*-metolachlor, 1.46 kg ai ha^{-1} of atrazine, and 0.188 kg ai ha^{-1} of mesotrione prior to planting, and POST glyphosate (Roundup PowerMAX®, Monsanto) at a rate of 0.84 kg ae ha^{-1} to keep the plots free of weeds other than volunteer corn.

When the hybrid corn flag leaves were fully expanded (approximately VT corn), volunteer corn and hybrid corn plants in 0.5-m^2 areas were cut off at the soil surface to quantify total aboveground biomass. At this time the volunteer corn and hybrid corn leaves were separated by plant (hybrid or volunteer), and the total leaf area of the hybrid and volunteer corn was measured in the field (from the 0.5-m^2 samples). The volunteer corn plants sampled at this point were in various stages of growth that ranged from V8 up to VT plants. The leaf area was calculated by removing each leaf at the stem and running the leaves through a LI-COR LI-3100 leaf area machine (LI-COR Biosciences, Lincoln, NE), which measures leaf area in square centimeters. After measuring the leaf area, volunteer corn and hybrid corn biomass were separated and placed into a drying oven for 5 d at 60 C and then weighed. The EARLY biomass samples always contained a volunteer corn plant, even in the volunteer corn densities of 0.5 and 2 plants m^{-2}. A few of the hybrid corn biomass samples from the LATE 0.5 and 2 plants m^{-2} densities did not always have a volunteer corn plant.

At volunteer corn maturity (approximately 7 to 14 d after hybrid corn maturity), corn ears were hand-harvested from volunteer corn plants growing within and between the center two hybrid corn rows in each plot and weighed to calculate the total volunteer corn grain yield in each plot. Volunteer corn grain yield was adjusted for weight of the corn cob using the standard ear corn conversion factor of 1.72 using ARM software (ARM 8.2.3, Gylling Data Management, Inc., Brookings, SD). After volunteer corn ears were hand-harvested, the center two hybrid corn rows were harvested from each plot with a plot combine (1987 Gleaner F3, AGCO, Duluth, GA) to calculate the total corn grain yield per plot. The grain yield for both the hybrid and volunteer corn was adjusted to 15.5% moisture.

Data Analysis. The hybrid corn leaf area, biomass per plant, and total grain yield data were checked for normality, checked for interactions in PROC MIXED, and modeled with linear regression using the PROC REG procedure in SAS 9.2 (SAS Institute, Inc., Cary, NC). The hybrid corn leaf area, biomass per plant, and grain yield data were separated by year (2010 and 2011) and by location (TPAC and PPAC) due to interactions between location and year. The volunteer corn leaf area and biomass per plant data were checked for normality, checked for interactions in PROC MIXED, and pooled if there were no interactions between year or location and modeled with linear regression using the PROC REG procedure in SAS.

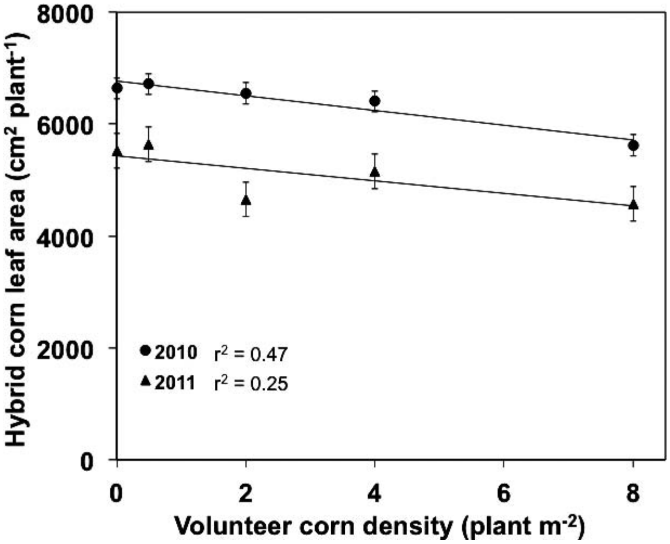

Figure 1. The hybrid corn leaf area (cm^2 $plant^{-1}$) when competing with EARLY planted volunteer corn ranging from targeted densities of 0 to 8 plants m^{-2} at Throckmorton Purdue Agricultural Center (TPAC) in 2010 and 2011. The data were fit to a linear regression model, $y = \beta_0 + \beta_1 x$. Parameter estimates ($\pm$ standard error) are as follows: 2010, $\beta_0 = 6{,}764 \pm 115$, $\beta_1 = -132 \pm 28$; 2011, $\beta_0 = 5{,}434 \pm 216$, $\beta_1 = -111 \pm 53$. The parameter x represents the volunteer corn density. The error bars represent the standard error.

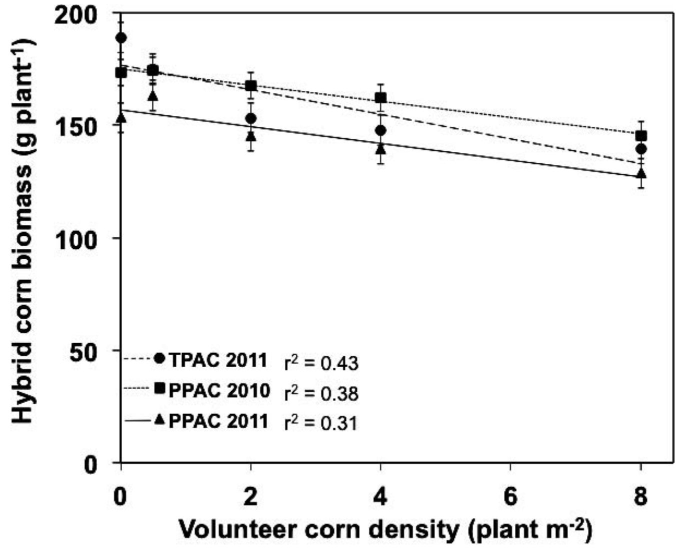

Figure 2. The hybrid corn biomass (g $plant^{-1}$) when competing with EARLY planted volunteer corn ranging from targeted densities of 0 to 8 plants m^{-2} at Pinney Purdue Agricultural Center (PPAC) and Throckmorton Purdue Agricultural Center (TPAC) in 2010 and 2011. The data were fit to a linear regression model, $y = \beta_0 + \beta_1 x$. Parameter estimates ($\pm$ standard error) are as follows: PPAC 2010, $\beta_0 = 175 \pm 3.7$, $\beta_1 = -3.6 \pm 0.9$; PPAC 2011, $\beta_0 = 157 \pm 4.5$, $\beta_1 = -3.8 \pm 1.1$; TPAC 2011, $\beta_0 = 177 \pm 4.8$, $\beta_1 = -5.5 \pm 1.2$. The parameter x represents the volunteer corn density. The error bars represent the standard error.

Results and Discussion

The EARLY planted volunteer corn reduced the hybrid corn leaf area per plant (when leaf area was sampled at approximately VT corn) at TPAC when the targeted volunteer corn density increased from 0.5 to 8 plants m^{-2} (Figure 1). For each volunteer corn plant per square meter, hybrid corn leaf area was reduced by 131 and 111 cm^2 $plant^{-1}$ at TPAC in 2010 and 2011, respectively (Figure 1), compared with no reduction in leaf area at PPAC (2010: $F = 1.46$, $P = 0.24$; 2011: $F = 4.56$, $P = 0.052$). Volunteer corn was less vigorous than hybrid corn, but there was no difference between volunteer corn leaf area ($F = 2.01$, $P = 0.12$) or biomass per plant ($F = 2.46$, $P = 0.07$) at any of the volunteer corn densities over the 2 yr and two locations of the study (Table 2). The difference between the hybrid corn leaf area and biomass per plant data from TPAC and PPAC may be partially explained by differences in the nitrogen fertilizer application practices used. TPAC was treated with a preplant fertilizer application while PPAC was sidedressed when the hybrid corn was approximately in the V3 growth stage (EARLY volunteer corn was approximately V3 as well). The coulters of the nitrogen sidedress unit mechanically injured volunteer corn plants that were hand-planted at PPAC (personal observation), which may have resulted in less vigorous growth and decreased competitive ability. The hybrid corn biomass per plant was not reduced at TPAC in 2010 ($F = 2.51$, $P = 0.13$), but was reduced at TPAC in 2011 and at PPAC in both years when volunteer corn density was increased (Figure 2). Again, the difference between the TPAC and PPAC biomass data may be attributed to differences in nitrogen fertilizer application practices. Competition by giant ragweed (*Ambrosia trifida* L.) for available nitrogen has been correlated to reduced corn biomass, leaf area, and grain yield when nitrogen is applied with a sidedressing unit compared to applied at corn planting (Johnson et al. 2007). Volunteer corn plants that were not injured by the mechanical sidedressing unit at PPAC may have had a nitrogen advantage and competed with the hybrid corn plants for nitrogen, lowering the biomass of the adjacent hybrid corn plants.

Table 2. The EARLY planted volunteer corn leaf area and biomass per plant.

Volunteer corn density (plants m^{-2})	Biomass g $plant^{-1}$ (SEM)	Leaf area cm^2 $plant^{-1}$ (SEM)
0.5	102 (13)	3,007 (400)
2	84 (8)	3,284 (205)
4	97 (14)	3,459 (348)
8	83 (14)	2,768 (231)

The LATE planted (emerging when the hybrid corn is approximately V4) volunteer corn had no effect on the hybrid corn leaf area per plant ($F = 1.07$, $P = 0.31$), biomass per plant ($F = 1.53$, $P = 0.22$), or hybrid corn grain yield ($F = 0.02$, $P = 0.89$) at TPAC. Only the hybrid corn biomass per plant ($F = 6.63$, $P = 0.01$, $r^2 = 0.10$), was affected by the LATE volunteer corn at PPAC, but the hybrid corn leaf area per plant ($F = 0.02$, $P = 0.89$) and hybrid corn grain yield ($F = 0.29$, $P = 0.59$) were not affected by the LATE volunteer corn. Travlos et al. (2011) and showed that barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] that emerged after V4 hybrid corn was much less competitive than barnyardgrass that emerged prior to V4 hybrid corn. Yet, Travlos et al. (2011) did illustrate that barnyardgrass growing in densities ranging from 6.5 to 13 plants m^{-2} could cause less than 9% hybrid corn grain yield reduction when it emerged later than V4 hybrid corn. The size of the LATE volunteer corn in our study locations (even at the 0.5 plants m^{-2} density) was similar to fall panicum (*Panicum dichotomiflorum* Michx.) and barnyardgrass (personal observation) and did not cause any measureable hybrid corn grain yield loss. Kropff and Spitters (1991) illustrated in a weed

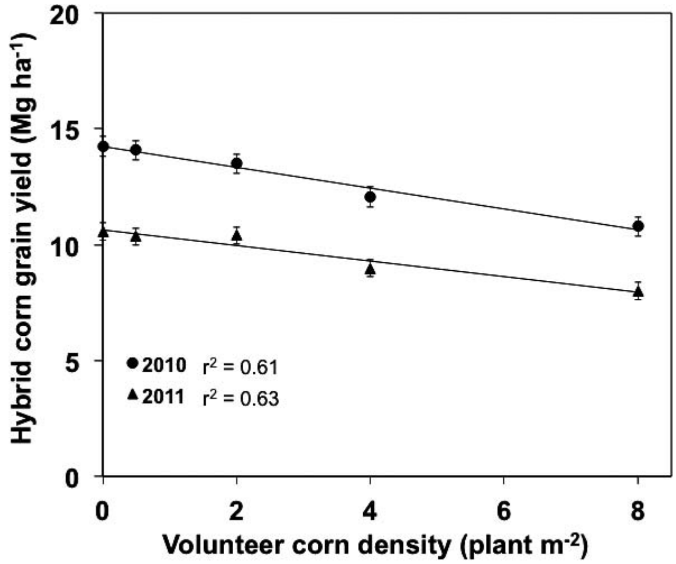

Figure 3. The hybrid corn grain yield (Mg ha^{-1}) when competing with EARLY planted volunteer corn ranging from targeted densities of 0 to 8 plants m^{-2} at Throckmorton Purdue Agricultural Center (TPAC) in 2010 and 2011. The data were fit to a linear regression model, $y = \beta_0 + \beta_1 x$. Parameter estimates ($\pm$ standard error) are as follows: 2010, $\beta_0 = 14 \pm 0.3$, $\beta_1 = -0.4 \pm 0.07$; 2011, $\beta_0 = 11 \pm 0.2$, $\beta_1 = -0.3 \pm 0.06$. The parameter x represents the volunteer corn density. The error bars represent the standard error.

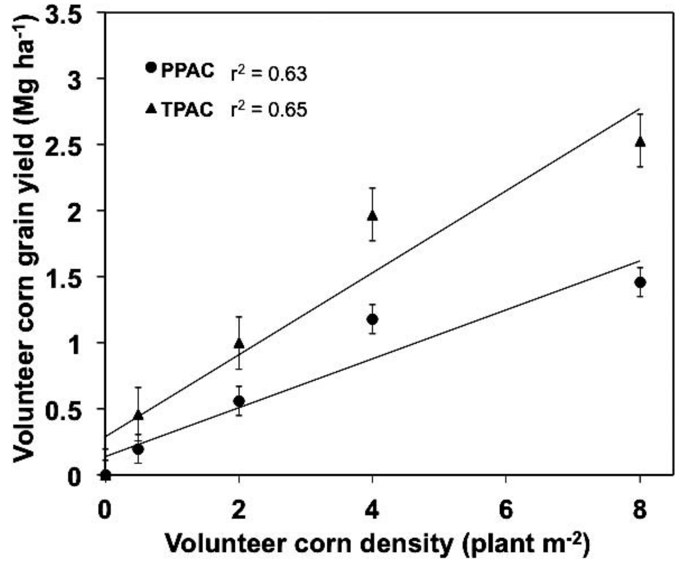

Figure 4. The volunteer corn grain yield (Mg ha^{-1}) when competing with EARLY planted volunteer corn ranging from targeted densities of 0 to 8 plants m^{-2} at Pinney Purdue Agricultural Center (PPAC) and Throckmorton Purdue Agricultural Center (TPAC). The data were fit to a linear regression model, $y = \beta_0 + \beta_1 x$. Parameter estimates ($\pm$ standard error) are as follows: PPAC, $\beta_0 = 0.15 \pm 0.08$, $\beta_1 = 0.18 \pm 0.02$; TPAC, $\beta_0 = 0.30 \pm 0.12$, $\beta_1 = 0.31 \pm 0.03$. The parameter x represents the volunteer corn density. The error bars represent the standard error.

competition model how weed leaf area and time of emergence can affect hybrid corn grain yield. Since weed emergence is delayed, crop yield loss has been shown to be reduced. Ghosheh et al. (1996) showed that johnsongrass rhizomes that sprout buds at corn emergence can cause corn grain yield loss while seedling johnsongrass (emerging from seeds) does not affect the grain yield of the corn plants. The rapid growth of hybrid corn, due to seed size differences in the case of johnsongrass, gave hybrid corn an advantage. Due to the fact that we did not see an interaction between treatments and the LATE volunteer corn in our study we can conclude that volunteer corn emerging after V4 hybrid corn is not a competitive weed.

Multiple studies have indicated that interspecific and intraspecific competition can begin early in the growing season and continue throughout the season (Beckett et al. 1988; Ghosheh et al. 1996; Hans and Johnson 2002; Page et al. 2010a,b). Recent research has shown that early red to far-red ratios can influence leaf orientation and plant growth even in the early seedling stage (Page et al. 2010a). Early season competition in hybrid corn can reduce grain yield, mainly due to a weed's ability to grow along side the crop canopy (i.e., escape shade caused by the canopy) and reduce resources available to the crop (nutrients, water, and light).

The biomass and leaf area of a crop are often accurate predictors of the grain yield of corn (Ngouajio et al. 1999). Larger plants (i.e., more biomass and leaf area) can accumulate more resources that in turn can be used to produce grain yield. At TPAC, volunteer corn reduced the hybrid corn grain yield at a rate of 0.44 and 0.33 Mg ha^{-1} for each volunteer corn plant per square meter in 2010 and 2011, respectively (Figure 3). The hybrid corn grain yield at PPAC was not reduced by the presence of volunteer corn (2010: $F = 3.41$, $P = 0.08$; 2011: $F = 2.13$, $P = 0.16$). Volunteer corn plants at TPAC were highly competitive with the hybrid corn plants throughout the growing season, yet volunteer corn has the capability to produce grain yield, which complicates any yield loss calculations.

Volunteer corn growing in corn does not cause grain contamination as it does in other crops. For example, in soybeans, volunteer corn densities of 0.5 plants m^{-2} can result in up to 16% grain contamination (Marquardt et al. 2012). When volunteer corn is growing and competing with corn, the production of grain by the volunteer plants can add to the total grain yield. While not all the volunteer corn plants in a field produce grain, even a small amount of grain production can offset the hybrid grain yield loss due to competition. There was no difference between years for volunteer corn grain yield (PPAC: $F = 2.95$, $P = 0.09$; TPAC: $F = 0.33$, $P = 0.56$), so volunteer corn grain yield was pooled by location. Our data illustrate that as volunteer corn densities increased, the volunteer corn grain yield also increased at TPAC and PPAC at a rate of 0.18 and 0.31 Mg ha^{-1}, respectively, for each additional volunteer corn plant per square meter (Figure 4). When the volunteer corn grain yield was added into the hybrid corn grain yield, any grain yield reduction due to competition (as was seen at TPAC) was eliminated (TPAC 2010: $F = 1.21$, $P = 0.28$; TPAC 2011: $F = 0.37$, $P = 0.55$). The addition of volunteer corn grain yield into the hybrid corn grain yield assumes that mechanical harvest equipment will be able to successfully harvest all of the grain produced by volunteer corn. The scope of our research did not focus on this issue; however, mechanical harvest inefficiencies are common when harvesting corn (Vagts 2003), and volunteer corn growing between rows may increase these inefficiencies and decrease the amount of volunteer kernels that are mechanically harvested. Other factors could potentially lower the quality of grain or grain yield. Blandino et al. (2008) showed that an increase in corn plant population (volunteer corn increases total plant population in a hectare) could result in higher incidences of diseases in corn grain. Disease due to volunteer corn, along with harvest inefficiencies, may result in an overall grain yield reduction even when volunteer corn produces acceptable quality grain.

GR volunteer corn growing in corn is a difficult weed to control. Control measures are limited to mechanical field cultivation, rotating herbicide-resistant hybrids (i.e., GR hybrids followed by glufosinate-resistant hybrids), or rotating to another crop such as soybean where more chemical control options exist (e.g. acetyl-CoA carboxylase inhibitors). Our data indicated that management of volunteer corn in corn is not necessary to protect hybrid corn grain yield when volunteer corn grain can be harvested, but the previously mentioned harvest inefficiencies and increased disease pressure could lower total corn yield and grain quality. Another factor in the management decision for controlling GR volunteer corn in corn involves the expression of other transgenic traits (mainly insect feeding resistance toxins, i.e., Bt traits) in GR volunteer corn. GR volunteer corn that is allowed to survive may (or may not) express Bt traits, which could potentially increase Bt selection pressure on targeted insect pests (Krupke et al. 2009) or cause higher levels of damage to adjacent Bt hybrid plants (Murphy et al. 2010). More research is necessary to determine the extent of the impact of GR volunteer corn expressing Bt traits on insect resistance management strategies, especially as seed mix refuges (where Bt and refuge seeds are mixed at planting) become more widely adopted. As increasing hectares of land are devoted to corn production (especially corn following corn), weed management approaches to reduce GR volunteer corn growing in corn may be necessary to decrease the potential for harvest contamination due to disease and to reduce the potential increase in Bt selection pressure on targeted insect pests.

Acknowledgments

The authors would like to thank Gowan Company for providing financial support for this project. The authors would also like to thank the Integrated Weed Management group at Purdue University for contributing to the success of this project.

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Received December 20, 2011, and approved April 10, 2012.