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Authors: Alms, Jill, Moechnig, Michael, Vos, David, and Clay, Sharon A.

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Yield Loss and Management of Volunteer Corn in Soybean

Jill Alms, Michael Moechnig, David Vos, and Sharon A. Clay*

Volunteer corn is often overlooked as a weed in soybean. To aid in management decisions, this study determined soybean yield loss attributed to volunteer corn and efficacy of various herbicides at several rates and timings. A hyperbolic equation estimated ($R^2 = 0.88$) incremental yield loss (I) of 39.7% at low density when maximum yield loss (A) was constrained to 71%, the highest yield loss observed in these trials, revealing a more competitive plant than many common midwestern weedy species. Clethodim applied at 51 g ai ha^{-1} at V4 soybean resulted in > 90% volunteer corn control with < 5% soybean yield loss, whereas if applied at 12.7 g ai ha^{-1} volunteer corn control was 15%, but soybean yield was 50% greater than the nontreated control. On the basis of these data, the partial volunteer corn control improved soybean yield. Timing of glufosinate application influenced volunteer corn control. Glufosinate applied to 15-cm-tall corn resulted in 33% control, whereas applications to 36- to 91-cm corn resulted in > 70% control. Glufosinate combined with grass herbicides improved control to > 85%, with concomitant yield increases. Results demonstrated that volunteer corn substantially reduced soybean yield at low densities and yield increased when volunteer corn was controlled with various herbicides. On the basis of these results, and current soybean grain and herbicide prices, soybean yield gains from volunteer corn control could increase net return by > \$150 ha^{-1}.

Nomenclature: Clethodim; glufosinate; glyphosate; quizalofop; corn, *Zea mays* L.; soybean, *Glycine max* (L.) Merr.

Key words: Clethodim, glufosinate, glyphosate, quizalofop, volunteer corn; yield loss.

El maíz voluntario es frecuentemente ignorado como una maleza en campos de soja. Para ayudar a la toma de decisiones de manejo, este estudio determinó la pérdida de rendimiento atribuida al maíz voluntario y la eficacia de varios herbicidas a varias dosis y momentos de aplicación. Una ecuación hiperbólica estimó ($R^2 = 0.88$) pérdidas de rendimiento incrementales (I) de 39.7% a densidades bajas cuando la pérdida máxima de rendimiento se limitó a 71%, la cual fue la pérdida de rendimiento más alta observada en estos ensayos, lo que reveló que el maíz voluntario es una planta más competitiva que muchas especies de malezas comúnmente observadas en el medio oeste. Clethodim aplicado a 51 g ai ha^{-1} durante el estadio V4 de la soja resultó en >90% de control de maíz voluntario con <5% de pérdidas en el rendimiento de la soja, mientras que si se aplicó a 12.7 g ai ha^{-1} el control del maíz voluntario fue 15%, pero el rendimiento de la soja fue 50% mayor que el de control sin tratamiento. Con base en estos datos, el control parcial del maíz voluntario mejoró el rendimiento de la soja. El momento de aplicación de glufosinate influyó en el control del maíz voluntario. Glufosinate aplicado a plantas de maíz de 15 cm de altura resultó en 33% de control, mientras que aplicaciones a maíz de 36 a 91 cm de altura resultó en >70% de control. Glufosinate combinado con herbicidas para gramíneas mejoraron el control a >85%, con incrementos concomitantes de rendimiento. Los resultados demostraron que el maíz voluntario redujo sustancialmente el rendimiento de la soja a bajas densidades y el rendimiento incrementó cuando el maíz voluntario fue controlado con varios herbicidas. Con base en estos resultados y los precios actuales de grano de soja y de herbicidas, las ganancias en el rendimiento de la soja producto del control del maíz voluntario pudo incrementar la rentabilidad neta en >\$150 ha^{-1}.

Growers often overlook volunteer corn as a serious weed in soybean. Infestations are patchy and the intermittent appearance of high densities and the perception that low densities do not reduce yield are viewed as justifications to ignore volunteer corn infestations (Jhala et al. 2014). In addition, before acetyl CoA carboxylase (ACCase) grass herbicides were available that could control volunteer corn in soybean and the introduction of glyphosate-resistant corn, volunteer corn control was achieved mechanically with cultivation, or by applying glyphosate using a rope-wick applicator or recirculating sprayer when the corn was taller than the soybeans (Beckett and Stoller 1988). Glyphosate

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* First, third, and fourth authors: Graduate Student, Research Associate, and Professor, Plant Science Department, South Dakota State University, Brookings, SD 57007; second author: Dow Agrosciences, Field Scientist, Toronto, SD 57268. Corresponding author's E-mail: Sharon.clay@sdstate.edu

effectively controlled conventional volunteer corn; however, this application often occurred after the first trifoliate stage (V1) stage of soybean growth and yield loss was measurable (Anderson et al. 1982).

Since 2000, a rotation of glyphosate-resistant corn followed by glyphosate-resistant soybean has been a common practice in South Dakota. For example, from 2008 to 2012, 85% of the corn and 98% of the soybean acres in South Dakota had a herbicide-resistant trait (most often glyphosate) (USDA-NASS 2013) and no-till acres increased (Lee et al. 2014). This high percentage of rotational crops with similar herbicide resistance, and less crop cultivation, has perpetuated volunteer corn as a problematic plant in corn–soybean cropping rotations throughout the midwestern United States. Growers are often reluctant to apply additional herbicides that would provide volunteer corn control because of the added cost and perceptions described above.

However, volunteer corn has been reported to compete with soybean for water, light, and nutrients. The possibility for yield reduction, interference with harvest, poorer soybean seed quality, and general unattractiveness in a soybean crop qualify volunteer corn as a weed (Andersen 1976; Young and Hart 1997). Volunteer corn has been proven to reduce soybean yields because of interspecific competition (Andersen et al. 1982; Beckett and Stoller 1988; Zimdahl 2004). There may also be intraspecific competition among volunteer corn plants as volunteer corn densities increase with the competitive effect on the cash crop lessened.

Volunteer corn is at least a F_2 generation plant that emerges from the previous years' unharvested corn grain. Individual plants, as well as clumps of multiple plants frequently sprouting from dropped ears, constitute volunteer corn populations. The occurrence of volunteer corn infestations can be influenced by harvest efficiency, tillage, and pest infestations (Owen and Zelaya 2005), among other factors. Missed or dropped grain and inefficiency of harvest machinery, which has been reported in one study to range from 53 to 127 kg ha^{-1} (Shauck et al. 2010), can contribute to volunteer corn populations (Owen and Zelaya 2005). Assuming 3,100 kernels kg^{-1} and 100% germination, this would be equivalent to 16 to 39 plants m^{-2} of volunteer corn the following season.

The increase in no-till acres in South Dakota may have both positive and negative effects on volunteer corn populations. Overwintering may reduce soil surface kernel number because of predation, physical movement, germination, or seed degradation (Buhler et al. 1997). For example, Brust and House (1988) reported that predation reduced weed seeds by 69% in no-till soybeans compared with a 27% loss when conventional tillage was used. Germination and emergence of volunteer corn, however, occur more easily with reduced or conservation tillage where seeds remain on or close to the soil surface vs. conventional tillage when seeds are buried (Beckett and Stoller 1988; Owen and Zelaya 2005).

Generally when weeds that emerge with the soybean are controlled within 4 to 6 wk after emergence, yield losses are minimized (Beckett and Stoller 1988; Zimdahl 2004). However, significant yield losses have been reported with glyphosate-resistant volunteer corn in soybeans, even if removed early. Deen et al. (2006) reported a 990–2,000 kg ha^{-1} soybean yield loss (i.e., 50 to 60% of the weed-free yield) in a glyphosate-only treatment when volunteer corn was treated at the two trifoliate leaf (V2) to three trifoliate leaf (V3) soybean stages compared with a weed-free treatment. The volunteer corn in the glyphosate treatment (Deen et al. 2006) was unaffected by glyphosate at this early stage and yield was similar to the untreated control in 50% of the environments tested. Another study specified the V1 stage of soybean to be the best stage for treatment of volunteer corn to avoid yield loss (Andersen 1976). These data indicate the need for control of volunteer corn early in the season. An option for controlling glyphosate-resistant volunteer corn is planting glufosinate-resistant soybeans and applying glufosinate as a POST treatment. The adoption of glufosinate-resistant soybean has had limited success, as over 95% of the soybean varieties planted in South Dakota continue to be glyphosate, rather than glufosinate, resistant (USDA-NASS 2013). However, glufosinate use may increase as glyphosate-resistant weeds become more common.

Many ACCase graminicides effectively control volunteer corn, including diclofop (Andersen 1976; Andersen et al. 1982), sethoxydim, quizalofop (Young and Hart 1997), fluazifop (Beckett and

Stoller 1988), clethodim, and fenoxaprop (Deen et al. 2006). One of the difficulties in convincing producers to incorporate these herbicides in soybean production is that at current prices, the addition of these herbicides double or triple herbicide costs compared with glyphosate alone (Johnson et al. 2015). Therefore, to justify the additional cost, soybean yield loss associated with volunteer corn must be quantified, guidelines for application timing to optimize volunteer corn control should be established, and the economic benefit associated with the added costs of volunteer corn control must be determined.

The objectives of this study were to: (1) determine soybean yield loss due to volunteer corn competition, (2) determine the effect of partially controlled volunteer corn on soybean yield, and (3) determine the timing of glufosinate alone or in combination with quizalofop or clethodim as an option for controlling volunteer glyphosate-resistant corn in glufosinate-resistant soybean. Each study was conducted in two field seasons in eastern South Dakota, a state where about 500,000 ha of corn and soybean are planted annually (USDA-NASS 2013).

Materials and Methods

Studies for soybean yield loss associated with (1) volunteer corn densities and (2) partially controlled volunteer corn in glyphosate-resistant soybean (Roundup Ready Asgrow 1404, relative maturity 1.4) were conducted in 2007 and 2008. A third study was conducted in 2009 and 2010 to examine early POST (EPOST) and late POST (LPOST) control of volunteer corn using glufosinate alone or in tank-mix combination with other grass herbicides and subsequent yield of glufosinate-resistant soybean. All studies were performed at the South Dakota State University Brookings Agronomy Farm on a Barnes loam soil (Fine-loamy, mixed, superactive, frigid Calcic Hapludolls). Soybean populations for these studies were 432,000 seeds ha^{-1}. Volunteer corn seeds were collected the year before each study at physiological maturity of the corn crop. In 2006, seeds were collected from Roundup Ready DKC 58-73 (a 108-d relative maturity hybrid) and in 2007, 2008, and 2009 seeds were from Roundup Ready DKC 51-45 (a 101-d relative maturity hybrid). All herbicide treatments were applied using 187 L ha^{-1} at 207 kPa and TeeJet 8003XR nozzles with specific herbicides, rates, and timings reported below. Treatments in 2007, 2008, and 2009 were applied with a bicycle sprayer, whereas in 2010 a backpack sprayer was used.

Treatments were arranged in a randomized complete block design with three (2009 experiment) or four (2007, 2008, 2010 experiments) replications. Individual plots were 3 m wide (four rows spaced 76 cm apart) and 15 m long and harvest areas were 1.5 m wide (center two rows) by 3 m long.

Soybean Yield Loss Due to Volunteer Corn. Immediately after planting glyphosate-resistant soybean with a four-row JD 7000 planter on May 18, 2007 and May 21, 2008, volunteer corn seeds were broadcast on the soil surface and incorporated to approximately a 0- to 2-cm depth using a harrow. Volunteer corn densities, chosen to provide a range of soybean yield loss, were counted in early July each year. In 2007, target densities were 0, 0.2, 0.6, 1.5 and 3.5 plants m^{-2} and in 2008, 0, 0.2, 0.9, 2.3, and 4.4 plants m^{-2}. Plots were kept weed free other than glyphosate-resistant corn both years with glyphosate (Roundup Weathermax; Monsanto Company, St. Louis, MO) at 870 g ai ha^{-1} applied on June 16, 2007 and on June 18, 2008.

Cobs on the volunteer corn plants were harvested manually from the center 1.5-m by 3-m area of the plot on October 2, 2007 and October 22, 2008 to prevent contamination of soybean yield and quantify corn grain weight. Soybean was harvested with a plot combine from the same area as corn harvest on October 13, 2007 and October 22, 2008, with yield reported at 13% moisture.

Partial Control of Volunteer Corn in Soybean. In a second study, soybean and volunteer corn were planted at the same time as the study above. A single volunteer corn density was used each year with 1.5 plants m^{-2} in 2007 and 2.2 plants m^{-2} in 2008. Glyphosate (Roundup Weathermax) was applied at 870 g ai ha^{-1} on June 16, 2007 and June 18, 2008.

Clethodim (Select 2EC®; Valent U.S.A. Corporation, Walnut Creek, CA) was applied at 12.7, 25.5, or 51 g ai ha^{-1} with crop oil concentrate at 0.5% v/v on June 28, 2007 and July 10, 2008 to result in volunteer corn control ranging from partial to complete (near 100%). Soybean was about 31 cm tall and at the V3 growth stage and volunteer corn was 51 cm tall in 2007. In 2008, soybean was 36 cm tall and at the four trifoliate (V4) to five trifoliate (V5) growth stage with volunteer corn 61 cm tall.

Control of volunteer corn was evaluated visually and rated on a 0 (no control) to 100 (complete control) scale. As the interest was in final end-of-season control, ratings were taken on September 27, 2007 and October 2, 2008.

Volunteer corn that remained in the plots was manually harvested and weighed from the center 1.5-m by 3-m-wide area on October 2, 2007 and October 22, 2008 and grain weight determined after mechanically shelling and weighing. Soybean was harvested with a plot combine from this same area on October 13, 2007 and October 22, 2008 with yield adjusted to 13% moisture.

Volunteer Corn Control with Glufosinate. In a third study, Liberty Link SO 80137 LL soybean was planted on May 11, 2009 and Liberty Link LT 1098 soybean was planted on May 28, 2010 at 420,000 plants ha^{-1} in rows spaced 76 cm apart. Glyphosate-resistant (glufosinate-susceptible) volunteer corn seeds were planted at a density to obtain 4.3 plants m^{-2} in 2009 and 3.9 plants m^{-2} in 2010.

Herbicide treatments were applied at two timings each year. Glufosinate (Liberty; Bayer Crop Science, Monheim, Germany) at 450 g ai ha^{-1} was (1) applied alone, or tank mixed with (2) quizalofop (Assure II; E. I. du Pont de Nemours and Company, Wilmington, DE) at rates of 38.6 or 19.3 g ai ha^{-1} or (3) clethodim at rates of 105 or 52.6 g ai ha^{-1}. All of these herbicide treatments included 1 kg $ha^{-1}$of ammonium sulfate. The treatments containing quizalofop and clethodim also included a crop oil concentrate at 1% v/v rate. Quizalofop and clethodim rates were: (1) equivalent to the low end of the recommended rate range for each product; or (2) half those rates. Rates less than those recommended were included to determine if partial rates were sufficient when mixed with a recommended rate of glufosinate (Liberty 280SL®) to control glufosinate-susceptible corn. An untreated check was also included for comparison. In both years, EPOST (mid-June) herbicide treatments and LPOST herbicide treatments were applied, although volunteer corn differed in height and soybean differed in growth stages between the 2 yr for each application. In 2009, the herbicide treatments were applied EPOST at the 15-cm (June 16) height of volunteer corn when soybean was at the V1 growth stage and LPOST when volunteer corn height was 30–46 cm (June 25) and soybean was at the V4 growth stage. In 2010 the EPOST herbicide treatments were applied when the height of volunteer corn was 20 to 36 cm (June 18) and soybean was at the V3 growth stage, whereas the LPOST herbicide treatments were applied when volunteer corn was 61 to 91 cm (July 6) and soybean was flowering (R1/R2 growth stage).

Control of volunteer corn was visually evaluated and rated on a 0 (no control) to 100 (complete control) scale on September 30, 2009 and September, 16, 2010. Soybean was harvested with a plot combine from the center 1.5-m by 3-m-wide area on October 21, 2009 and October 6, 2010 with yield adjusted to 13% moisture.

Statistical Analyses. Data were pooled between years for the competition study. The weed-free soybean yield for each replication each year was used to calculate the percent soybean yield loss by corn densities in each replicated block. The independent variable was corn density and dependent variable was soybean yield. Density vs. soybean yield was fit to the rectangular hyperbolic yield-loss function (Cousens 1985): $YL = (I \times D)/(1 + [I \times D]/A)$ using the Solver program, which uses an iterative approach to minimize error, in Microsoft Excel (Clay et al. 2012). YL is % yield loss, D is the volunteer corn plant density, I describes slope of the curve at low volunteer corn density, and A estimates maximum yield loss. The constraint for A was set at 71 as this was the greatest soybean yield loss observed in either year at the densities used. The R^2 value for the best-fit equation when A was constrained was calculated.

Soybean yield means for other studies were analyzed by ANOVA and compared with the Student–Newman–Keuls test at the 0.05 level of probability. The random effect in each study was year, whereas the fixed effects were volunteer corn density in study 1, clethodim rate in study 2, and graminicide herbicide, rate, and application time in study 3.

Results and Discussion

Growing Degree Days and Precipitation during the Study Period. Growing degree day (GDD) total (base 10 C) in 2007 was 1,380, about 10% above the 30-yr (1970–2000) average, whereas in

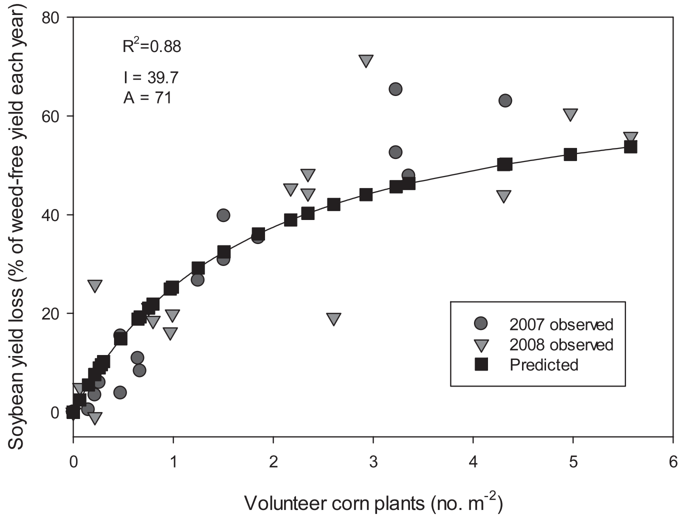

Figure 1. Percent soybean yield loss due to volunteer corn in 2007 (circles) and 2008 (triangles). A hyberbolic equation (yield loss = [density × I]/1 + [density × I]/A) (Cousens 1985) was fit to the combined data set with predicted values shown (squares). The R^2 value was 0.88, with an incremental yield loss (I) = 39.7 when the maximum yield loss (A) was constrained to 71%, the maximum loss observed in the two treatment years.

2008 GDD was similar to the 30-yr average (1,250 total GDD) (data not shown). Total precipitation for 2007 and 2008 growing seasons was similar (about 34 cm), although in 2007 about half (16 cm) of the precipitation occurred in August, during grain fill, whereas in 2008 about 14 cm occurred in June during the early to mid-vegetative stages. Weed-free soybean yield was greater in 2007, 3,138 kg ha^{-1} compared with 2,231 kg ha^{-1} in 2008. Total precipitation for the 2009 growing season was 37 cm, with 18 cm occurring in June and July. Precipitation in 2010 was 65 cm, with June (vegetative stages) and September (late grain-fill stages) receiving the majority of the precipitation.

Volunteer Corn Reduced Soybean Yield. Actual volunteer corn densities ranged from 0.15 to 4.3 plants m^{-2} in 2007 and from 0.06 to 5.6 plants m^{-2} in 2008. Soybean yield loss averaged over all plots containing volunteer corn was 25% in 2007 and 29% in 2008. Three of eight plots containing < 0.3 plants m^{-2} volunteer corn had a 9% average yield increase compared with weed-free yield, whereas the other five plots with these densities had an average yield loss of 8%. The maximum yield loss in the volunteer corn plots was 71% (Figure 1) observed at 3 plants m^{-2}. Lower soybean yield loss at higher volunteer corn densities may have been due to intraspecific competition among volunteer corn plants.

The hyperbolic model described the combined 2-yr yield loss data very well ($R^2 = 0.88$) (Figure 1), with an I value of 39.7 when the A value was constrained for the maximum yield loss observed (71%). These data indicate that volunteer corn as a single plant in this study was more competitive compared with reports of studies where clumps of volunteer corn from buried corn ears were used to compete with soybean (Andersen et al. 1982; Beckett and Stoller 1988). Solving the yield loss equation developed from the data in this study indicates a 1% yield loss for each 0.04 plants m^{-2}. This estimated loss per plant is about five times greater than losses reported by Andersen et al. (1982), where a 1% yield loss was observed for each 0.185 plants m^{-2}, or Beckett and Stoller (1988), who reported that each 0.22 plants m^{-2} resulted in a 1% yield loss when clumps of 10 plants were used. Soybean yield loss may have been less with clumps vs. single plants because of intraspecific competition among clumped volunteer corn plants.

Soybean yield was reduced 10% with a volunteer corn density of 0.5 plants m^{-2} and a 41% yield loss was observed with a density of 16 plants m^{-2} in a narrow row-spacing study (19 cm) (Marquardt et al. 2012). Our results from 76-cm row spacing showed similar yield loss results at the lower density, with a 10% soybean yield loss at a volunteer corn density of 0.4 plants m^{-2}. Although we did not obtain densities as high as 16 plants m^{-2}, we observed a 51% yield loss at an average density of 4.4 plants m^{-2}. The hyperbolic model fit to our data suggests that soybean yield loss at high volunteer corn densities may plateau because of increased intraspecific competition among corn plants (Clay et al. 2009).

Soybean yield losses due to volunteer corn were similar to shattercane (*Sorghum bicolor*) (Fellows and Roeth 1992), where 0.6 plants m^{-2} averaged 20% yield loss; cocklebur (*Xanthium pensylvanicum*) (Barrentine 1974), where 4.4 plants m^{-2} reduced soybean yield by 50%, and Palmer amaranth (*Amaranthus palmeri* S. Wats.) and common waterhemp (*Amaranthus rudis* L.), which reduced yield 79 and 56%, respectively, at 10.5 plants m^{-2} (Bensch et al. 2003). Volunteer corn was much more competitive than some grass weeds, including giant foxtail (*Setaria faberi*), barnyardgrass (*Echino-*

chloa crus-galli*), and green foxtail (*Setaria viridis*). For example, giant foxtail at 13.2–26.4 plants m^{-2} resulted in 26% soybean yield loss (Harrison et al. 1985), whereas 1 plant m^{-2} in our study had a similar loss. Vail and Oliver (1993) reported that barnyardgrass densities of 42, 110, and 250 plants m^{-2} resulted in 10, 25, and 50% soybean yield loss, whereas 50% yield loss was expected with four volunteer corn plants m^{-2}. Weaver (2001) reported an I value of 0.7 (compared with 39.7 in this study) and an A value 80% with green foxtail densities ranging from 500 to 600 plants m^{-2}. Volunteer corn may be more competitive than other grass weeds because of its taller growth habit and wider leaves compared with other grasses.

Volunteer corn plants produced grain at the end of the season. Yields ranged from 254 to 2,214 kg ha^{-1} from 0.2 to 3.5 plants m^{-2} in 2007, whereas in 2008 corn yield was 428 to 5,662 kg ha^{-1} from 0.2 to 4.4 plants m^{-2}. In addition, these data indicate that seed production per plant was two times greater at the low densities (127 g plant^{-1} in 2007 and 214 g plant^{-1} in 2008) compared with the higher density (63 g plant^{-1} in 2007 and 128 g plant^{-1} in 2008). Although these seeds are another generation (F_3) removed from the original hybrid, these seeds may perpetuate volunteer corn plants the following season(s) if not controlled. It is unclear, however, if these plants would be as detrimental in the following crop because of expected vigor losses as seed generations get farther removed from the original hybrid.

Volunteer corn plant yield in the Andersen et al. (1982) study ranged from 130 to 2,210 kg ha^{-1} at a density of four plants m^{-2} using clumps of volunteer corn. This was considerably lower than the yield of our volunteer corn at a similar density where 4.4 plants m^{-2} averaged 5,660 kg ha^{-1}. This supports the hypothesis that intraspecific competition played a role in soybean yield loss because of volunteer corn in clumps vs. single plants.

Partial Control of Glyphosate-Resistant Volunteer Corn in Glyphosate-Resistant Soybean. Clethodim rates of 12.7, 25.5, and 51 g ai ha^{-1} resulted in 16, 77, and 98% control of volunteer corn in 2007, respectively, whereas in 2008 observed control was 12, 54, and 91%, respectively. Yield loss in untreated plots averaged 31% (2007) and 36% (2008). Partially controlling volunteer corn resulted in less soybean yield loss than if no treatment was applied. Yield loss at the lowest clethodim rate was 21 and 14% in 2007 and 2008, respectively, and with the high rate, where excellent control was observed, was 5% each year.

Volunteer corn control using clethodim in our study differed from results reported by Currie et al. (2007). They reported that 6.8, 13.6, and 27.2 g ai ha^{-1} of clethodim provided 100% control of volunteer glyphosate-resistant corn when applied at the V2, V3, and V6 corn stages, respectively. In our study 12.7 g ai ha^{-1} of clethodim averaged only 15% control of volunteer corn at V5 and 25.5 g ai ha^{-1} applied at about V7 averaged about 60% control. In our study, a 51 g ai ha^{-1} rate of clethodim was needed to achieve $>$ 90% control.

Our results also differed from those reported by Deen et al. (2006) and Marquardt and Johnson (2013). Deen et al. (2006) reported no differences in soybean yields with rates of 30 or 60 g ai ha^{-1} of clethodim tank mixed with glyphosate at 0.9 kg ae ha^{-1} when 0.5% (v/v) surfactant was included. Although we used similar glyphosate rates applied at similar volunteer corn growth stages, there was a 16% soybean yield loss at the low rate and a 5% yield loss at the high clethodim rate.

The study by Marquardt and Johnson (2013) resulted in no difference in volunteer corn control (92–99%) or soybean yield when clethodim (79g ai ha^{-1}) and glyphosate (840 g ae ha^{-1}) were tank mixed and applied to $\leq$ 30 cm or $\approx$ 90 cm volunteer corn at densities ranging from 0.5 to 16 plants m^{-2}. This rate was 1.5$\times$ our highest rate of clethodim. We observed a 5% soybean yield loss at our high rate (51 g ai ha^{-1}) with similar (91–98%) control. The Marquardt and Johnson (2013) study used drilled (19-cm rows) soybean compared with our 76-cm rows, which may account for soybean yield loss differences.

Volunteer Corn Control in Glufosinate-Resistant Soybean. Glufosinate alone in both years provided greater volunteer corn control at the LPOST timing both years (Table 1). The height of the volunteer corn at the LPOST timing in 2009 (30–46 cm) was close to the same height as the EPOST timing in 2010 (20–36 cm). In 2009, glufosinate applied when the plants were about 15 cm tall resulted in only 33% control, whereas in 2009 and 2010, application when the plants were larger ($>$ 30 cm tall) had nearly 80% control. Poor glufosinate control at the earliest corn growth stage in 2009 can be explained by a combination of factors including

Table 1. Efficacy of herbicides for volunteer glyphosate-resistant corn control in glufosinate-resistant soybean. Visual observations for percent control, 0 = no control and 100 = complete control. Observations for 2009 were taken September 30 and for 2010, September 16.[a]

Herbicide	Rate	Volunteer corn control 2009[b] Early	2009[b] Late	2010[b] Early	2010[b] Late
	g ai ha^{-1}	%			
Glufosinate[c]	450	33 e	79 d	73 f	83 e
Glufosinate[c] + quizalofop[d]	450 + 38.6	96 ab	86 d	100 a	94 bcd
Glufosinate[c] + quizalofop[d]	450 + 19.3	97 ab	84 c	90 d	93 cd
Glufosinate[c] + clethodim[d]	450 + 105	99 a	92 b	95 bc	96 abc
Glufosinate[c] + clethodim[d]	450 + 52.6	99 a	87 c	98 ab	95 bc

[a] Means presented within each year with no common letter(s) are significantly different according to Student–Newman–Keuls LSD test where $P \leq 0.05$.

[b] In 2009, treatments were applied early, when volunteer corn was 15 cm tall (June 16), and late, when volunteer corn was 30 to 46 cm tall (June 25). In 2010, treatments were applied early, when volunteer corn was 20 to 36 cm tall (June 18), and late, when volunteer corn was 61 to 91 cm tall (July 6).

[c] Treatments included 1 kg ha^{-1}of ammonium sulfate.

[d] The quizalofop and clethodim treatments included a crop oil concentrate at 1% v/v rate.

(1) the growing point of corn typically does not emerge from the soil until the V6 growth stage (Ritchie et al. 1997) and (2) the majority of applied glufosinate does not translocate from treated leaves (< 1 to 15% of applied) (Steckel et al. 1997).

Glufosinate combined with a grass herbicide at either rate or timing improved volunteer corn control. In 2009, EPOST tank-mixed treatments averaged 98% control, whereas LPOST treatment averaged about 87% control. In 2010 EPOST and LPOST mixture treatments averaged 95% control. There were some differences in control ratings between rates, with low rates more effective on the smaller rather than larger plants. Quantitative measurements (e.g., biomass) should be done to determine the true extent of these differences.

Soybean yields in all herbicide treatments were two to three times greater than soybean yields in season-long untreated volunteer corn treatments both years. In 2009, there was no difference in yield among any of the herbicide treatments at either timing (Table 2). In 2010, there were more differences among application timing; soybean had higher yields in EPOST treatments than in LPOST treatments. At

Table 2. Glufosinate-resistant soybean yield of treatments used to control volunteer glyphosate-resistant corn.[a]

Herbicide	Rate	Soybean yield 2009 Early	2009 Late	2010 Early	2010 Late
	g ai ha^{-1}	kg ha^{-1}			
Glufosinate[b]	450	2,600 a	2,580 a	3,030 bcd	2,800 d
Glufosinate[b] + quizalofop[c]	450 + 38.6	2,650 a	2,620 a	3,540 a	2,950 cd
Glufosinate[b] + quizalofop[c]	450 + 19.3	2,560 a	2,450 a	3,350 abc	2,980 cd
Glufosinate[b] + clethodim[c]	450 + 105	2,670 a	2,650 a	3,460 ab	2,930 cd
Glufosinate[b] + clethodim[c]	450 + 52.6	2,850 a	2,730 a	3,310 abc	3,090 a-d
Nontreated control		910 b		1,200 e	

[a] Means presented within each year with no common letter(s) are significantly different according to Student–Newman–Keuls LSD test where $P \leq 0.05$.

[b] Treatments included 1 kg ha^{-1}of ammonium sulfate.

[c] The quizalofop and clethodim treatments included a crop oil concentrate at 1% v/v rate.

the EPOST timing, only soybean treated with the high rate (38.6 g ai ha^{-1}) of quizalofop had greater yield than glufosinate alone. At the LPOST timing, yields for all herbicide treatments were similar and averaged 12% less than average yields in the EPOST treatments. These data indicate that to minimize yield loss, control of volunteer corn is needed before it is 46 cm tall, although the plant can be controlled by later-season applications.

Unlike a study by Burke et al. (2005) that reported antagonism when clethodim and glufosinate were applied together to goosegrass (*Eleusine indica*) vs. clethodim applied alone, we saw $>$ 96% control with EPOST timings of either rate. At LPOST timings control was better at high than at low rates, although the lowest observed control was 87%.

Volunteer corn was highly competitive in soybean and because of high yield losses at low densities should not be ignored as an innocuous plant in soybean fields. The competitive ability of volunteer corn was found to be as great as or greater than other weeds typically found in soybean. These losses were reduced with herbicide treatment even if volunteer corn was only partially controlled. On the basis of average herbicide costs gleaned from surveys of South Dakota dealerships and published in the South Dakota 2015 Pest Management Guide—Soybean (Johnson et al. 2015), the herbicide treatment cost at any of the rates tested would be economically feasible even at $<$ 1 plant m^{-2} densities. Assuming that soybean sells for US$312 $(MT)^{-1}$, returns of $150 to $300 ha^{-1} above treatment costs (in 2015) could be realized. Reduced rates of clethodim resulted in partial control of volunteer corn, but high rates gave the best control and had minimal yield losses. Glufosinate with a grass herbicide provided better control than glufosinate alone and gave excellent ($>$ 90% in most cases) control of glyphosate-resistant volunteer corn in glufosinate-resistant soybean. However, to minimize yield loss, glufosinate treatments should be applied either with another grass herbicide, or after growing point emergence but before volunteer corn is 46 cm tall.

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