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## WEED SCIENCE

# The Effect of Duration of Corn (*Zea mays*) Interference on Cotton (*Gossypium hirsutum*) Growth and Yield

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### ABSTRACT

**Widespread use of glyphosate-resistant (GR) corn in rotation with cotton increases the incidence of volunteer GR corn in subsequent cotton stands. Experiments were conducted in Mississippi in 2011 and 2012 to determine cotton response to volunteer corn present at 0.3, 1.6, or 3.2 plants per m of crop row allowed to persist for zero, one, two, six, eight, 10 and 12 weeks after emergence or until cotton harvest. Cotton maturity was accelerated at a density of 3.2 plants per m of crop row. Neither cotton height nor yield was affected by corn removal timing at the low corn density. Cotton height and yield decreased as the time of corn removal was delayed at the medium and high corn densities. No differences in cotton height were observed from increasing corn density at removal timings up to two weeks after cotton emergence (WACE). At each corn removal timing four WACE and beyond, increasing corn density led to reductions in cotton height. No differences in cotton yield were observed from increasing density at corn removal timings zero or one WACE; increases in corn density at removal timings beyond one WACE generally led to reductions in cotton yield. These data indicate medium to high populations of volunteer corn generally should be removed by four to six WACE to prevent height reductions and yield loss.**

Herbicide-resistant (HR) crops have been rapidly adopted over the course of the past two decades in the United States. The domestic acreage seeded to HR corn or cotton cultivars has increased from ~10% in 1997 to 94% in 2018 (USDA-ERS, 2018; USDA-NASS, 2018). The majority of the acreage seeded to HR crops has been composed of glyphosate-resistant (GR) cultivars (Owen and Zelaya, 2005). Recent commercialization of cultivars with resistance to glufosinate, glyphosate, and either 2,4-D or dicamba has added postemergence (POST) weed control tools for use in cotton, corn and soybeans (Behrens et al., 2007; Feng and Brinker, 2014; Richburg et al., 2012; Wright et al., 2010). However, glyphosate remains a key component of weed control systems despite years of improper stewardship leading to the development of HR weed species (Egan et al., 2014; Heap, 2018; Mortensen et al., 2012). Systems that utilize rotation may incorporate different crops, but often these crops utilize the same technology, such as GR traits.

Production systems utilizing cotton rotated with corn have been discussed extensively in the popular press (Muzzi, 2003; Stalcup, 2007; Smith, 2018). Reddy et al. (2006) reported a cotton yield advantage of up to 19% following a rotation to corn in a reduced-tillage system, along with increased yellow nutsedge (*Cyperus esculentus*) control relative to a continuous-cotton system. While the benefits of crop rotation are well documented, rotating crops of the same GR technology can lead to challenges such as increased occurrence of GR volunteer crops from previous growing seasons, which are difficult to control due to the inability of glyphosate to suppress them (Duke, 2005; Marshall, 1998; Riar et al., 2013). As such, GR volunteer corn can present a challenge to cotton producers given cotton has been shown to be sensitive to early season weed competition.

Differential cotton sensitivity to early season weed competition has been reported with different weed species. While the concept of a critical period for weed control (CPWC) is not new (Zimdahl, 1988), the literature illustrates an intuitive difference in CPWC values depending on weed species and density. Barnett and Steckel (2013) investigated

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cotton competition with giant ragweed (*Ambrosia trifida* L.) populations of 0.8 or 1.6 plants $m^{-1}$ and reported that competition through the 12-leaf cotton growth stage resulted in 34 and 50% reductions in cotton height, respectively. GR horseweed [*Conyza canadensis* (L.) Cronq.] populations of 20 and 25 plants $m^{-1}$ allowed to compete with cotton from emergence until the sixth node caused yield loss, and season-long (SL) competition resulted in up to a 46% reduction in lint yield (Steckel and Gwathmey, 2009). Chandler (1977) found that SL velvetleaf (*Abutilon theophrasti* Medik.) and spurred anoda [*Anoda cristata* (L.) Schlecht] competition reduced seed cotton yields. Johnsongrass [*Sorghum halepense* (L.) Pers.] competition at four, eight, 16 and 32 plants per 10 m of row decreased seed cotton yield up to 21, 55, 76 and 82%, respectively, following SL competition (Bridges and Chandler, 1987). Keeley and Thullen (1989) reported Johnsongrass interference for six, nine, 12 and 25 weeks after cotton emergence (WACE) reduced cotton yields 20, 60, 80 and 90%, respectively. Fast et al. (2009) reported that the critical timing of Palmer amaranth (*Amaranthus palmeri* S. Wats) removal in GR cotton was 19 days after emergence. Conversely, Buchanan and Burns (1970) reported an approximate CPWC of eight weeks in cotton production systems containing multiple grass and broadleaf weed species in order to avoid major yield losses and height and stem width reductions; interference from emerging weeds after this CPWC did not affect cotton yield. Coble and Byrd (1992) state a general cotton CPWC of four to eight WACE. Bukun (2004) described the CPWC of cotton grown in Turkey as ranging from 100 to 1,174 GDD or from one to 12 WACE in order to avoid greater than 5% yield loss. Thomas et al. (2007) and Clewis et al. (2008) reported decreased cotton height and yield following SL competition with increasing GR and glufosinate-resistant corn densities, respectively, but did not quantify the effect competition duration had on yield. It has been shown that weeds emerging after the CPWC do not have an effect on cotton yield (Buchanan and Burns, 1970; Papmichail, 2002) and thus the duration of early-season competition is the most important factor in investigating the CPWC in cotton production.

Most previous research has investigated cotton response to competition with broadleaf or grass weed species, excluding volunteer corn. Thomas et al. (2007) investigated the effect of GR volunteer corn density on cotton response following SL competition but did not include multiple removal timings. Due to the potential for increased incidences of GR volunteer corn in GR cotton production systems, experiments were conducted to determine the effect of various densities of GR volunteer corn allowed to compete with GR cotton for various durations.

## MATERIALS AND METHODS

**Experimental Design.** Field experiments were conducted at the R.R. Foil Plant Science Research Center in Starkville, MS in 2011 and 2012 and at the Black Belt Branch Experiment Station near Brooksville, MS in 2011. Site information is shown in Table 1. Cotton cultivar 'DP0924 B2RF' (Bayer Corporation, 100 Bayer Boulevard, Whippany, NJ 07981) was seeded to conventional seedbeds at a rate of 128,440 seeds $ha^{-1}$ and a depth of 2.5 cm in all experiments. Plots were composed of four 97 cm rows 12.2 m in length and arranged in a randomized complete block design with four replications and a factorial arrangement of treatments. Plots were fertilized with 101 kg $ha^{-1}$ N as 32% liquid nitrogen according to soil test recommendations. Insecticide and plant growth regulator applications were managed in accordance with local recommendations.

**Table 1. Details for locations of experiments in 2011 and 2012**

| Location | Year | Longitude | Latitude | Elevation m | Soil Type[a] | Sand-Silt-Clay % | SOM[b] % | pH | Planting Date |
|---|---|---|---|---|---|---|---|---|---|
| Brooksville | 2011 | 88°32'W | 33°15'N | 75 | Okolona silty clay (fine, smectic, thermic oxyaquic haploderts) | 8-51-41 | 2.00 | 6.8 | 26 May |
| Starkville | 2011 | 88°46'W | 33°28'N | 77 | Catalpa silty clay loam (fine, smectic, thermic fluvaguentic hapludolls) | 18-52-30 | 1.25 | 7.2 | 18 May |
| Starkville | 2012 | 88°46'W | 33°28'N | 77 | Catalpa silty clay loam (fine, smectic, thermic fluvaguentic hapludolls) | 18-52-30 | 1.25 | 7.2 | 21 May |

[a] Source: U.S. Department of Agriculture, Natural Resources Conservation Service (2016) http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

[b] SOM: Soil organic matter

GR volunteer corn density (Factor A) was fixed at 0.3 (low), 1.6 (medium) or 3.2 (high) plants per m of cotton row and was achieved with $F_2$ seeds saved from a previous harvest of the corn hybrid 'P1184HR' (Dow DuPont, P.O. Box 1000 Johnston, Iowa 50131). Seed were hand planted into the center two rows of each plot immediately following cotton planting to obtain the densities described by Factor A. Volunteer corn removal timing (Factor B) occurred at zero (corn-free control), one, two, four, six, eight, 10, or 12 weeks after cotton emergence (WACE) or not at all (season-long competition). At each removal timing, volunteer corn plants were removed by hand. Other weeds were controlled with POST applications of 0.87 kg ae $ha^{-1}$ glyphosate as needed. Cotton maturity was recorded as nodes above cracked boll (NACB), which was recorded along with cotton heights from ten cotton plants randomly chosen from the center two rows of each plot. NACB is an indicator of plant maturity and a decision-making technique for harvest-aid timing (Brecke et al., 2001). NACB counts and height measurements were recorded prior to harvest aid application when the weed-free control reached cut-out (five or less nodes above white flower; Bourland et al., 1992). This method has been used in previous work to determine treatment effects on cotton growth and maturity (Buchanan and Burns, 1970; Kerby et al., 1992). Any GR volunteer corn plants remaining after harvest aid application (1.68 kg ai $ha^{-1}$ ethophon + 0.08 kg ai $ha^{-1}$ thidiazuron + 0.42 kg ai $ha^{-1}$ tributyl phosphorotrithioate) were removed by hand immediately before harvest to prevent any machinery complications. The center two rows of each plot were harvested with a spindle picker modified for small-plot research. Weather conditions in each experiment were consistent with historical averages.

**Statistical Analyses.** All data were subjected to an analysis of variance using PROC MIXED METHOD = TYPE3 (SAS 9.4, SAS Institute, 100 SAS Campus Drive, Cary, NC 27513) with means separated using Fisher's protected LSD test at the $\alpha = 0.05$. Data points with corresponding studentized residual values exceeding 2.5 were classified as outliers and removed prior to conducting ANOVA. All data met proper model distribution assumptions. The three year-location combinations were combined and treated as environment. Volunteer corn density and corn removal timing were analyzed as fixed factors whereas environment (the blocking factor) was considered a random effect. This experiment was designed to characterize cotton response to competition with volunteer corn at multiple densities and for different durations over a broad inference space. Thus, the experiment used multiple environment trials (METs), which are advantageous in making inferences over difficult to control factors such as time and space (Blouin et al., 2011; Carmer et al., 1989; Walker et al., 2008; Yang, 2010). As such, all data are presented as averages pooled across environments. Cotton NACB, height, and yield were independently regressed over volunteer corn density and removal timing using the PROC REG feature of SAS 9.4. No adequate polynomial models were found using either the raw data or various transformations performed on the data. Whenever a two-factor interaction between volunteer corn density and volunteer corn removal timing was detected for any response parameter, the SLICE feature of the pdmix800 macro designed to conduct pairwise least squared means comparisons in PROC MIXED in SAS 9.4 was used at the $\alpha = 0.05$ level of significance (Saxton, 1998).

## RESULTS AND DISCUSSION

Cotton maturity as quantified by NACB was not affected by an interaction between corn density and removal timing, nor by corn removal timing alone ($P = 0.2029$, 0.0683, respectively). However, volunteer corn density did affect cotton maturity as quantified by NACB ($P = 0.0289$); this effect is shown averaged over corn removal timing in Table 2. Cotton plants competing with the high density of volunteer GR corn (3.2 plants row $m^{-1}$) exhibited accelerated maturity (4 NACB) relative to plants competing with the medium and low volunteer GR corn densities (5 NACB). This observation is likely due to the depletion of resources available for cotton growth following competition with increased densities of volunteer corn resulting in reduced vegetative robustness (reduced height and node counts, Barnett and Steckel, 2013; Buchanan and Burns, 1970). Decreased NACB may indicate accelerated maturity, which can result in reduced yield.

**Table 2. Effect of GR volunteer corn density on cotton maturity as measured by nodes above cracked-boll counts at harvest aid application averaged over corn removal timing [Z,Y]**

| Density (Plants row $m^{-1}$) | NACB (count) |
|---|---|
| 0.3 | 5a |
| 1.6 | 5a |
| 3.2 | 4b |

[Z] Abbreviations: GR, glyphosate-resistant; NACB, nodes above cracked boll.

[Y] Different letters signify means that differ according to Fisher's LSD ($\alpha = 0.05$).

An interaction between volunteer corn density and removal timing affecting cotton height was detected (P < 0.0001). At low volunteer corn density (0.3 plants row $m^{-1}$), no differences were observed in cotton height due to corn removal timing (data not shown). At medium volunteer corn density (1.6 plants row $m^{-1}$), cotton height was maximized (115 cm) by volunteer corn removal timing at zero (volunteer corn-free) or two WACE (Table 3). Cotton height was minimized (99 cm) by corn removal six, eight, 10, or 12 WACE at the medium volunteer corn density (Table 3). At the high (3.2 plants row $m^{-1}$) volunteer corn density, cotton height was maximized (112 cm) following volunteer corn removal at zero, one, or two WACE (Table 3), and minimized (93 cm) following volunteer corn removal six, eight, 10, 12, WACE or not at all (SL competition). Similarly, Keeley and Thullen (1989) reported six, nine, 12 and 25 weeks of Johnsongrass (*Sorghum halepense*) interference reduced cotton height by 10, 20, 30 and 40%, respectively. When volunteer corn removal timing was fixed at zero, one, or two WACE, no change in cotton height was observed due to changes in volunteer corn density (data not shown). However, changes in volunteer corn density at corn removal timings of four, six, eight, 10, 12, and SL did affect cotton height (Table 4). At these volunteer corn removal timings, increases in volunteer corn density generally led to decreased cotton height (Table 4). These results are consistent with Thomas et al. (2007) and Clewis et al. (2008), which reported reduced cotton height at increasing volunteer corn densities.

An interaction between volunteer corn density and removal timing affecting cotton yield was detected (P < 0.0001). When volunteer corn density was fixed at 0.3 plants row $m^{-1}$, removal timing had no effect on cotton yield (data not shown). At the medium (1.6 plants row $m^{-1}$) volunteer corn density, yield was maximized by volunteer corn removal two or four WACE, and minimized by volunteer corn removal eight, 10, and 12 WACE or not at all (SL competition; Table 3). At the high (3.2 plants row $m^{-1}$) volunteer corn density, yield was maximized by volunteer corn removal zero, one, two, or four WACE and was minimized by removal eight, 10, or 12 WACE or not at all (SL competition; Table 3). Cotton yield was not affected by increasing volunteer corn density when removal timing was fixed at zero, one, or four WACE (Table 4). However, cotton yield generally decreased with increasing volunteer corn density when removal timing was fixed at two, six, eight, 10, 12 WACE or not at all (SL competition; Table 4). These results are consistent with previous work that suggest cotton must be kept weed-free four to eight WACE to avoid yield loss (Buchanan and Burns, 1970; Bukun, 2004; Byrd and Coble, 1991), and that cotton yield can be severely reduced by SL weed competition (Bridges and Chandler, 1987; Chandler, 1977; Clewis et al., 2008; Steckel and Gwathmey, 2009; Thomas et al., 2007).

**Table 3. Effect of GR volunteer corn removal timing on cotton height and yield when fixed at medium (1.6 plants row $m^{-1}$) or high (3.2 plants row $m^{-1}$) GR volunteer corn densities [Z,Y]**

| Density (plants row $m^{-1}$) | Removal Timing (WACE) | Cotton Height (cm) | Cotton Yield (kg $ha^{-1}$) |
|---|---|---|---|
| 1.6 | 0 | 115a | 2,528bc |
| | 1 | 110b | 2,483bc |
| | 2 | 116a | 3,033a |
| | 4 | 109b | 2,694ab |
| | 6 | 103c | 2,328bcd |
| | 8 | 102c | 2,039de |
| | 10 | 99c | 1,807e |
| | 12 | 99c | 1,821e |
| | SL | 108b | 2,159cde |
| 3.2 | 0 | 111a | 2,530a |
| | 1 | 110a | 2,568a |
| | 2 | 112a | 2,397a |
| | 4 | 105b | 2,295a |
| | 6 | 97c | 1,883b |
| | 8 | 93c | 1,529bc |
| | 10 | 95c | 1,445c |
| | 12 | 94c | 1,409c |
| | SL | 96c | 1,403c |

[Z] Abbreviations: GR, glyphosate-resistant; WACE, Weeks after cotton emergence.

[Y] Different letters signify means that differ according to Fisher's LSD. Values within the same density that share a letter are not significantly different (α = 0.05).

**Table 4. Effect of GR volunteer corn density on cotton height and yield when fixed at various removal timings [Z,Y]**

| Removal Timing (WACE) | Density (plants row $m^{-1}$) | Cotton Height (cm) | Cotton Yield (kg $ha^{-1}$) |
|---|---|---|---|
| 0 | 0.3 | 115a | 2,698a |
| | 1.6 | 112a | 2,530a |
| | 3.2 | 111a | 2,529a |
| 1 | 0.3 | 112a | 2,717a |
| | 1.6 | 110a | 2,568a |
| | 3.2 | 110a | 2,483a |
| 2 | 0.3 | 116a | 3,033a |
| | 1.6 | 112a | 2,627ab |
| | 3.2 | 112a | 2,397b |
| 4 | 0.3 | 109a | 2,694a |
| | 1.6 | 108ab | 2,660a |
| | 3.2 | 105b | 2,295a |
| 6 | 0.3 | 111a | 2,520a |
| | 1.6 | 103b | 2,328a |
| | 3.2 | 97c | 1,883b |
| 8 | 0.3 | 109a | 2,556a |
| | 1.6 | 102b | 2,039b |
| | 3.2 | 93c | 1,529c |
| 10 | 0.3 | 108a | 2,593a |
| | 1.6 | 99b | 1,807b |
| | 3.2 | 95b | 1,445b |
| 12 | 0.3 | 110a | 2,670a |
| | 1.6 | 99b | 1,821b |
| | 3.2 | 94c | 1,409c |
| SL | 0.3 | 110a | 2,669a |
| | 1.6 | 108a | 2,159b |
| | 3.2 | 96b | 1,403c |

[Z] Abbreviations: GR, glyphosate-resistant; WACE, Weeks after cotton emergence.

[Y] Different letters signify means that differ according to Fisher's LSD. Values within the same removal timing that share a letter are not significantly different (α = 0.05).

**Significance of Findings for Cotton Management.** Cotton maturity (as quantified by NACB counts) was not greatly affected by competition with GR volunteer corn. Competition with the high volunteer GR corn density slightly reduced cotton NACB counts and this may be attributed to increased depletion of the available resources necessary for additional vegetative growth. Cotton height and yield response to GR volunteer corn competition are affected by an interaction of volunteer corn density and removal timing. Cotton can withstand competition with volunteer corn densities of 3.2 plants row $m^{-1}$ for up to four WACE without yield being adversely affected. At a high volunteer corn density cotton height was more sensitive to prolonged competition than yield, contrary to Buchanan and Burns (1970) which reported cotton yield as being more sensitive to competition than height or stem diameter. The evolution of varieties over the past 40 years and the difference in environments may contribute to these contrasting results.

Volunteer corn persisting until cotton harvest was removed by hand in this experiment, however, large-scale producers would not likely have this option. Thus, the effect of corn present at harvest on harvest efficiency and quality should be considered as weeds present in cotton may interfere with harvest by slowing the speed of the harvest equipment and may physically interfere with lint removal (Coble and Byrd, 1992). It would be reasonable to assume that free-standing corn during cotton harvest could be a detriment to harvest efficiency as well as to equipment itself. These data indicate that at low densities, volunteer corn plants did not affect seed cotton yield; however, as volunteer corn densities increased, yield reductions were observed. During the growing season, an increase in weed population combined with an increased period of interference will impact crop yield. Although cotton height and yield reductions occurred with the presence of higher densities and prolonged interference periods of volunteer corn, these data confirm previous conclusions that volunteer GR corn is not as competitive as many grass and broadleaf weed species common to cotton production (Buchanan and Burns, 1970; Thomas et al., 2007).

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## DISCLAIMER

No conflicts of interest have been declared. Any mention of a proprietary or trademarked product does not imply endorsement.

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