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Competitive Effects of Hybrid Corn (*Zea mays*) on Replanted Corn

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Initial corn (IC) in a replant situation, which is surviving corn from the initial planting, as well as volunteer corn from the previous season, is a competitive weed, but little is known regarding the effect of IC density on grain yield of desirable replant corn (RC). Field trials were established in central and northeast Missouri during 2008 to 2010 to determine the impact of IC on the leaf chlorophyll, stalk diameter, and grain yield of RC. Glyphosate-resistant RC was planted in 76-cm rows, with hybrid glyphosate-resistant IC established for season-long competition between rows at densities of 0 to 8 plants m^{-2}. At vegetative growth stages with six and eight leaf collars and at tasseling (V6, V8, VT), RC leaf nitrogen levels were reduced by 5 to 30% in the presence of IC at densities of one to eight plants m^{-2} compared with control plants lacking competition. Stalk diameters of RC at the VT growth stage were reduced from 8 to 30% by IC as densities increased from 0.5 to 8 plants m^{-2}. Grain yield of row corn was reduced by IC, with yield losses ranging from 7 to 81%. Growth rate and biomass accumulation of hybrid and volunteer corn from V2 to VT were compared in the greenhouse to determine if competitive potential was similar. The second filial generation (F_2) of corn from hybrid (DKC '63-42′) corn was collected from a field in central Missouri and southeastern Nebraska. There were no statistical differences found in growth rate or biomass accumulation between hybrid and F_2 corn up to VT, although F_2 plant biomass was numerically (up to 41%) lower at numerous growth stages. Hybrid corn is likely to be equally or more competitive with RC than volunteer corn. This research documents that in areas where IC remains among replanted corn, the IC has a negative impact at all densities evaluated.

Nomenclature: Glyphosate; corn, *Zea mays* L.

Key Words: Grain yield, leaf chlorophyll, replant, stalk diameter, volunteer corn.

En una situación de resiembra, el maíz inicial (IC) el cual es el maíz sobreviviente de la siembra inicial, al igual que el maíz voluntario de la temporada anterior, son malezas competitivas, pero se conoce poco acerca del efecto de la densidad de IC en el rendimiento de grano del maíz de resiembra (RC). Se establecieron experimentos de campo en el centro y noreste de Missouri, desde 2008 a 2010, para determinar el impacto de IC en chlorophyll foliar, diámetro de tallo, y rendimiento de grano de RC. RC resistente a glyphosate fue sembrado en hileras espaciadas a 76 cm, con IC híbrido resistente a glyphosate establecido para obtener competencia durante toda la temporada de crecimiento entre las hileras a densidades de 0 a 8 plantas m^{-2}. En los estados vegetativos de desarrollo con seis y ocho nudos foliares y en la formación de la panoja (V6, V8, VT), los niveles foliares de nitrógeno en RC se redujeron entre 5 y 30% en la presencia de IC a densidades de una a ocho plantas m^{-2}, al compararse con plantas testigo sin competencia. El diámetro de los tallos de RC en el estado VT se redujo entre 8 y 30% al aumentar las densidad de IC de 0.5 a 8 plantas m^{-1}. El rendimiento de grano del maíz fue reducido por el IC, con pérdidas de entre 7 y 81%. La tasa de crecimiento y la acumulación de biomasa del maíz híbrido y voluntario desde V2 a VT se comparó en el invernadero para determinar si el potencial competitivo fue similar. La segunda generación filial (F_2) del maíz híbrido (DKC '63-42') fue colectada de un campo de maíz en el centro de Missouri y en sureste de Nebraska. No hubo diferencias estadísticas en tasa de crecimiento o acumulación de biomasa entre híbridos y F_2 de maíz hasta VT, aunque la biomasa por planta de F_2 fue numéricamente más baja (hasta 41%) en varios estados de desarrollo. Es probable que el maíz híbrido sea igual o más competitivo con RC que el maíz voluntario. Esta investigación documenta que en áreas donde IC se mantiene entre maíz de resiembra, el IC tiene un impacto negativo en todas las densidades evaluadas.

No-tillage production systems as well as genetic improvements have contributed to earlier initial planting dates for corn. Current planting dates for the central United States are approximately 2 wk earlier than in the 1980s (Kucharik 2006). Cool soil temperatures and excessive rainfall early in the growing season, however, can result in poor initial stands that will require replanting. Removal of the initial corn (IC) planted may be necessary to

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preclude competition with replant corn (RC). Competition with desirable corn can also result from volunteer corn, which occurs with continuous corn production. Continuous corn is increasing in frequency as commodity prices rise.

Both volunteer corn and undesirable hybrid corn can compete with row corn for nutrients, especially nitrogen. Nitrogen contributes to the photosynthetic potential of plants, and deficiencies result in reduced grain production (Cordes et al. 2004; Gonzalez and Salas 1995; Hellwig et al. 2002). Jolley and Pierre (1977) reported grain yield reductions of 46 and 39% when nitrogen fertilizer rates were reduced from 168 and 134 to 0 kg ha^{-1}, respectively. Lambert et al. (2000) also found that as nitrogen fertilizer rates decreased from 269 to 0 kg N ha^{-1}, grain yield of corn decreased up to 46%.

Reductions of available nitrogen for corn have frequently been studied following competition with weeds. Across a mixture of species, Lindquist et al. (2010) found that available soil nitrogen was reduced by 50% when 80 to 364 weeds m^{-2} competed with corn up to V6. Tollenaar et al. (1994a; 1994b) reported that corn leaf chlorophyll was reduced up to 51% at high (133 to 150 weeds m^{-2}) weed densities. Hellwig et al. (2002) and Johnson et al. (2002) stated that grass weeds accumulated up to 59 and 38 kg N ha^{-1}, respectively, when competing with up to 31-cm-tall corn; grain yield losses were 17 and 16%, respectively. Individual weed species also negatively affect corn. Ghosheh et al. (1996) reported that grain yields were reduced 47% by johnsongrass (*Sorghum halepense* L. Pers.) at a density of 1.2 plants m^{-1} row. Beckett et al. (1988) showed that grain yield was reduced 18 and 22% after season-long competition of corn with giant foxtail (*Setaria faberi* Herrm.) at 65 to 105 plants m^{-1} row, and shattercane (*Sorghum bicolor* L. Moench) at 13 to 20 plants m^{-1} row, respectively.

The lack of sufficient nutrients for corn also affects corn stalk strength. Weeds reduce available light for corn plants, resulting in taller corn with smaller-diameter stalks. Moolani et al. (1964) found that stalk diameters were reduced by as much as 29% with high densities of smooth pigweed (*Amaranthus hybridus* L.); resultant grain yields were reduced by 39%. Thomison (2010) reported that thicker corn stalks had overall greater stalk strength and resistance to lodging. Stalk lodging is identified as one of the most problematic issues in corn, reducing grain yield by 5 to 20% annually (Flint-Garcia et al. 2003; Hondroyianni et al. 2000; Zuber and Kang 1978).

Undesirable corn should be viewed as a weed. Volunteer corn, which emerges from seed remaining from the previous year, is often described as one source of undesirable corn. A number of reports indicate that volunteer corn significantly reduces yields up to 83% in broadleaf crops (Andersen et al. 1982; Beckett and Stoller 1988; Clewis et al. 2008; Thomas et al. 2007). In corn production systems, volunteer corn has also been reported to reduce grain yield. With high densities, Alms et al. (2008) and Marquardt et al. (2012) reported that 8.5 and 8 volunteer plants m^{-2} resulted in grain yield losses of up to 40 and 23%, respectively. However, it was suggested that yield losses may be recovered by volunteer corn grain production (Marquardt et al. 2012). This would assume that the spatial arrangement of the volunteer corn would allow harvest.

Little research has been conducted to determine specific competitive effects of IC on RC. Several university extension publications suggest that the initial stand must be removed to preclude yield losses (Larson 2009; Smith 2011; Thompson and Steckel 2007). Terry et al. (2012) also demonstrated that IC planted a few weeks earlier than RC had a competitive advantage, resulting in 12% RC yield loss.

Research to determine the competitive effect of IC or volunteer corn in corn involves the use of hybrid vs. the second filial generation (F_2) corn. Grain yield of hybrid corn is superior to that of F_2 corn, but comparisons of biomass accumulation are poorly documented. Therefore, it is unclear whether hybrid and volunteer corn are similar for competitive potential. The objectives of this research were to determine: (1) the effects of hybrid IC density on nitrogen availability, stalk diameters, and grain yield of RC; and (2) the growth rate and biomass accumulation of hybrid vs. F_2 corn.

Materials and Methods

Field Trials. Field trials were established in 2008, 2009, and 2010 at multiple locations in Missouri. During 2008, trials were conducted at the Greenley Research Center (40.02°N, 92.19°W) near Novelty (hereafter referred to as Novelty). In 2009, trials were conducted at the Bradford Research and Extension Center (38.89°N, 92.2°W) near Columbia (hereafter referred to as Columbia) and at Novelty. During 2010, trials were established at Columbia and near Mokane (38.67°N, 91.87°W; hereafter referred to as Mokane). Soil at Novelty was a Putnam silt loam (fine, smectitic, mesic Vertic Albaqualfs) with 2.9 and 2.3% organic matter and pH of 5.6 and 6.1 in 2008 and 2009, respectively. Soil at Columbia was a Mexico silt loam (fine, smectitic, mesic Vertic Epiaqualfs) with 1.8 and 2.8% organic matter and pH of 6.3 and 6.3 in 2009 and 2010, respectively. Soil at Mokane was a Treloar (sandy over loamy, mixed, superactive, calcareous, mesic Oxyaquic Udifluvents)–Haynie (coarse-silty, mixed, superactive, calcareous, mesic Mollic Udifluvents) complex with 1.4% organic matter and a pH of 7.0. Experimental areas were maintained under no-till conditions; for Novelty in 2008, Columbia in 2009, and Mokane in 2010 the previous crop was soybean and for Novelty in 2009 and Columbia in 2010 the previous crop was corn.

Glyphosate-resistant corn (DKC '63-42') was established at all site years in 76-cm rows at a depth of 3.8 cm and plant population of 69,190 seeds ha^{-1}. Each plot included four rows of corn (3 m total width) for a length of 13.7 m. Planting dates were: May 20, 2008 and May 22, 2009 at Novelty; May 21, 2009 and April 19, 2010 at Columbia; and April 21, 2010 at Mokane. Before or immediately after planting, glyphosate (Roundup WeatherMax®, 0.87 kg ae ha^{-1}, Monsanto Co., 800 N. Lindbergh Blvd., St. Louis, MO 63167) and atrazine + *s*-metolachlor (Bicep II Magnum®, 0.6 kg ai ha^{-1} + 0.37 kg ai ha^{-1}, Syngenta Crop Protection, P.O. Box 18300, Greensboro, NC 27419) were applied to plot areas to preclude competition by noncorn plants. Glyphosate at 0.87 kg ae ha^{-1} and mesotrione (Callisto®, 0.17 kg ai ha^{-1}, Syngenta Crop Protection, P.O. Box 18300, Greensboro, NC 27419) were applied POST to remove any noncorn species. All herbicides were applied at a speed of 4.8 km h^{-1} with a CO_2-pressurized backpack sprayer equipped with XR8002 TeeJet (TeeJet: Spraying Systems Co. World Headquarters, P.O. Box 7900, Wheaton, IL 60187-7900) flat-fan nozzle tips calibrated to deliver 140 L ha^{-1} at 138 kPa. Ammonium nitrate was broadcast at 167 kg N ha^{-1} at Novelty before planting corn in 2008, and at 140 kg N ha^{-1} on May 22, 2009. A rate of 140 kg N ha^{-1} was applied on April 22, 2009 and April 19, 2010 at Columbia, and April 13, 2010 at Mokane. Scharf and Lory (2006) stated that on average, U.S. corn producers apply 1.12 kg N ha^{-1} (1 lb N $acre^{-1}$) for each 62.5 kg ha^{-1} (1 bushel $acre^{-1}$) of grain produced. Average grain yields for northeast and central Missouri counties ranged from 6,635 to 9,513 kg ha^{-1} from 2008 to 2009 (USDA 2009, 2010). Therefore, a nitrogen rate of 140 kg N ha^{-1} is an acceptable rate for a projected grain yield of approximately 7,823 kg ha^{-1} (125 bushels $acre^{-1}$).

In addition to use for RC, DKC 63-42 was used for the IC. Seed was planted randomly by hand using a jab planter at a depth of 2.5 to 3.8 cm throughout each plot at the same time of planting RC. A random planting pattern for the IC represents an incomplete stand or incomplete level of controlling initially planted corn in a replant situation. Additionally, the spatial arrangement of the IC and RC rows may influence the competition for available resources; therefore, a random planting pattern represents the average resultant competitive effects. The competitive potential of IC can be influenced by planting time of RC following control of IC. The competitive potential of IC can be increased because of early establishment and increased growth or reduced because of frost, herbicide, or flooding injury. The IC was planted and emerged at the same time as RC to eliminate environmental factors that may influence the competitive potential of IC. In some situations, RC may be planted when the size of IC is very small because of incomplete control or injury to IC. Plot treatments included nine intended IC densities: 0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, and 4 plants m^{-2} in 2008 and 0, 0.5, 1, 2, 3, 4, 6, 7, and 8 plants m^{-2} in 2009 and 2010. IC densities were estimated after corn emergence to determine actual densities in each plot. In 2009, IC emergence was low at both locations. At Novelty, IC was replanted. However, at Columbia, IC was not replanted because of the rapid growth of RC; therefore, densities remained low, ranging from 0 to 3.4 plants m^{-2}.

Estimates of the competitiveness of IC included leaf chlorophyll measurements, stalk diameters, and grain yield of RC. Fifteen plants from the two center rows of each plot were randomly selected and tagged to allow repeated measurement of leaf nitrogen and stalk diameter from the same plants

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throughout the growing season. Leaf chlorophyll measurements were taken at the V6, V8, and VT growth stages using a Minolta SPAD chlorophyll meter (Minolta USA, 101 Williams Drive, Ramsey, NJ 07446 68). The SPAD meter is a unitless estimate of chlorophyll content in plant leaves; results provide an accurate assessment of nitrogen status (Scharf et al. 2006; Vetsch and Randall 2004). Measurements were taken on the apex of the youngest mature leaf, halfway between the midrib and leaf margin. Stalk diameters were recorded from tagged RC plants at the VT growth stage using an electronic caliper; location of measurement included the widest axis of the stalk on the internode directly above the corn ear leaf. Before grain harvest, ears from IC plants were removed from each plot to accurately assess the yield of RC. Grain was harvested from the two center rows of each plot, with moisture levels adjusted to 15.5%. Yields were estimated at Novelty on October 10 and November 3 in 2008 and 2009, respectively. Yields at Columbia were collected on November 6 and October 5 in 2009 and 2010, respectively. Grain yield at Mokane was estimated on October 20, 2010.

Experimental design was a randomized complete block with four replications at all site years, except for Mokane in 2010 where treatments were replicated six times. For leaf chlorophyll and stalk diameters, subsamples were averaged to compute a mean for each plot. A MIXED procedure in SAS (statistical software version 9.2, SAS Institute, Inc., 100 SAS Campus Drive, Cary, NC 27513) was used to determine effects on leaf chlorophyll, stalk diameters, and grain yield of RC. Leaf chlorophyll, stalk diameters, and grain yields were then regressed across IC densities. Polynomial linear and quadratic orthogonal contrasts were performed to determine significance and the order of polynomial regression for IC densities with the aforementioned data. Location and year were considered random factors; therefore, data were pooled for site years with the same IC densities. Because of different IC densities at Novelty in 2008 and Columbia in 2009, data were analyzed separately.

Greenhouse Trials. Greenhouse trials were conducted in 2012 to 2013 to evaluate growth characteristics of DKC 63-42 and F_2 corn. F_2 corn originated from corn cobs collected in the fall of 2012 from a field in Missouri (F_2-MO) and a field in Nebraska (F_2-NE). Both MO and NE fields were planted with DKC 63-42 in 2012. In the greenhouse, hybrid and F_2 corn were planted at a depth of 2.5 cm in 28-cm-diam by 30-cm-deep polypropylene pots containing Mexico silt loam soil; 1% organic matter and pH 5.9. After corn emergence, pots were fertilized every 2 wk with 20–20–20 (N–P–K) fertilizer (Jack's Classic®, JR Peters Inc. 6656 Grant Way, Allentown, PA 18106) dissolved in water at a concentration of 3 g L^{-1}; 458 ml of liquid fertilizer was added to each pot, which resulted in an equivalent rate of 44.8 kg N ha^{-1}. Plants grown to vegetative maturity (VT) were fertilized five times, resulting in a total of 224 kg N ha^{-1}, which is similar to a nitrogen fertilizer rate for season-long corn production. All plants were grown in a greenhouse at 25 to 30 C with supplemental lighting providing an average photosynthetic photon flux density of 500 µmol photon m^{-2} s^{-1} for a 16-h photoperiod.

All corn populations (DKC 63-42, F_2-MO, F_2-NE) were evaluated for emergence timing, growth rate, and biomass accumulation. Emergence timing was determined by recording the number of days after planting required for cotyledon unfurling. Growth rate was determined by recording the number of days required to achieve target V stages of V2, V3, V5, V7, V9, and VT. Biomass was evaluated by harvesting plants at the target V stage and drying at 48 C for 3 to 5 d.

Greenhouse experiments were arranged in a completely randomized design and conducted three times. Corn was planted on October 19, 2012, January 17, 2013, and March 27, 2013. For growth rate and biomass, five replicate plants were utilized for each population at each V stage. For emergence, V stage was not considered a factor; therefore, there were a total of 30 replicates for each corn population. Data were subject to an ANOVA using the PROC MIXED procedure in SAS to determine the effects of corn population on emergence timing, growth rate, and biomass accumulation. Experimental run was considered a random factor; therefore, data were pooled. Mean differences were determined using Fisher's protected LSD at $P = 0.05$.

Table 1. Polynomial linear and quadratic orthogonal contrasts for the effect of initial corn (IC) density on leaf chlorophyll levels (SPAD meter) at vegetative growth stages with six and eight leaf collars and at tasseling (V6, V8, VT), stalk diameters, and grain yield of replant corn (RC). Data recorded from field trials at 5 site years in Missouri: Novelty 2008; Columbia 2009; combined site years (Novelty 2009, Columbia 2010, and Mokane 2010).

Effect	Combined site years[a]		Novelty 20008[b]		Columbia 2009[c]	
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
	Pr > F					
SPAD V6	< 0.0001**	0.9653	0.7216	0.2483	0.0017**	0.3859
SPAD V8	< 0.0001**	0.0378*	< 0.0001**	0.9704	< 0.0001**	0.2033
SPAD VT	< 0.0001**	0.0013**	< 0.0001**	0.3657	0.0004**	0.2403
Stalk diameter	< 0.0001**	< 0.0001**	< 0.0001**	0.2051	0.0002**	0.1280
Yield	< 0.0001**	< 0.0001**	0.4576	0.3901	< 0.0001**	0.4351

[a] IC density: zero to eight plants m^{-2}.

[b] IC density: zero to four plants m^{-2}.

[c] IC density: 0 to 3.4 plants m^{-2}.

* Significant effect at $\alpha = 0.05$.

** Significant effect at $\alpha = 0.01$.

Results and Discussion

Field Trials. IC influenced leaf chlorophyll of RC at V6, V8, and VT growth stages (Table 1). Densities as few as 0.5 IC plants m^{-2} reduced RC leaf chlorophyll (Figure 1). For 3 site years with IC densities ranging from zero to eight plants m^{-2}, RC leaf chlorophyll levels were reduced at all IC densities (Figure 1A). Leaf chlorophyll measurements were 10 to 47% lower at the VT growth stage compared with the V6 and V8 growth stages. Densities of one to four IC plants m^{-2} reduced RC leaf chlorophyll by 5 to 22% compared with the untreated control across all growth stages. Densities of six to eight plants m^{-2} reduced chlorophyll by 13 to 30% compared with plants without competition. For site years with lower densities of IC (zero to

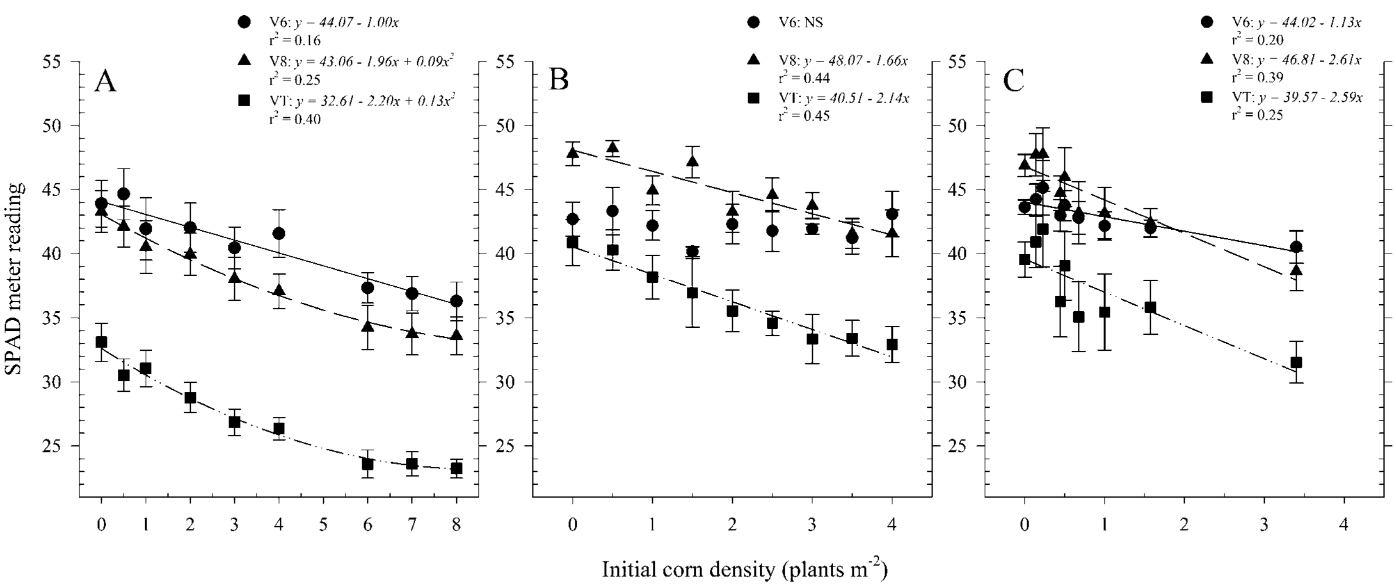

Figure 1. Leaf chlorophyll levels of replant corn (RC) in response to increasing densities of initial corn (IC) at three Missouri locations in 2008 to 2010. Leaf chlorophyll levels measured with a SPAD meter were estimated over 5 site years: Novelty 2009, Columbia 2010, Mokane 2010 (A); Novelty 2008 (B); and Columbia 2009 (C). Measurements represent the mean of 15 RC plants in each plot with values recorded at vegetative growth stages with six and eight leaf collars and at tasseling (V6, V8, VT). IC densities ranged from zero to eight plants m^{-2} (A), zero to four plants m^{-2} (B), and 0 to 3.4 plants m^{-2} (C). Vertical lines above and below each point indicate standard errors of the mean.

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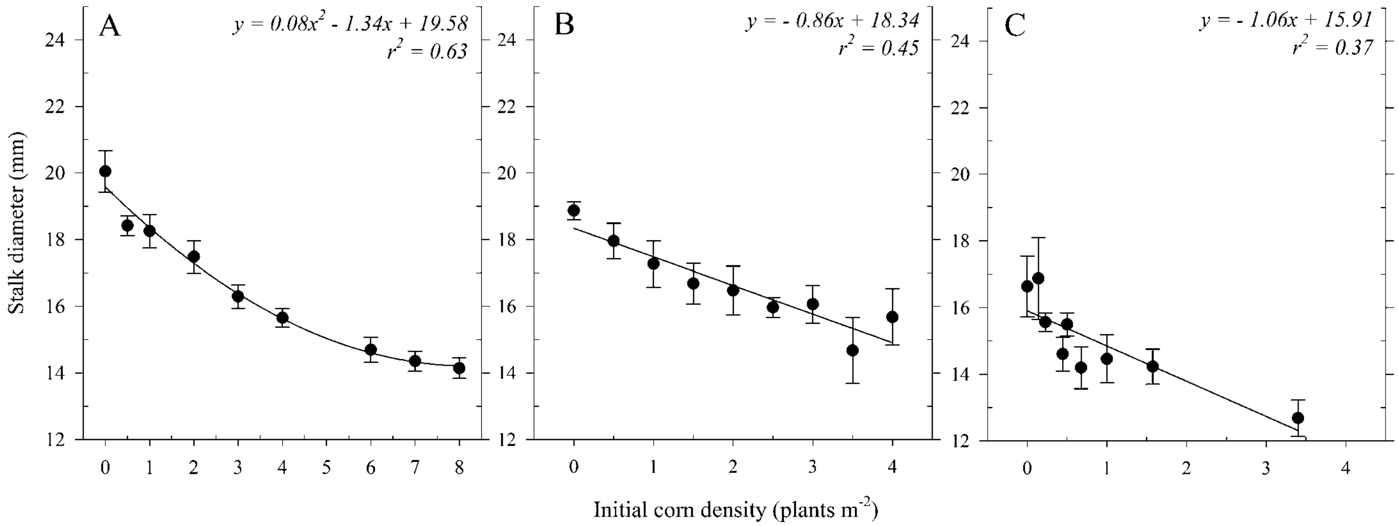

Figure 2. Diameter of replant corn (RC) stalks in response to increasing densities of initial corn (IC) at three Missouri locations in 2008 to 2010. Stalk diameters were estimated after season-long competition with IC over 5 site years: Novelty 2009, Columbia 2010, Mokane 2010 (A); Novelty 2008 (B); and Columbia 2009 (C). Stalk diameters measured from 15 RC plants in each plot at the VT growth stage with an electronic caliper. IC densities ranged from zero to eight plants m^{-2} (A), zero to four plants m^{-2} (B), and 0 to 3.4 plants m^{-2} (C). Vertical lines above and below each point indicate standard errors of the mean.

four plants m^{-2}), reductions in leaf chlorophyll were least prevalent at the V6 growth stage (Figures 1B and 1C). At Novelty in 2008, chlorophyll measurements were similar across all densities of IC at V6 (Figure 1B). For the V8 and VT growth stages, reductions ranged from 8 to 20% at densities of two to four plants m^{-2} compared with the untreated control. For Columbia 2009, leaf chlorophyll levels were reduced at all growth stages with increasing IC densities, ranging from 3 to 20% lower at IC densities ranging from 0.45 to 3.4 plants m^{-2} (Figure 1C).

Corn leaf chlorophyll levels are an indicator of potential grain yield. Scharf et al. (2006) determined that relative chlorophyll measurements from V5 to R5 were related directly to available nitrogen fertilizer, with a coefficient of determination of 0.53 to 0.76 from 24 trials over 4 yr across seven north-central states. Weed competition can reduce available nitrogen. Tollenaar et al. (1994a,b) reported that corn leaf chlorophyll was reduced by 51% when plants competed with 133 to 150 weeds m^{-2}; subsequent grain yields were reduced 34%. Cordes et al. (2004) discovered that corn leaf chlorophyll was reduced by 4 to 8% and grain yield reduced 4 to 41% by common waterhemp (*Amaranthus rudis* Sauer) densities of 369 to 445 plants m^{-2}. Hellwig et al. (2002) found that the nitrogen content of corn biomass as well as grain yield were reduced 35 and 26%, respectively, when corn competed with 300 plants m^{-2} of giant foxtail, barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], and large crabgrass (*Digitaria sanguinalis* L. Scop.). Our findings suggest that the IC is a competitive weed with RC for available nitrogen, with reductions in late-season RC leaf nitrogen of 22 to 30% at four and eight plants m^{-2}, respectively (Figure 1).

RC stalk diameter was another factor reflecting the competitive impact of IC (Figure 2). For all site years, the relationship between stalk diameter of RC and IC density between zero and four plants m^{-2} was linear. For site years where IC density ranged from zero to eight plants m^{-2}, the slope relating RC stalk diameter to IC density was lower between four to eight than zero to four plants m^{-2}. The impact of IC on stalk diameter reductions varied between low and high densities of the IC. With low IC densities (0.5 to 4 plants m^{-2}), RC stalk diameters were reduced 1 to 5 mm (8 to 22%) compared with the untreated control. High IC densities (four to eight plants m^{-2}) only reduced RC stalk diameters an additional 1 to 1.5 mm (an additional 8%).

Competition with IC for both light and available nitrogen may have affected RC stalk diameter. In this research, reductions in stalk diameter followed decreases in leaf nitrogen levels. White et al. (1978) reported that stalk diameters of corn were reduced by 15% when nitrogen was a limiting factor.

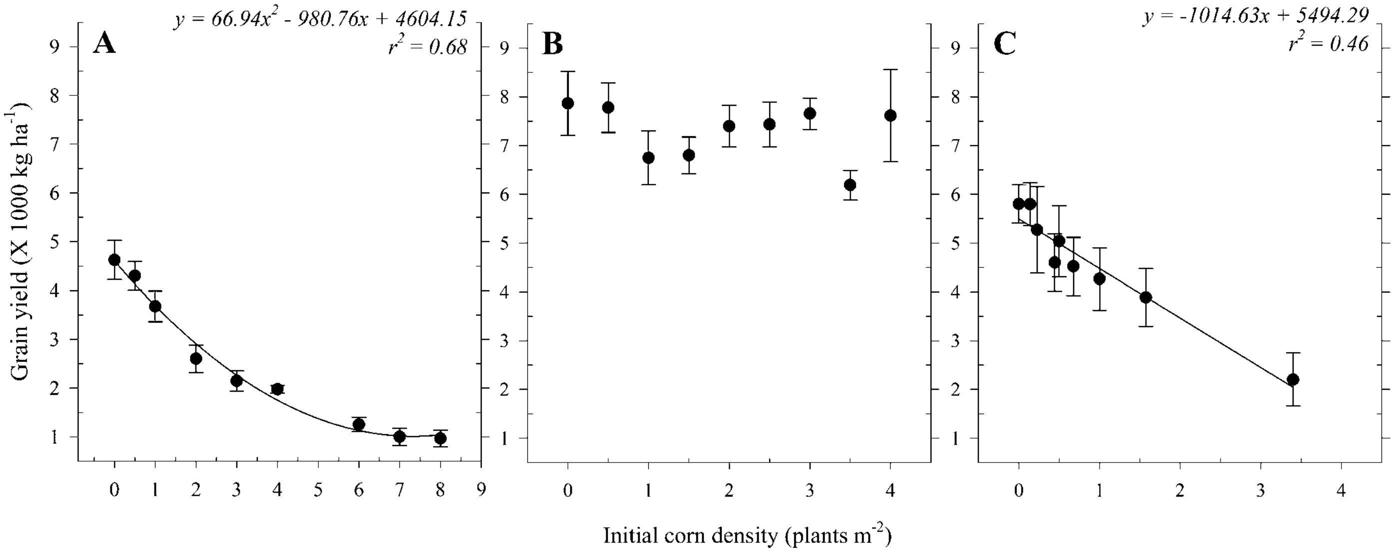

Figure 3. Grain yield of replant corn (RC) in response to increasing densities of initial corn (IC) at three Missouri locations in 2008 to 2010. Grain yield of RC was estimated after season-long competition with IC over 5 site years: Novelty 2009, Columbia 2010, and Mokane 2010 (A); Novelty 2008 (B); and Columbia 2009 (C). Grain yield estimated from the two center rows of each plot and adjusted to 15.5% moisture. IC densities ranged from zero to eight plants m^{-2} (A), zero to four plants m^{-2} (B), and 0 to 3.4 plants m^{-2} (C). Vertical lines above and below each point indicate standard errors of the mean.

Moolani et al. (1964) found that stalk diameters of corn were reduced by as much as 29% following competition with high densities of smooth pigweed; corn yield was ultimately reduced 39%. With increased competition, corn plants likely respond by growing taller, which results in smaller-diameter stalks. Subsequently, stalk lodging may increase, reducing grain yield. Stalk lodging reduces corn grain yield by 5 to 20% annually (Flint-Garcia et al. 2003; Hondroyianni et al. 2000; Zuber and Kang 1978). Losses could contribute additional kernels to harvested fields, increasing the likelihood of volunteer corn in subsequent cropping systems. Shauck and Smeda (2011) identified several factors influenced by moisture that can affect the loss of kernels at harvest. The relationship of increased plant height and lodging were not estimated in this research; reduced stalk diameter likely reflected limited nitrogen availability.

Reductions in grain yield of RC were observed at IC densities greater than 0.5 plants m^{-2} for site years with zero to eight plants m^{-2} (Figure 3A). The inverse relationship between RC grain yield and IC densities of zero to four plants m^{-2} appeared linear for 4 of 5 site years (Figures 3A–C). For site years with a greater range of IC density, grain yield losses of 7 to 20% were observed at densities as low as 0.5 to 1 plant m^{-2}, compared with the untreated control. Densities of two to four plants m^{-2} resulted in grain yield losses of 44 to 58%. The impact of additional IC plants at higher densities (> four plants m^{-2}) was less prevalent. Densities of four to eight vs. zero to four plants m^{-2} resulted in only up to 23% additional yield loss. At Novelty in 2008, grain yield was not affected by IC (Figure 3B). One likely explanation is the higher nitrogen fertilizer rate (167 kg N ha^{-1}) used at this site year, which resulted in the smallest effects (lower slope) on leaf chlorophyll content (Figure 1B) and stalk diameter (Figure 2B). At Columbia in 2009, 140 kg N ha^{-1} was applied and grain yield was 21% lower at densities as low as 0.45 plants m^{-2} and 62% lower at 3.4 plants m^{-2} (Figure 3C).

These results confirm the negative impact of IC on RC. In Indiana, Terry et al. (2012) reported a 12% reduction in grain yield of RC when planted into an IC density of 20,000 plants ha^{-1} (two plants m^{-2}) compared with a site with no IC. The timing of replanting was when IC reached the V3 to V4 growth stage. Established IC may have a competitive advantage once RC emerges. In this trial, the IC and RC were established at the same time to eliminate environmental factors that may influence competitive potential. Results from 4 of 5 site years suggest that IC is very competitive with RC when established at the same time. However, 1 of 5 site

Table 2. Dry weight biomass of hybrid and two F_2 corn populations (DKC '63-42', F_2-NE, F_2-MO) at six growth stages. Biomass estimates were averaged over five replicates and three greenhouse experimental runs.

Population	Biomass					
	V2	V3	V5	V7	V9	VT
	g plant^{-1}					
DKC '63-42'	0.32 a	0.50	1.79	8.45	16.46	71.23
F_2-NE	0.29 a	0.70	1.67	6.76	13.87	67.54
F_2-MO	0.19 b	0.48	1.39	5.00	12.98	67.33
LSD[a]	0.06	NS	NS	NS	NS	NS

[a] Mean separation determined by Fisher's protected LSD at P = 0.05; different letters within a column indicate a significant difference.

years suggests that the yield losses due to IC competition with RC may be overcome with higher nitrogen fertilizer rates.

Greenhouse Trials. Emergence timing of hybrid and two F_2 populations of corn were statistically similar (P = 0.1235; data not shown). Also, the time interval to reach specific growth stages and the biomass of hybrid vs. F_2 corn were overall similar. Across six growth stages, hybrid and F_2 corn reached V2, V3, V5, V7, V9, and VT at 12.8, 15.5, 23.9, 30.6, 36.9, and 61.2 d, respectively. Numerically, biomass accumulation was higher for DKC 63-42 compared with F_2 corn at most growth stages, but only significantly greater than F_2-MO at V2 (Table 2).

Comparable vigor of DKC 63-42 and F_2 corn suggests that both could be competitive with desirable corn. For volunteer corn at densities of 0.1 and 0.5 plants m^{-2}, Jeschke and Doerge (2008) in Minnesota, South Dakota, and Iowa predicted yield losses to be 0.4 and 1.5%, respectively, on the basis of a pooled analysis of university data (four trials: two in Minnesota, one in South Dakota, one in Iowa). A technology development publication by Monsanto (Anonymous 2010) predicted grain yield losses at volunteer densities of 0.25 to 5 plants m^{-2} to be 0.6 to 11.8%, respectively (test locations: Minnesota, South Dakota, Iowa, Nebraka, Kansas, Colorado). Marquardt et al. (2012) reported up to 23% row corn yield loss when competing with volunteer corn at a density of eight plants m^{-2}. In South Dakota, Alms et al. (2008) found that grain yield losses from volunteer corn ranged from 0 to 9% and 0 to 40% when volunteer corn was competing at densities of 0 to 3.5 and 0 to 8.5 plants m^{-2}, respectively. For hybrid corn representing a stand of IC, yields of RC were reduced 7 to 58% for densities from 0.5 to 4 plants m^{-2}; densities up to eight plants m^{-2} reduced yield up to 81%. The impact of IC vs. volunteer corn on desirable corn may be related to the availability of nitrogen.

Overall, initial corn in a replant situation should be considered a competitive weed. The IC competed with RC for initial nutrient and light resources, reflected in reduced leaf nitrogen levels and smaller stalk diameters of RC. Ultimately, competition from IC was reflected in reduced grain yield of RC. In many field situations, a decision to replant corn is made after the final stand of IC is known or a herbicide has been applied to remove IC. Growers often replant specific areas within a field where stands of IC are below acceptable levels. This research documents that in areas where IC remains among replanted corn, the IC has a negative impact at all densities. It should be expected that if IC was allowed to continue growing before establishment of RC, which occurs in many fields, the extent of competition would be greater. From the greenhouse experiment, emergence and dry-weight biomass of hybrid and F_2 corn (true volunteer corn) were comparable at most growth stages. However, the vigor of hybrid corn may result in greater competition in a replant situation than emergence of volunteer corn in production systems where corn is planted in consecutive years.

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