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Functional relationships between giant ragweed (*Ambrosia trifida*) interference and sweet corn yield and ear traits

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Field experiments were conducted to quantify functional relationships between giant ragweed density and sweet corn yield and ear traits. A rectangular hyperbolic model was fit to yield loss measured in terms of marketable ear mass, appropriate for the processing industry, and boxes of 50 marketable ears, relevant to the fresh market industry. The initial slope of the hyperbolic yield loss function (I), which describes the linear portion of yield loss as weed density (weeds per square meter) approaches zero, was 119 for loss of ear mass and 97 for loss of boxes of ears. Furthermore, 10 of 12 ear traits including green ear mass, husked ear mass, ear length, filled ear length, ear width, number of kernels per row, number of rows, kernel depth, kernel mass, and kernel moisture content were significantly affected by giant ragweed interference.

Nomenclature: Giant ragweed, *Ambrosia trifida* L. AMBTR; sweet corn, *Zea mays* L. 'GH0937'.

Key words: Competition, crop quality, economic threshold, yield loss.

Sweet corn is one of the most popular vegetable crops in the United States, exceeding $800 million in farm value. Production has steadily increased due to growing demand in the United States and in Asian, European, and South American export markets (Tracy 2001). Sweet corn is consumed as a fresh and processed vegetable, and within each of these markets further market subdivisions exist. Both total production and value of processed sweet corn has increased 60% over the last 25 years (Anonymous 1988, 2003). Processing by canning and freezing was estimated to increase value of sweet corn by 300 to 400% (Kaukis and Davis 1986).

Although extensive weed science research has been conducted on dent corn, comparatively little research has been conducted on sweet corn. The primary difference between sweet corn and other types of maize is gene expression that determines endosperm carbohydrate content as well as many other genes that affect maize growth (Azanza et al. 1996; Tracy 2001). Differences between dent corn and sweet corn include phenotypic traits, such as emergence rate and canopy height (Azanza et al. 1996; Hassell et al. 2003; Treat and Tracy 1994), and cultural practices such as planting density, planting date, and harvest timing. Moreover, extensive variation in canopy development and density exists among sweet corn hybrids (Bisikwa 2001; Pataky 1992). Such differences among maize hybrids call into question the extent to which literature on weed interactions with dent corn can be used to improve weed management in sweet corn.

Sweet corn also differs from dent corn in a number of ear traits affecting yield, appearance, kernel quality, and ultimately marketability; however, relative importance depends upon the intended market of the crop (Tracy 2001). For example, green ear mass is important for whole-kernel and cream-style processed markets, but relatively unimportant in the fresh market where flavor is essential. Ear length, kernel moisture, and sugar content are just a few of the ear traits that could be influenced by weed interference (Van Wychen et al. 2001). Sweetness makes up most of sweet corn flavor and is dependent on kernel sucrose content (Azanza et al. 1996). Kernel moisture, sucrose concentration, and starch levels change rapidly as the crop matures (Tracy 2001). Weed–crop competition for light and moisture will reduce photosynthetic rate and sucrose biosynthesis, thus it may impact sweetness and ear quality. Ear appearance, including ear length, tip fill, and row configuration, influence the attractiveness of the crop to consumers and product recovery rates for processors (Simonne et al. 1999; Tracy 2001). There is no information on the impact of weeds on sweet corn yield or ear quality but it would be beneficial for the development of integrated weed management systems.

Giant ragweed is one of the most competitive annual weeds in dent corn (Harrison et al. 2001) and soybean [*Glycine max* (L.) Merr.] (Baysinger and Sims 1991; Stoller et al. 1985; Webster et al. 1994). In dent corn, Harrison et al. (2001) found a 13.6% yield loss from the first giant ragweed per 10 m^2 and a maximum yield loss of 90% at high ragweed densities. Giant ragweed occurrence within dent corn and soybean fields has increased over the last 30 years, becoming the second-most common late season weed observed in Indiana (Johnson et al. 2005). There are giant ragweed cohorts in the Midwest that emerge after PRE herbicides lose their effectiveness and after glyphosate has been applied. Giant ragweed occurs throughout sweet corn fields in Illinois and is often one of the largest weeds at harvest (M.M.W., personal observation). The objective of this study was to quantify relationships between giant ragweed density and sweet corn yield and ear traits associated with quality.

Materials and Methods

Experimental Methodology

Field experiments were conducted in 2004 and 2005 at the Northern Illinois Agronomy Research Center at Dekalb, IL, and the Crop Sciences Research and Education Center at Urbana, IL. The soil at Dekalb was a Flanagan silt loam (fine, smectitic, mesic Aquic Argiudoll) with 4.8% organic matter and pH of 6.0 and the soil at Urbana was a Flanagan silt loam with 3.6% organic matter and pH of 6.4. The previous crop was soybean, with the exception of alfalfa at Urbana in 2004. The experimental area was chisel-plowed either in the fall or spring, followed by one pass each of a disk harrow and a field cultivator prior to planting. Sweet corn was planted in 76-cm rows with four-row planters at Dekalb[1] and Urbana.[2] Glufosinate-tolerant sweet corn ('GH0937', a *sugary1* endosperm mutant) was planted at 70,400 seeds ha^{-1} on May 5, 2004, and May 6, 2005, in Dekalb and at 69,200 seeds ha^{-1} on May 6, 2004, and May 4, 2005, in Urbana. The Dekalb site was fertilized on April 13, 2004, and April 8, 2005, by applying 202 kg N ha^{-1}. The Urbana site received 52 kg N ha^{-1}, 46 kg P ha^{-1}, and 54 kg K ha^{-1} on March 23, 2004, following alfalfa and 202 kg N ha^{-1} on March 22, 2005.

Five giant ragweed density treatments were established: 0, 0.11, 0.32, 0.65, and 1.29 plants m^{-2}. The experimental design was a randomized complete block with four replications. Experimental units measured 12.2 m in length by four rows wide (3.0 m). Giant ragweed was established only within the two center rows of experimental units.

A large, naturally occurring population of giant ragweed was used at Dekalb. When giant ragweed had two to four true leaves, inverted 950-ml plastic cups with a 10-cm diameter opening were temporarily staked to the soil to protect giant ragweed seedlings for each density treatment. Glufosinate was applied at a rate of 0.41 kg ai ha^{-1} with 5% (v/v) ammonium sulfate, which killed all weeds not protected by the cups. Cups were removed and, when necessary, protected areas were thinned to a single giant ragweed seedling.

The giant ragweed population was relatively small and nonuniform at Urbana, therefore the site was overseeded to ensure adequate weed emergence. Giant ragweed seeds were collected from Dekalb in the previous fall of each year, cleaned, and then stored at 4 C. To promote germination, giant ragweed seeds were stratified 10 to 12 wk prior to planting. Immediately following sweet corn planting, 12 to 15 giant ragweed seeds were hand planted 2 cm deep to establish the densities. After emergence, giant ragweed seedlings were thinned to achieve the appropriate density.

Experimental sites were kept free of all other weeds by handweeding and herbicides. *S*-metolachlor at 1.78 kg ai ha^{-1} was applied to the entire experimental sites. The weed-free plots were treated PRE with atrazine at 2.2 kg ai ha^{-1}. On June 4, 2005, at Urbana, giant ragweed seedlings were covered with cups, as described above, to permit application of glufosinate at 0.46 kg ai ha^{-1} with 2.5% (v/v) ammonium sulfate as well as *S*-metolachlor at 1.78 kg ai ha^{-1}.

The experimental site at Urbana in 2005 was sprinkler irrigated three times (June 10, June 22, and July 2); each event totaling 2.5 cm of water to prevent crop stand loss due to abnormally low rainfall.

Data Collection

Marketable ears were hand harvested 18 to 22 d after anthesis from 6.1 m of the center two rows on August 9, 2004, and August 3, 2005, at Dekalb and July 26, 2004, and July 28, 2005, at Urbana. Ears were considered marketable if kernels were full and yellow. Ears (including silks + husks) meeting these criteria exceeded 3.8 cm in diameter at Dekalb in 2005 and 4.4 cm in diameter in remaining locations and years. Total number and mass of ears were recorded. Five ears from each plot were randomly selected, sealed in plastic bags, and placed on ice. Within 24 h, ears were analyzed for green ear mass (cob + kernels + silks + husks), husked ear mass (cob + kernels), ear width at the midpoint, ear length, filled ear length, number of rows, number of kernels per row, and kernel depth. Kernels were removed from the cob with an electric knife in 2004 and a power corn cutter[3] in 2005. Kernel mass was determined as husked ear mass minus cob mass. Percentage of kernel moisture was determined gravimetrically using a 20-g sample of kernels. Another 20-g kernel sample was ground with a mortar and pestle, then gently squeezed through 0.5-mm nylon mesh. A digital refractometer[4] was used to determine percentage of total sugar content of kernel sample. Recovery, the percentage of green ear mass represented by kernel mass, was calculated. The final giant ragweed density in each plot was recorded on the day of crop harvest.

Statistical Analyses

Green ear mass and boxes of ears were analyzed separately. Mass of green ears per unit area was a yield assessment of sweet corn grown for processing. Number of boxes of ears per unit area, with one box equaling 50 ears was a yield assessment of sweet corn grown for the fresh market. Mass and number of boxes in a plot were divided by mass or number of boxes in the weed-free plot to provide relative yield. Percentage of yield loss was calculated as unity minus relative yield. A rectangular hyperbola equation (Cousens 1985) was fit to percentage of yield loss in each year and location:

$$Y_l = \frac{IN}{1 + \frac{IN}{A}} \qquad [1]$$

where Y_l is percentage of yield loss (mass or boxes), N is giant ragweed density (expressed in plants m^{-2}), I is the linear region of the function's slope as giant ragweed density approaches zero, and A is maximum yield loss. Parameter estimates were determined using an iterative least-squares procedure (SigmaPlot 8.0[5]). Lack of fit was assessed by the magnitude of root mean square errors (RMSE) and standard errors of parameter estimates. The extra sum of squares principle for nonlinear regression analysis (Ratkowsky 1983) was employed to evaluate the similarity of parameter estimates between locations and years. Comparisons were made by calculating a variance ratio of individual and pooled residual sums of squares. If parameter estimates were constant across locations or years, data were pooled accordingly.

Ear trait losses were calculated using the same approach as calculating yield loss. Equation 1 was fit to ear trait losses and evaluated for similarity across environments as described above. Bonferroni joint confidence intervals (Neter et al. 1990) were then calculated for *I* and *A* parameter estimates of Equation 1. Giant ragweed density influenced ear traits when 95% Bonferroni joint confidence intervals of parameter estimates did not include zero. Contrasts of parameter estimates were made among ear traits and determined significant when 95% Bonferroni joint confidence intervals failed to overlap.

Results and Discussion

Air temperature and rainfall were similar at Dekalb and Urbana within a year, however they varied across years (Figure 1). Cumulative rainfall from planting to harvest in 2005 was 59% of precipitation in 2004. The upper temperature threshold for net photosynthesis gain in dent corn, 30 C (Gilmore and Rogers 1958), was exceeded three times more often in 2005, compared to 2004. High air temperatures also affect sweet corn pollen viability and kernel fill (Magoon and Culpepper 1932). As a result, sweet corn yields reflect the drought and high temperature conditions of 2005. Weed-free yields in 2004 averaged 20.9 Mg ha^{-1} or 1,350 boxes ha^{-1}, compared to 12.9 Mg ha^{-1} or 886 boxes ha^{-1} in 2005.

Despite different growing conditions between years, the effect of giant ragweed density on mass and boxes of ears was similar. *F* values indicated sweet corn yield responses to giant ragweed density were consistent among locations and years (P = 0.52 and greater); therefore data were pooled among site-years. Low densities of giant ragweed caused a significant loss in mass and boxes of ears (Figure 2). The maximum predicted loss of mass and boxes of ears (*A*) was 100%. As ragweed density approaches zero, yield loss (parameter *I* in Equation 1) was 119 (±19) for loss of ear mass and 97 (±17) for loss of boxes of ears. While these two yield loss functions are statistically similar (P = 0.17), there may be a biological basis for subtle differences in yield loss functions of green ear mass and number of ears. Per-plant kernel mass and kernel number was reduced by plant population density (Cox 1996; Tetio-Kagho and Gardner 1988) or weed interference (Tollenaar et al. 1997) to a greater extent than ear number in dent corn. In our work a lower *I* value for boxes of ears indicated, at the onset of weed interference, sweet corn began losing ear mass before ear number was affected. Initial reductions in ear number, resulting from greater levels of weed interference, would occur after additional loss of ear mass.

The *I* parameter has been used as an index for comparing tolerance among crop cultivars (Lindquist and Mortensen 1998), the effect of weed emergence times on crop yield (Harrison et al. 2001), and the relative competitiveness among weed species (Swinton et al. 1994). Comparison of previously reported *I* parameters on an equivalent weed density scale in dent corn indicates sweet corn hybrid 'GH0937' may have similar tolerance to weed interference. When giant ragweed emerged with dent corn hybrid 'Countrymark 727', Harrison et al. (2001) reported an *I* value of 136 (adjusted to equivalent weed density scale). However across 13 site-years, Lindquist (2001) found that *I* ranged from 3 to 34 for velvetleaf (*Abutilon theophrasti* Medicus) interference in dent corn. Cardina et al. (1995) reported some of the highest *I* values; up to 60 for velvetleaf interference in one year of no-tillage dent corn. Sweet corn phenotypes differ substantially in canopy density (Bisikwa 2001) and this has significant effect on crop tolerance to wild proso millet (*Panicum miliaceum* L.) interference (M.M. Williams II and R.A. Boydston, unpublished data). The extent to which weed interactions with dent corn relate to sweet corn interactions with the same weed species require further study.

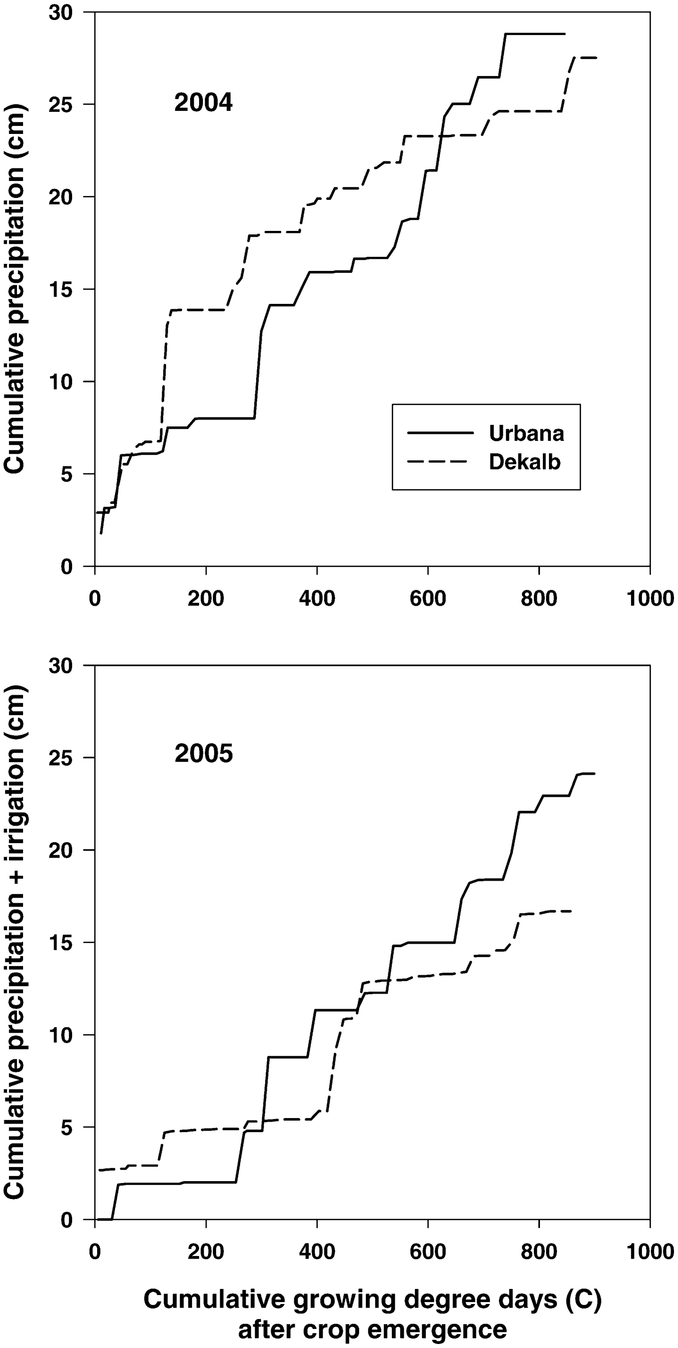

FIGURE 1. Cumulative precipitation plotted against cumulative growing degree days after crop emergence at Urbana and Dekalb, IL, in 2004 and 2005. Precipitation in 2005 at Urbana includes three irrigation events totaling 7.5 cm of water.

As weed density approaches zero, ear traits most consistently affected by giant ragweed interference included ear mass, followed by kernel number. Response of ear traits varied by year and location as evidenced by the *F* tests for

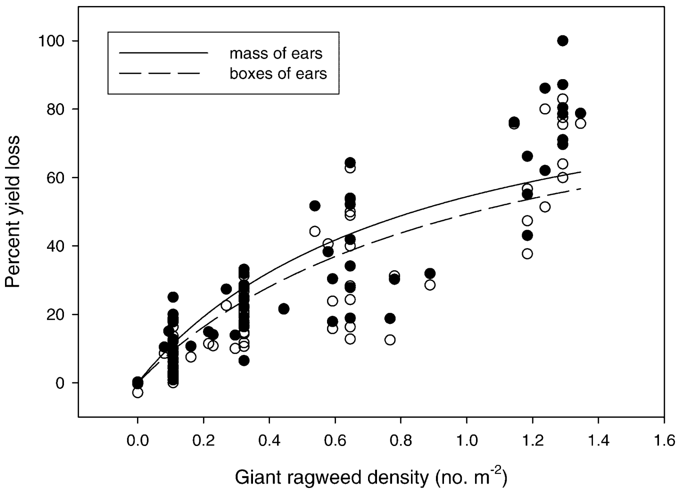

FIGURE 2. Effect of giant ragweed density on percentage of sweet corn yield loss of mass (filled circles) and boxes (open circles) of marketable ears. The regression equations are yield loss of mass = $119x/(1 + 119x/100)$ (root mean square error = 12.0), and yield loss of boxes = $97x/(1 + 97x/100)$ (root mean square error = 12.3).

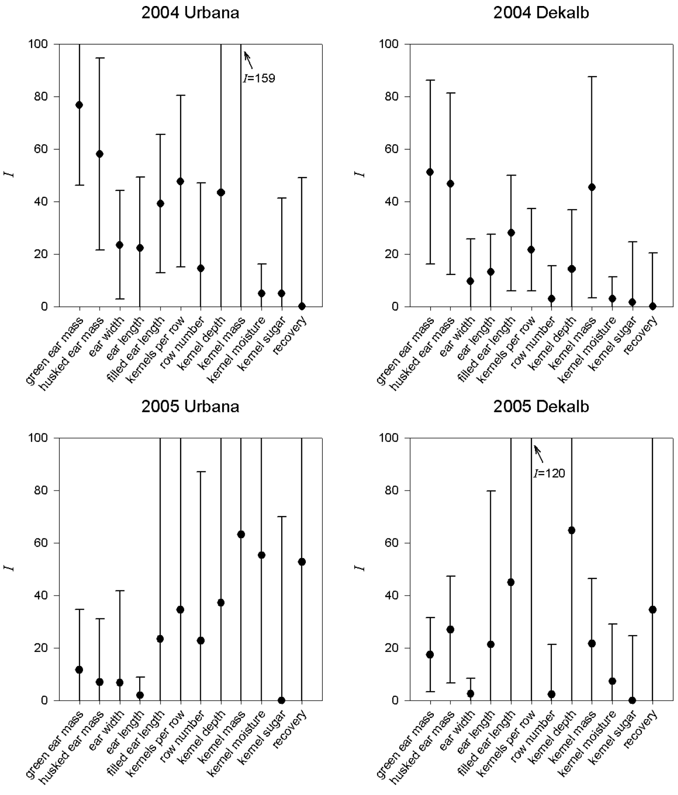
2004 Urbana
2004 Dekalb
2005 Urbana
2005 Dekalb

FIGURE 3. Estimates of *I* obtained from fitting Equation 1 to loss of 12 ear traits due to giant ragweed density in 2004 and 2005 in Dekalb and Urbana, IL. Vertical bars are 95% Bonferroni joint confidence intervals for estimates of *I*, ear trait loss as weed density approaches zero.

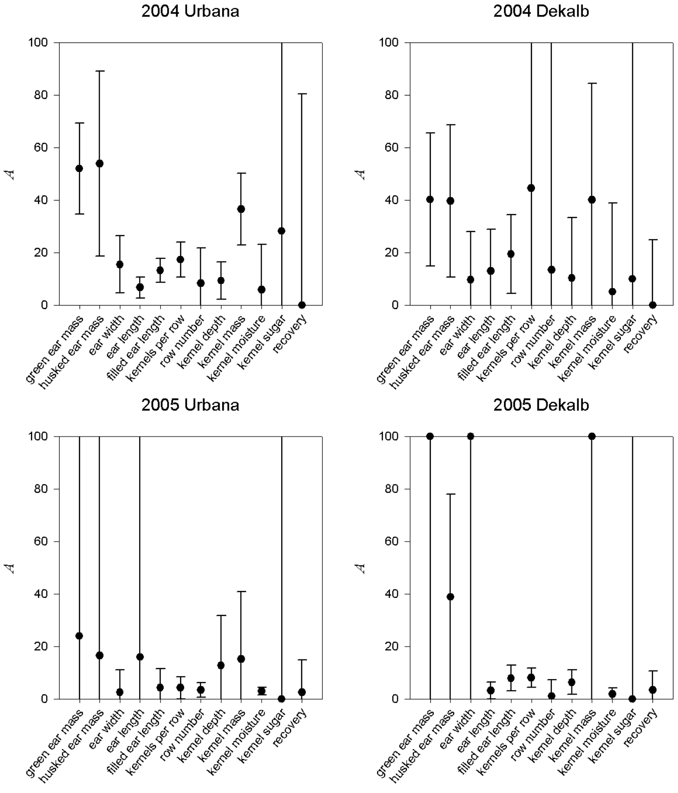
2004 Urbana
2004 Dekalb
2005 Urbana
2005 Dekalb

FIGURE 4. Estimates of *A* obtained from fitting Equation 1 to loss of 12 ear traits due to giant ragweed density in 2004 and 2005 in Dekalb and Urbana, IL. Vertical bars are 95% Bonferroni joint confidence intervals for estimates of *A*, maximum ear trait loss.

comparing nonlinear models ($P < 0.05$), therefore data were not pooled among site-years. *I* values for green ear mass and husked ear mass were significant in 3 of 4 site-years and ranged from 18 to 77 for green ear mass and 27 to 58 for husked ear mass (Figure 3). Therefore, marketable ears would be predicted to lose as much as 77% green ear mass with the first giant ragweed per square meter. Filled ear length and kernel number were affected in 2004 as evidenced by *I* values significantly different than zero. As an example, marketable ears would be predicted to lose as much as 48% of their kernels with the first giant ragweed per square meter. Other ear traits with significant *I* values in at least one site-year included ear width and kernel mass.

Maximum predicted ear trait loss was significant for all ear traits in one or more site-years except kernel sugar content and recovery. Kernel number was influenced by weed interference in 3 of 4 site-years, as evidenced by significant *A* values for filled ear length and number of kernels per row (Figure 4). Maximum ear trait loss was highest for green ear mass and husked ear mass in 2004, ranging from 40 to 54%. Interpretation of maximum ear trait loss (*A*) should consider that only marketable ears were analyzed for ear traits. Therefore, results could be used to predict how weed interference affects marketable ears. As weed density increases, ears become smaller and eventually fail to develop fully. This is supported by the observation that, when considered on an area basis, maximum yield loss is 100% (Figure 2).

Giant ragweed interference resulted in sweet corn kernels with elevated moisture content in 1 of the 4 site-years of the study, suggesting weed interference delayed crop maturity. Kernel moisture decreased as sweet corn matured and was significantly affected by environmental conditions (Azanza et al. 1996; Lass et al. 1993). Others have reported delays in crop maturity associated with weed interference and drought stress. Ear and ovule development in dent corn was delayed when late vegetative stages are subjected to drought stress (Ritchie et al. 1993), an environmental condition that could be exacerbated by weed interference. Black et al. (1996) reported delays in soybean maturity from hemp sesbania [*Sesbania exaltata* (Raf.) Rydb.] interference. Sweet corn maturity influences kernel quality traits, such as flavor and texture, and uniform maturity is highly desirable (Tracy 2001). Delayed or increased variation in crop maturity due to weed interference warrant consideration in the development of weed management systems for sweet corn.

Total sugar content of the hybrid studied here, a *sugary1* endosperm mutant, was not affected by giant ragweed interference. Most fresh market hybrids utilize endosperm mutants such as *sugary enhancer1, shrunken2,* or a combination of several mutants that have higher total sugar content than *sugary1* endosperm mutants (Tracy 2001). The extent to which sugar content of other hybrids may be influenced by giant ragweed interference is unknown, particularly in hybrids that assimilate higher total sugar concentrations than *sugary1* mutants.

Parameter estimates of ear trait loss were sometimes variable (Figures 3 and 4). For example, kernel mass had some of the highest parameter estimates across most environments; however, few were significant at $\alpha = 0.05$. Inherent in the design of these experiments was that only five of the total ears harvested per plot (up to 70) could be analyzed for individual ear traits within 24 h of harvest. Extending ear trait analysis in time, especially for kernel moisture and sugar content, is inappropriate since losses occur immediately postharvest as sugars of *sugary1* endosperm mutants are converted to phytoglycogen (Tracy 2001). Rate of sugar loss within 24 h can be delayed with cooling (Garwood et al. 1976). Because giant ragweed is considered one of the most competitive annual weeds in dent corn and soybean, relatively low densities were established in this study (as few as two plants per plot). With the exception of perhaps weed-free and highest weed density plots, competitive effect of giant ragweed on sweet corn was likely nonuniform at other weed densities. Consequently, crop response to weed density treatments may have been more variable as measured from a five-ear subsample than if all ears could have been analyzed. Area of influence experiments are particularly valuable method at low weed densities (Jordan 1989) and could refine the effect of weed interference on individual crop plants.

This research quantifies the effect of giant ragweed density on both mass and boxes of ears. In the sweet corn processing industry, growers are compensated for mass of marketable ears they produce, whereas in the fresh market industry the economic unit of production is boxes of marketable ears. Mass of ears may be affected to a greater extent by weed interference than boxes of ears; however, our data indicate these responses were similar at $\alpha = 0.05$. Therefore economic thresholds for giant ragweed management in sweet corn may be the same, regardless of whether the crop is destined for the fresh market or one of several processing markets. As an example, our data indicate a giant ragweed density of 0.04 weeds m^{-2} (=1 weed per 25 m^2) would result in 5% loss of ear mass. Harrison et al. (2001) report a similar weed density for 5% yield loss in dent corn when giant ragweed emerged with the crop; however, 5% yield loss required 0.42 weeds m^{-2} (=10.5 weeds 25 m^{-2}) for giant ragweed emerging 4 wk after the crop. Delayed sweet corn planting reduced yield losses due to interference from common lambsquarters (*Chenopodium album* L.) and velvetleaf (Williams 2006) and may be one of several tactics for managing giant ragweed–infested fields.

Sources of Materials

[1] John Deere 7300 planter, Deere & Company, One John Deere Place, Moline, IL 61265-8098.

[2] Monosem NG Plus vacuum planter, A.T.I. Inc., 17135 W. 116th Street, Lenexa, KS 66219.

[3] Power corn cutter, A&K Development Company, 410 Chambers, Eugene, OR 97402.

[4] AR200 Digital Refractometer, Leica Microsystems Inc., Educational and Analytical Division, P.O. Box 123, Buffalo, NY 14240.

[5] SigmaPlot 2002 for Windows, Version 8.02. SPSS, Inc., 444 N. Michigan Avenue, Chicago, IL 60611.

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