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Has Breeding Improved Soybean Competitiveness with Weeds?

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Soybean yield gain over the last century has been attributed to both genetic and agronomic improvements. Recent research has characterized how breeding efforts to improve yield gain have also secondarily impacted agronomic practices such as seeding rate, planting date, and fungicide use. To our knowledge, no research has characterized the relationship between weed–soybean interference and genetic yield gain. Therefore, the objectives of this research were to determine whether newer cultivars would consistently yield higher than older cultivars under increasingly competitive environments, and whether soybean breeding efforts over time have indirectly increased soybean competitiveness. Field research was conducted in 2014, 2015, and 2016 in which 40 maturity group (MG) II soybean cultivars released between 1928 and 2013 were grown season-long with three different densities of volunteer corn (0, 2.8, and 11.2 plants m^{-2}). Soybean seed yield of newer cultivars was higher than older cultivars at each volunteer corn density ($P < 0.0001$). Soybean seed yield was also higher in the weed-free treatment than at low or high volunteer corn seeding rates. However, soybean cultivar release year did not affect late-season volunteer corn shoot dry biomass at either seeding rate of 2.8 or 11.2 seeds m^{-2}. The results indicate that while soybean breeding efforts have increased yield potential over time, they have not increased soybean competitiveness with volunteer corn. These results highlight the importance of other cultural practices such as planting date and crop row spacing for weed suppression in modern soybean production systems.
Nomenclature: Corn, *Zea mays* L.; soybean, *Glycine max* (L.) Merr.
Key words: Crop–weed competition, genetic gain.

Soybean seed yields in the United States have increased 24.3 kg ha^{-1} yr^{-1} from 1924 to 2016 (USDA National Agricultural Statistics Service 2017). Specht et al. (1999) concluded that 50% of this increase could be attributed solely to genetic gain and hypothesized that improvements in agronomic practices and their interactions with genetic gain as well as increases in atmospheric carbon dioxide also played significant roles. Rowntree et al. (2013) found that earlier planting combined with genetic gain has increased yield in maturity group (MG) III soybean. Rincker et al. (2014) reported that newer cultivars within a given MG reach maturity about 1 wk later than those from the 1950s, which explains in part why yields of newer cultivars may respond more positively to earlier planting. Multiple studies have also suggested that more recently released soybean cultivars are genetically adapted to produce higher yields under greater intraspecific competition than those released in earlier years due to high-density breeding tactics (Cober et al. 2005; De Bruin and Pedersen 2009; Specht et al. 1999; Suhre et al. 2014). Suhre et al. (2014) found that branch yield per plant and harvest index were increased in newer cultivars relative to older ones, indicating improved carbon partitioning during the seed fill period. Other studies have found much greater dry matter accumulation in newer than older soybean cultivars but no change in harvest index (Cober et al. 2005; De Bruin and Pedersen 2009).

Agronomic improvements have increased protection of soybean yield potential by conferring a competitive advantage over weeds (Bullock et al. 1998; Knezevic et al. 2003; Yelverton and Coble 1991). Breeding efforts have also resulted in increased intraspecific competitive ability, which allows for cultural practices such as narrower crop row spacing (De Bruin and Pedersen 2008). However, we are not aware of previous research that has determined the effect of breeding on the interspecific competitive ability of soybean with weeds. Volunteer corn has been a well-documented weed in soybean production systems and has become increasingly prominent due to the widespread adoption of herbicide-resistant, transgenic crops (Andersen and Geadelmann 1982; Beckett and

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Stoller 1988; Deen et al. 2006; Marquardt et al. 2012). Beckett and Stoller (1988) found that up to 51% loss in wide-row (76 cm) soybean yield occurred at volunteer corn densities of 10 to 11 plants m^{-2} compared with weed-free soybean. They also reported that a clump of 10 plants of volunteer corn created an area of influence with a radius of up to 86 cm. Marquardt et al. (2012) found that narrow-row (<60 cm) soybean yield loss was 41% at volunteer corn densities of 16 plants m^{-2}.

The objectives of this study were to determine (1) whether modern soybean cultivars yield more than older cultivars across a range of competitive crop–weed environments, and (2) whether soybean breeding over time has indirectly increased soybean competitiveness with weeds. Our hypothesis was that recently released soybean cultivars would be more competitive than older releases and would attain some of their increased yield potential under increasingly competitive environments. Volunteer corn was chosen as a model weed for these objectives due to its competitive ability and its common occurrence in midwestern soybean fields.

Materials and Methods

Experimental Design. Field research was conducted during 2014, 2015, and 2016 at the University of Wisconsin Arlington Agricultural Research Station near Arlington, WI (43.18°N, 89.20°W). Soil type at this site is a Plano silt loam (Fine-silty, mixed, superactive, mesic Typic Arguidolls). Volunteer corn seed was collected from the field in the fall before spring planting for each year of study and was the F_2 progeny of a locally distributed hybrid ('RK585RR,' Renk Seed, 6809 Wilburn Road, Sun Prairie, WI). Forty MG II soybean cultivars (Table 1) and three seeding densities of volunteer corn (0 [weed-free], 2.8 [low], and 11.2 [high] seeds m^{-2}) were arranged in a randomized complete block design in a split-plot arrangement with three replicates. The seeding density of volunteer corn was used as the whole-plot factor, and soybean cultivar was used as the subplot factor. The soybean cultivars used in this study are the same 39 MG II public cultivars used by Rowntree et al. (2013) with the addition of a more recently released cultivar from Iowa State University ('IAR1902SCN'). Plot dimensions were 2.3-m wide by 5.8-m long, and soybeans were seeded in four rows at 400,000 seeds ha^{-1} with 38-cm row spacing using a cone-style plot planter (ALMACO, 99 M Avenue, Nevada, IA). Volunteer corn seed was planted in-row with soybean. Metribuzin (TriCor® DF, United Phosphorus, King of Prussia, PA) and *S*-metolachlor (Dual II Magnum®, Syngenta, Greensboro, NC) at 0.42 and 1.43 kg ai ha^{-1}, respectively, were applied PRE for early-season control of weeds other than volunteer corn. Weed escapes were removed by hand as needed throughout the growing season.

Table 1. List of maturity group II soybean cultivars, year of release, and plant introduction number (PI no.).

Cultivar	Year of release	PI no.[a]
'Korean'	1928	PI548318
'Mukden'	1932	PI548391
'Richland'	1938	PI548406
'Hawkeye'	1947	PI548577
'Harosoy'	1951	PI548573
'Lindarin'	1958	PI548589
'Harosoy 63'	1963	PI548575
'Hawkeye 63'	1963	PI548578
'Amsoy'	1965	PI548506
'Corsoy'	1967	PI548540
'Beeson'	1968	PI548510
'Amsoy 71'	1970	PI548507
'Wells'	1972	PI548630
'Harcor'	1975	PI548570
'Vickery'	1978	PI548617
'Wells II'	1978	PI548513
'Amcor'	1979	PI548505
'Beeson 80'	1979	PI548511
'Century'	1979	PI548512
'Corsoy 79'	1979	PI518669
'Century 84'	1984	PI548529
'Elgin'	1984	PI548557
'Preston'	1985	PI548520
'Burlison'	1988	PI533655
'Conrad'	1988	PI525453
'Elgin 87'	1988	PI518666
'Jack'	1989	PI540556
'Kenwood'	1989	PI537094
'RCAT Angora'	1991	PI572242
'IA 2021'	1995	—
'Savoy'	1996	PI597381
'Dwight'	1997	PI597386
'IA 2038'	1998	—
'IA 2050'	2000	—
'IA 2052'	2000	—
'Loda'	2001	PI614088
'IA 2068'	2003	—
'IA2065'	2005	—
'IA 2094'	2006	—
'IAR1902SCN'	2013	—

[a] Dash (—) indicates plant introduction number is not available.

Data Collection. Soybean and volunteer corn plant density were measured at the time of emergence. In 2015 and 2016, 3 volunteer corn plants $plot^{-1}$ and 3 soybean plants $plot^{-1}$ were flagged randomly for in-season growth measurements. At V4 and R1 soybean

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growth stages, height and width of each flagged plant were measured to determine shoot cylindrical volume (V) as a nondestructive indicator of plant growth and competitive ability (Bussler et al. 1995; Colquhoun et al. 2001; Conley et al. 2002). Relative shoot volume (V_R) of soybean and volunteer corn were calculated using Equation 1.

$$V_R = \frac{V_{weed}}{V_{weed} + V_{crop}} \quad [1]$$

At soybean maturity (R8), flagged volunteer corn plants in each plot were cut at the ground level, machine chopped, and dried at 55 C to constant mass to determine aboveground shoot biomass. Soybean grain was harvested from each plot by machine (ALMACO) and dried. Total sample mass was determined, and soybean grain was separated from volunteer corn seed and other debris. The soybean mass was measured, and a percentage relative to total sample mass was calculated to determine plot yield (Marquardt et al. 2012). Soybean grain was adjusted to 13% moisture before data analysis.

Statistical Analysis. Data were subjected to a mixed-effect regression analysis using PROC MIXED in SAS v. 9.3 (SAS Institute, Cary, NC). The main effects of volunteer corn seeding rate, soybean cultivar year of release, and the rate by year of release interaction were treated as fixed effects. Variables were removed from the model if deemed insignificant by the −2 log-likelihood method (Suhre et al. 2014). Block, cultivar, environment, and cultivar by environment and block (environment by release year) interactions were considered to be random effects. Cultivar was assigned as random, because cultivars were selected from a large pool of available cultivars over eight decades (Rowntree et al. 2013). Fixed effects were tested for significance ($\alpha = 0.05$) using the appropriate F-test. All volumes and volunteer corn shoot biomass were transformed [$y = \ln(x)$] and V_R values were transformed [$y = \arcsin(\sqrt{x})$] to meet assumptions of ANOVA.

Results and Discussion

Soybean density at emergence was affected by environment but not by year of release (unpublished data), indicating that even though density at emergence was different among years, density was similar among soybean cultivars. Additionally, neither soybean yield nor volunteer corn shoot dry biomass was affected by environment, so data were pooled across years.

Table 2. Influence of volunteer corn seeding rate on soybean yield and volunteer corn shoot dry biomass at R8 soybean pooled across cultivars and years.[a]

Volunteer corn seeding rate	Soybean yield	Volunteer corn shoot dry biomass[b]
—seeds m^{-2}—	—kg ha^{-1}—	—g $plant^{-1}$—
0 (weed-free)	3,110 a	—[c]
2.8 (low)	2,420 b	98 a
11.2 (high)	1,535 c	68 b

[a] Values followed by the same letter within a column do not differ ($P < 0.05$).
[b] Data were back-transformed for presentation.
[c] No data.

Soybean Yield. Soybean seed yield was reduced when grown with volunteer corn, and the high volunteer corn density reduced yield more than the low density (Table 2). Seed yield (kg ha^{-1}) was higher for more recently released cultivars than older cultivars at each volunteer corn seeding rate (Figure 1). The rate of genetic yield gain at the weed-free, low, and high volunteer corn seeding rates were 15.5 ± 1.6, 12.9 ± 1.4, and 5.4 ± 1.4 kg ha^{-1} yr^{-1}, respectively. The rates of gain did not differ between the weed-free and low volunteer corn seeding rates, but both were greater than at the high volunteer corn seeding rate.

The rates of soybean genetic yield gain reported here are lower than some rates reported by others, which were as high as 24.1 kg ha^{-1} yr^{-1} for MG II cultivars (Rincker et al. 2014; Rowntree et al. 2013; Suhre et al. 2014). Even so, our results showed increased soybean yield with cultivar release year even at the highest competition level. This suggests that even in highly competitive environments, newer

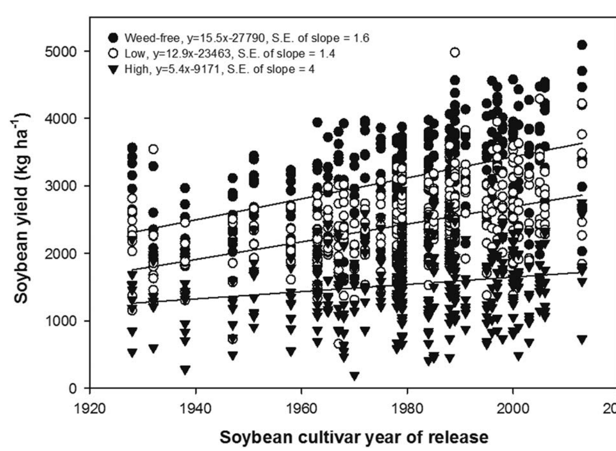

Figure 1. Relationship between soybean seed yield and year of release of 40 maturity group II soybean cultivars at three volunteer corn seeding rates.

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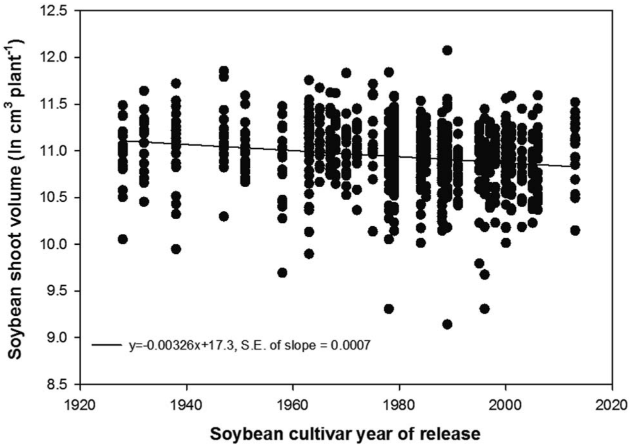

Figure 2. Relationship between the natural logarithm of R1 soybean shoot volume and year of release of 40 maturity group II soybean cultivars pooled across competitive environments.

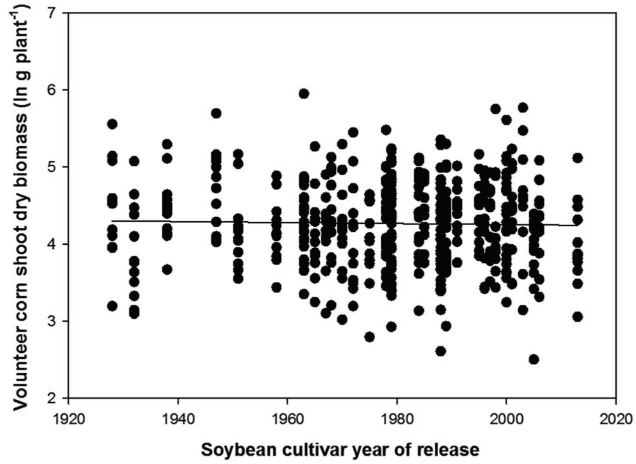

Figure 3. Relationship between the natural logarithm of volunteer corn shoot dry biomass and year of release of 40 maturity group II soybean cultivars pooled across competitive environments.

soybean cultivars attained more of their yield potential compared with older cultivars.

Soybean Competitive Ability. Soybean cultivar release year and volunteer corn seeding rate interacted to affect V4 soybean shoot volume. The volunteer corn seeding rate and cultivar release year did not interact to affect R1 soybean shoot volume, and there was no difference between soybean shoot volume across competitive environments. This indicates that yield loss in the presence of volunteer corn was not associated with reduced growth in the early reproductive phases. R1 soybean shoot volume decreased approximately 1 cm^3 per year of release (Figure 2). This is likely due to shorter soybean height of newer compared with older cultivars (unpublished data) and is consistent with results of previous research (Suhre et al. 2014; Ustun et al. 2001) that has shown breeding for decreased lodging has shortened stem height.

A more direct indicator of whether soybean competitive ability with weeds has changed over time is how it impacts the growth of neighboring weeds. Volunteer corn shoot dry biomass (g $plant^{-1}$) was less for the high than the low seeding rate (Table 2). These results are consistent with results of previous research that showed greater intraspecific competition among volunteer corn plants as density increased (Beckett and Stoller 1988). Neither volunteer corn volume (V_{weed}) nor the V_R at either V4 or R1 soybean were significant for any of the fixed effects (unpublished data). Volunteer corn shoot dry biomass at the high seeding rate was 30 g $plant^{-1}$ less compared with the lower seeding rate (Table 2) but was not affected by soybean cultivar year of release (Figure 3). The lack of soybean cultivar effect suggests that less volunteer corn shoot dry biomass at the higher seeding rate was likely due to greater intraspecific competition than interspecific competition.

These results show that breeding efforts have led to robust modern soybean cultivars with the ability to produce higher yields compared with older cultivars in highly competitive environments. The results suggest that while there has been an increase in soybean intraspecific competitive ability (Suhre et al. 2014), yield gain over time is not associated with greater suppressive ability of the highly competitive species volunteer corn. However, interspecific competitive ability of newer cultivars in less competitive environments is not known. Greater weed-suppressive ability of soybean cultivars may be realized if breeders include selection under a range of competitive environments, but gains would potentially be small and of much less priority than increased yield potential and disease resistance. These results highlight the importance of other cultural practices for weed suppression in soybean production systems such as narrow row spacing, earlier planting, and optimal seeding rates (Bullock et al. 1998; Knezevic et al. 2003; Rowntree et al. 2013). While our research focus was to understand potential changes in soybean competitiveness over time with a highly competitive weed species, future research is warranted to determine soybean weed-suppressive ability relative to a less competitive weed species or mixed weed species communities.

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