Volunteer Glyphosate-Resistant Corn and Soybean Competition and Control

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VOLUNTEER GLYPHOSATE-RESISTANT CORN AND SOYBEAN
COMPETITION AND CONTROL

BY

JILL ALMS

A thesis submitted in partial fulfillment of the requirements for the
Master of Science
Major in Plant Science
South Dakota State University
2015
VOLUNTEER GLYPHOSATE-RESISTANT CORN AND SOYBEAN
COMPETITION AND CONTROL

This thesis is approved as a creditable and independent investigation by a
candidate for the Master of Science degree and is acceptable for meeting the thesis
requirements for this degree. Acceptance of this thesis does not imply that the
conclusions reached by the candidate are necessarily the conclusions of the major
department.

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ABSTRACT

VOLUNTEER GLYPHOSATE-RESISTANT CORN AND SOYBEAN

COMPETITION AND CONTROL

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2015

The continuous use of glyphosate-resistant crops has resulted in volunteer crops with the same herbicide resistance as the cash crop and an increasing weed problem. Volunteer corn reduces soybean yields however; little research has examined corn yield loss due to volunteer corn or volunteer soybean competition. These studies investigated yield loss and control of volunteer soybean in corn, and volunteer corn in soybean and corn. Using several densities of competitive plants, the yield loss was fit to a hyperbolic equation that indicated incremental yield loss (I value) to be 29.9 for volunteer corn in soybeans, 5.6 for volunteer corn in corn, and 3.2 for volunteer soybeans in corn. These data indicate that yield loss due to volunteer corn in soybean was six times greater than yield loss due to volunteer corn in corn and about ten times greater than yield loss due to volunteer soybean in corn. Reduced rates of clethodim resulted in partial control of volunteer corn in soybeans. Soybean yield loss was observed with 12.7 or 25.5 g a.i. ha\(^{-1}\) clethodim however, 51 g a.i. ha\(^{-1}\) clethodim showed minimal soybean yield loss. Glufosinate with a reduced rate of graminicide proved to be an option for excellent (>90%) to good (>80%<90%) control of glyphosate-resistant volunteer corn in soybeans.
However, to prevent yield loss, this option worked best when volunteer corn height was 46 cm or less. Densities of 12.9 soybean plants m$^{-2}$ or greater resulted in significant corn yield loss. Several herbicide options adequately controlled volunteer soybeans in corn, with better control when treatments were applied to V-2 soybeans compared with applications applied at the V3-V4 soybean stage. Results indicated that volunteer corn caused yield loss in corn. However, yield loss was minimal and grain from the volunteer corn may offset yield loss from the main crop. Glufosinate controlled volunteer glyphosate-resistant corn in glufosinate-resistant corn. Results also demonstrated that the timing of volunteer corn control in corn may be critical. Corn yield loss was minimized with glufosinate applications to volunteer corn that was 30 cm tall or less.
CHAPTER 1: VOLUNTEER CORN IN SOYBEANS

Introduction

Since 2000, a rotation of glyphosate-resistant corn followed by glyphosate-resistant soybean has been a common practice due to the weed control spectrum and inexpensive treatment costs. For example, from 2008 to 2012, 85% of the corn and 98% of the soybean crops in South Dakota has had some type of herbicide resistant trait (most often glyphosate) (South Dakota Agricultural Report 2013). This high percentage of rotational crops with similar herbicide resistance has perpetuated volunteer corn as a problematic weed in corn-soybean cropping rotations of the Midwestern United States. 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 its unattractiveness qualify volunteer corn as a weed (Young and Hart 1997; Andersen 1976). Volunteer corn has been proven to reduce soybean yields due to 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.

Volunteer corn is the F₂ generation plant that emerges from corn grain unharvested from the previous crop year. Individual plants, as well as clumps of multiple plants frequently sprouting from dropped ears, constitute volunteer corn populations. The possibility of volunteer corn infestations occurring can be affected by harvest efficiency, tillage, and pest infestations (Owen and Zelaya 2005). During harvest,
missed or dropped grain and efficiency of harvest machinery can contribute to possible
volunteer corn populations (Owen and Zelaya 2005). One study of corn harvest
inefficiencies found average harvest losses ranging from 53 to 127 kg ha\(^{-1}\) (0.79 to 1.89
bu a\(^{-1}\)) (Shauck et al. 2010). Assuming 3100 kernels/ kg and 100% germination, this
would be equivalent to a maximum of 16 to 39 plants m\(^{-2}\) of volunteer corn the following
season. Although overwintering may reduce surface kernel number due to animal
consumption, physical movement, germination or seed degradation (Buhler et al. 1997).
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 versus
conventional tillage when seeds are buried (Beckett and Stoller 1988; Owen and Zelaya
2005).

Other grass species have been proven to cause soybean yield loss. At giant foxtail
densities of 13.2-26.4 plants m\(^{-2}\), comparable to densities estimated for corn harvest
losses (Shauck et al. 2010), Harrison et al. (1985) detected a 26% soybean yield loss.
High densities of other grass weeds have been reported to result in even greater losses.
For example, Vail and Oliver (1993) observed a 50% soybean yield loss with 250
barnyardgrass (Echinochloa crus-galli) plants m\(^{-2}\). An 80% soybean yield loss was
reported with green foxtail (Setaria viridis) densities of 500-600 plants m\(^{-2}\) by Weaver
Significant early-season competition can result from glyphosate-resistant volunteer corn in soybeans. Deen et al. (2006) reported a 990-2000 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 removed at the two- to three-leaf stage compared to a weed-free treatment. These data indicate the need for control of volunteer corn early in the season. Generally when weeds that emerge with the crop are controlled within 4 to 6 weeks after emergence, soybean yield losses are minimized (Beckett and Stoller 1988; Zimdahl 2004). Another study specified the first trifoliate stage (V1) of soybeans to be the best stage for treatment of volunteer corn to avoid yield loss (Andersen 1976).

Before grass herbicides were available for use in soybeans, volunteer corn was controlled mechanically with cultivation. In addition, in years prior to the release of Roundup-Ready soybeans, glyphosate was applied using a rope-wick applicator or recirculating sprayer when the corn was taller than the soybeans (Beckett and Stoller 1988). Glyphosate effectively controlled conventional volunteer corn; however, this application often occurred after the V1 stage of soybean growth and often yield loss was still measurable. With the introduction of glyphosate-resistant corn in 1998, glyphosate no longer effectively controls glyphosate-resistant volunteer corn (Andersen et al. 1982; Deen et al. 2006). However, because glyphosate controlled the broadspectrum of broadleaf and grass weeds, and other graminicides were expensive, growers often overlooked volunteer corn as a major problem. Another option for controlling glyphosate-resistant volunteer corn has been to plant Liberty Link soybean (glufosinate-resistant) and apply glufosinate (Liberty) as a post-emergence treatment. This option has
had limited success, as over 95% of the soybean varieties planted in South Dakota continue to be glyphosate, rather than glufosinate, resistant (SD Agriculture 2013).

According to South Dakota Agriculture Surveys (2013) >90% of corn acreage was treated with glyphosate, therefore it can be assumed that a high percentage of volunteer corn is glyphosate resistant and producers need to consider herbicides other than glyphosate for control. However, the impact of volunteer corn must be quantified to provide the evidence to a producer that the increased herbicide cost will benefit soybean profitability due to increased yield. Many graminicides have been shown to effectively control volunteer corn in previous research. As grass herbicides were developed for soybeans, effective volunteer corn control was seen with 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). The drawback is that at current prices, the addition of these herbicides would increase herbicide cost two to three times compared to glyphosate alone (Johnson et al. 2015). In order to justify the additional cost, the benefit, efficacy, and guidelines for application timing to optimize volunteer corn control must be established.

The objectives of this study were to: 1) determine soybean yield loss due to volunteer corn competition at different densities, 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 soybeans. Each study was
conducted in two field seasons in eastern South Dakota in an area where about 500,000 ha of corn and soybean are planted annually.

**Materials and Methods**

**Volunteer Corn Competition in Soybeans**

Studies were conducted at the South Dakota State University, Brookings Agronomy Farm in 2007 and 2008 on a Barnes loam soil (Fine-loamy, mixed, superactive, frigid Calcic Hapludolls). Average volunteer corn densities (± 1 std dev) were established at 0, 0.2 (±0.06), 0.6 (±0.11), 1.5 (±0.25), and 3.5 (±0.53) plants m⁻² in 2007 and 0, 0.2 (±0.1), 0.9 (±0.12), 2.3 (±0.18), and 4.4 (±1.1) plants m⁻² in 2008. The treatments were established in a randomized complete block design with four replications. Plots were 4 rows wide (76-cm row width) and 15 m long. While total precipitation for each growing season was similar (about 34 cm), in 2007 about half (16 cm) of the precipitation occurred in August during or just after pollination, whereas, in 2008 about 14 cm occurred in June during the early to mid-vegetative stages.

The source of the volunteer corn seed was collected the year prior to each study from plots near Beresford, SD. Seed from Dekalb Roundup Ready DKC 58-73 (a 108 d relative maturity hybrid) was collected in 2006 after physiological maturity and manually spread on the soil surface on May 18, 2007. Corn seed was collected from Dekalb Roundup Ready DKC 51-45 (a 101 d relative maturity hybrid) after physiological maturity in 2007 and manually spread on the soil surface on May 21, 2008. Each year, the seed was stored in a dry location with a temperature of about 0 degrees C from harvest (October) until planting. The volunteer corn seed was incorporated about 4 cm
below the soil surface using a field cultivator each year. Roundup Ready Asgrow 1401 soybeans (relative maturity 1.4) were planted at a rate of 432,000 plants ha$^{-1}$ in 76 cm wide rows on May 18, 2007 and May 21, 2008. After volunteer corn emergence, manual counts were completed across each plot to quantify volunteer corn densities. The plots were kept weed-free both years with an application of Roundup Weathermax (glyphosate) at 870 g a.i. ha$^{-1}$ and ammonium sulfate at 2.8 kg ha$^{-1}$ (2.5 lb/A) applied on June 16, 2007 and on June 18, 2008. Treatments were applied with a bicycle sprayer using 187 L ha$^{-1}$ at 207 kPa and TeeJet 8003XR nozzles.

Ears of volunteer corn were manually harvested from the center 1.5 m of each 3 m wide plot on October 2, 2007 and October 22, 2008. After harvest volunteer corn grain was mechanically shelled, separated and weighed. The soybeans were harvested with a plot combine from the center 1.5 m of each 3 m wide plot on October 13, 2007 and October 22, 2008. Soybean yields were recorded and adjusted to 13% moisture.

**Partial Control of Volunteer Corn in Soybeans**

Studies were conducted at the South Dakota State University, Brookings Agronomy Farm in 2007 and 2008 on a Barnes loam soil. Volunteer corn was established at an average density of 1.5 plants m$^{-2}$ in 2007 and 2.2 plants m$^{-2}$ in 2008. The treatments were established in a randomized complete block design with four replications. Plots were 4 rows wide (76-cm row width) and 15 m long.

Volunteer corn seed was collected in the fall the year prior to each study from the same varieties as described above and seeded at the same dates as the competition study. The volunteer corn seed was incorporated about 4 cm below the soil surface using a field
cultivator each year. Asgrow 1401 soybeans (relative maturity 1.4) were planted at a rate of 432,000 plants h\(^{-1}\) on May 18, 2007 and May 21, 2008. After volunteer corn emergence, manual counts were completed to quantify volunteer corn density. The plots were kept weed-free both years with an application of Roundup Weathermax (glyphosate) at 870 g a.i. ha\(^{-1}\) on June 16, 2007 and June 18, 2008. Clethodim was applied at 12.7, 25.5, or 51 g a.i. ha\(^{-1}\) on June 28, 2007 and July 10, 2008 to result in volunteer corn control ranging from partial to complete (near 100\%). All treatments included crop oil concentrate at 0.5% v/v. At the time of application the soybeans were about 31 cm tall and 3-trifoliate in 2007 and about 36 cm tall and 4- to 5-trifoliate in 2008 and the volunteer corn was about 51 cm tall in 2007 and about 61 cm tall in 2008. Treatments were applied with a bicycle sprayer using 187 L ha\(^{-1}\) at 207 kPa and TeeJet 8003XR nozzles. Visual control ratings (0-100%) of volunteer corn were taken on September 27, 2007 and October 2, 2008. A 0 rating indicated no control whereas 100 indicated complete control. By this time in the season, 100% indicated no volunteer corn present.

Volunteer corn that remained in the plots was manually harvested and weighed from the center 1.5 m of each 3 m wide plot on October 2, 2007 and October 22, 2008. After harvest volunteer corn grain was mechanically separated and weighed. The removal of volunteer corn was done to help combine efficiency for soybean. The soybeans were harvested with a plot combine from the center 1.5 m of each 3 m wide plot on October 13, 2007 and October 22, 2008. Soybean yields were adjusted to 13% moisture.
Volunteer Corn Control with Glufosinate

Studies were conducted at the South Dakota State University, Brookings Agronomy Farm on a Barnes loam soil in 2009 and 2010. Treatments were established in a randomized complete block design with 3 replications in 2009 and 4 replications in 2010. Plots were 4 rows wide (76-cm row width) and 15 m long. Total precipitation for the growing season was about 37 cm for 2009 and about 65 cm for 2010. The majority (18 cm) of the precipitation in 2009 occurred in June and July. Precipitation for 2010 was nearly twice that of 2009 with June and September receiving the majority of the precipitation.

Mustang Liberty Link SO 80137 LL soybeans (relative maturity 1.0) were planted on May 11, 2009 and Croplan Liberty Link LT 1098 soybeans (relative maturity 1.0) were planted on May 28, 2010 at 420,000 plants ha\(^{-1}\). Volunteer corn seed was manually spread on the soil surface on the same day as soybean planting. The volunteer corn seed was incorporated about 4 cm below the soil surface using a field cultivator each year. The source of the volunteer corn seed was collected the year prior to each study from plots near Beresford, SD. Seed from Roundup Ready Dekalb 58-16 (a 108 d relative maturity hybrid) was used in 2009 and Roundup Ready Dekalb 52-59 (a 102 d relative maturity hybrid) was used in 2010. Average volunteer corn density was 4.3 plants m\(^{-2}\) in 2009 and 3.9 plants m\(^{-2}\) in 2010.

Herbicide treatments included glufosinate at a labelled rate alone or in combination with either quizalofop or clethodim. Quizalofop and clethodim rates were: 1) equivalent to the low end of the recommended rate range for each product and 2) half
those rates. Rates less than recommended were included to determine if partial rates were sufficient when mixed with a recommended rate of glufosinate to control glufosinate-susceptible corn. An untreated check was also included for comparison. Herbicide treatments and additives used are listed in Table 1-1. Treatments were applied at two timings each year. In 2009 a single application was applied to either the 15 cm or 30-46 cm tall volunteer corn on June 16 or June 25. Soybeans were 1 trifoliate (V1) or 4 trifoliate (V4) at time of application in 2009. In 2010 the application was applied to either the 20-36 cm or 61-91 cm volunteer corn on June 18 or July 6. Soybeans were 3 trifoliate (V3) or flowering (R1/R2) at time of application in 2010. In 2009, treatments were applied with a bicycle sprayer using 187 L ha$^{-1}$ at 207 kPa and TeeJet 8003XR nozzles. In 2010, treatments were applied with a backpack sprayer using 187 L ha$^{-1}$ at 207 kPa and TeeJet 8003XR nozzles.

Control of volunteer corn was visually rated on a scale of 0 (no control) to 100 (complete control) on July 9 and September 30, 2009 and July 27 and September 16, 2010. Soybeans were harvested with a plot combine from the center 1.5 m of each 3 m wide plot on October 21, 2009 and October 6, 2010. Soybean yield was recorded and adjusted to 13% moisture.

**Statistical Analysis**

Corn density was used as an independent variable and soybean yield was used as the dependent variable. An F-test determined yield loss in the competition study was not statistically different between years; therefore, data was pooled between the years. Corn density data versus soybean yield was fit to the hyperbolic yield equation (Cousens
YL = \frac{(I \cdot D)}{(1 + (I \cdot D)/A)}\) using iterative methods in the “Solver” add-on in Microsoft Excel (2013). YL is % yield loss, D is the density, I is a variable that describes incremental yield loss at low densities and A is the estimated maximum yield loss. A 100% yield loss threshold was used for the A parameter, as soybean yield would be 0.

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 using ARM (2015). The random effect in each study was year, whereas the fixed effects were corn density in study 1, clethodim rate in study 2, and herbicide treatment, application timing, and graminicide rate in study 3.

**Results and Discussion**

**Volunteer Corn Competition in Soybeans**

Although rainfall and planting date were similar between years, yield potential was greater in 2007. Growing degree days (base 10°C) were about 10% above normal all year, whereas in 2008 GDD were similar to normal (data not shown). Soybean yields in the weed-free treatment were 3138 kg ha\(^{-1}\) (46.7 bu a\(^{-1}\)) and 2231 kg ha\(^{-1}\) (33.2 bu a\(^{-1}\)) in 2007 and 2008, respectively. The difference in yield may be due to the slightly warmer temperatures in 2007.

Soybean yields were greatly reduced by the presence of volunteer corn and suggests that volunteer corn can be highly competitive with soybeans. Soybean yield loss was consistent between the two years and ranged from 0-54% in 2007 and 0-58% in 2008 when compared to a treatment with no volunteer corn, with average volunteer corn densities of 0-3.5 and 0-4.4 plants m\(^{-2}\), respectively. As volunteer corn density increased,
soybean yield decreased. The $I$ value (incremental yield loss) was calculated to be 29.9
(A value set to 100) (Figure 1-1). The $R^2$ value for the equation was 0.89, a high value,
which indicates that 89% of the soybean yield loss variability was explained by volunteer
corn density in the equation.

Average yield of the volunteer corn plants ranged from 254 to 2214 kg ha$^{-1}$ in
2007 with densities from 0.2 to 3.5 plants m$^{-2}$ and from 428 to 5662 kg ha$^{-1}$ in 2008 with
densities from 0.2 to 4.4 plants m$^{-2}$. Corn yield was 0.12 kg per plant for 0.2 plants m$^{-2}$
and 0.06 kg per volunteer corn plant when volunteer corn density was 3.5 plants m$^{-2}$ in
2007. In 2008, individual plant yields were 0.21 kg per plant for the 0.2 plants m$^{-2}$
density and 0.13 kg per plant for the 4.4 plants m$^{-2}$ density. While these seeds are another
generation ($F_3$) removed from the original cross, the seed from these volunteer corn
plants are potential volunteer corn plants the following season if they are not controlled.
It is unclear however if these plants would be as detrimental to soybean growth and yield
due to the expected decrease in vigor obtained in the original generation.

Volunteer corn in this study, which was planted to obtain single plants, was more
competitive compared to two studies that quantified soybean yield loss using clumps of
volunteer corn. Results of this study estimated that each 0.034 plants m$^{-2}$ resulted in an
average of 1% yield loss. This loss is about 6 times more than either Andersen et al.
(1982) who reported that each 0.185 plants m$^{-2}$, and Beckett and Stoller (1988) who
reported that each 0.22 plants m$^{-2}$ caused an average 1% soybean yield loss. Andersen et
al. (1982) and Beckett and Stoller (1988) reported on yield loss when clumps of 10
volunteer corn plants were present compared to single volunteer corn plants in this study.
Soybean yield loss may have been less with clumps versus single plants at similar densities due to intraspecific competition between the volunteer corn plants.

Yield of the volunteer corn plants in the Andersen et al. (1982) study ranged from 130-2210 kg ha$^{-1}$ at a density of 4 plants m$^{-2}$ using clumps of volunteer corn. This was considerably lower than the 5662 kg ha$^{-1}$ yield of our volunteer corn at the 4.4 plants m$^{-2}$ density in 2008. This supports the theory that intraspecific competition plays a role in soybean yield loss due to volunteer corn in clumps versus single plants.

Another study using narrow row (19 cm row spacing) soybeans reported a 10% decrease in soybean yield with a volunteer corn density of 0.5 plants m$^{-2}$ and a 41% yield loss with a density of 16 plants m$^{-2}$ (Marquardt et al. 2012). Our study used 76 cm row spacing soybeans and showed similar yield loss results to the lower density with a 9.6% soybean yield loss observed at a volunteer corn density of 0.6 plants m$^{-2}$ (Figure 1-2). The estimated yield loss at this density (0.6 plants m$^{-2}$) would be about 15%. Although we did not obtain densities as high as 16 plants m$^{-2}$ we observed a 58% yield loss at an average density of 4.4 plants m$^{-2}$. Soybean yield loss may plateau at higher volunteer corn densities due to increased intraspecific competition among volunteer corn plants.

Volunteer corn in this study proved to be more competitive than some other grasses in soybeans. A study looking at giant foxtail ($Setaria faberi$) interference in soybeans found 13.2-26.4 plants m$^{-2}$ resulted in 26% soybean yield loss (Harrison et al. 1985). Their study was researching giant foxtail clumps that ranged from 3-6 plants per clump. We saw similar soybean yield loss with volunteer corn densities of 1-2 plants m$^{-2}$. Vail and Oliver (1993) found barnyardgrass interference to cause 0-78% soybean yield
loss with densities of 0-500 plants per m$^2$. Barnyardgrass densities of 42, 110, and 250 plants m$^2$ caused 10, 25, and 50% soybean yield loss (Vail and Oliver 1993). We observed 10% soybean yield loss with less than 1 volunteer corn plant m$^-2$ and we observed a 50% yield loss with about 3 plants m$^-2$. Compared to Vail and Oliver’s (1993) research, volunteer corn in our study was about 42-83% more competitive than barnyardgrass. Researching green foxtail in soybeans, Weaver (2001) found $I=0.7$ and the maximum soybean yield loss was 80% at densities ranging from 500-600 plants m$^2$. A maximum soybean yield loss of 58% was observed with 5-6 volunteer corn plants m$^-2$. Our yield loss was comparable to these studies at much lower volunteer corn densities than the densities of the grasses researched in the previous studies suggesting that volunteer corn is considerably more competitive than many other grass species in soybeans. One reason that volunteer corn may be so much more competitive than other grass weeds is that volunteer corn is a much larger plant compared to other grass weeds. Volunteer corn is able to grow taller than the soybeans shading out the soybeans.

Soybean yield loss due to volunteer corn was comparable to yield loss due to another grass species. Fellows and Roeth (1992) revealed shattercane (Sorghum bicolor) densities of 0.6 plants m$^-2$ resulted in soybean yield loss of 10-29% over three years. Our study resulted in similar yield loss with volunteer corn densities of about 1 plants m$^-2$. Shattercane resembles corn and grain sorghum, which explains why yield loss may be similar for these two species.

The yield loss results that we obtained in our study are comparable to yield loss associated with some broadleaf weeds. For example, previously it has been found that a
common cocklebur density of 4.6 plants m\(^{-2}\) resulted in a 50% soybean yield loss (Barrentine 1974), comparatively our study indicated a 58% yield loss with a volunteer corn density of 4.4 plants m\(^{-2}\).

A study completed in Kansas showed a soybean yield loss of 79, 56, and 38% for Palmer amaranth (*Amaranthus palmeri*), common waterhemp (*Amaranthus rudis*), and redroot pigweed (*Amaranthus retroflexus*), respectively, at a weed density of 10.5 plants m\(^{-2}\) (Bensch et al. 2003). At our highest average density of 4.4 plants m\(^{-2}\) we observed a yield loss of 58%. This suggests that volunteer corn in soybeans may be more competitive than these Amaranth species because yield loss was close to or equivalent at a volunteer corn density that was less than half the density of these weeds.

**Partial Control of Volunteer Corn in Soybeans**

Even partially controlled volunteer corn resulted in soybean yield loss when compared to a treatment with no volunteer corn, although losses were less than nontreated. Clethodim rates of 12.7, 25.5, and 51 g a.i. ha\(^{-1}\) applied at the 3-trifoliate growth stage resulted in 16, 77, and 98% control of volunteer corn in 2007, respectively, whereas the same rates applied at the 4-5-trifoliate growth stage resulted in 12, 54, and 91% control in 2008, respectively (Table 1-2). Yield loss associated with these control ratings was 21, 14, and 5% in 2007 and 14, 18, and 5% in 2008, respectively (Table 1-2). All treatments resulted in greater soybean yield than the treatment with no control of volunteer corn. A treatment containing the same volunteer corn density each year and no herbicide treatment resulted in a 31% yield loss in 2007 with 1.5 plants m\(^{-2}\) and a 36%...
yield loss in 2008 with 2.2 plants m$^{-2}$. The results at these two densities fit with the yield loss equation in the density study.

Even partial control of volunteer corn resulted in a yield increase compared to a treatment with the same density of volunteer corn that was not sprayed with clethodim. At the 12.7 g a.i. ha$^{-1}$ clethodim rate soybean yields increased by 13% in 2007 and 27% in 2008. At the 25.5 g a.i. ha$^{-1}$ clethodim rate soybean yields increased by 24% in 2007 and 4% in 2008. At the 51 g a.i. ha$^{-1}$ clethodim rate soybean yields increased by 30% in 2007 and 36% in 2008. Even though soybean yield did increase if the volunteer corn was partially controlled compared to the no control treatment, the need for complete control of volunteer corn is supported by the data that show significant yield losses from these partially controlled plants.

In 2007 the yield of the weed free plot was 3138 kg ha$^{-1}$. With a volunteer corn density of 1.5 plants m$^{-2}$ the yield was reduced 31% or about 973 kg ha$^{-1}$ in a treatment with no volunteer corn control. With a soybean price of $0.37/kg ($10/bu) this would be a loss of about $360 per hectare ($145 per acre) with no control. In 2007, with the low, medium and high clethodim rates we used there would be a soybean income loss of about $244, 163, 58 per hectare ($98, 65, and 23 per acre), respectively. This is a difference of $116, 197, 302 per hectare ($47, 80, and 122 per acre) compared with no control. With the cost of the clethodim treatments being an additional $1.30, 2.60, and 5.20 per acre for chemical, any of the applications would be justified, unless application costs (equipment/operator/etc.) per acre are very expensive.
In 2008 the yield of the weed free plot was 2231 kg ha\(^{-1}\). With a volunteer corn density of 2.2 plants m\(^{-2}\) the yield was reduced 36% or about 803 kg ha\(^{-1}\) in a treatment with no volunteer corn control. With a soybean price of $0.37/kg ($10/bu) this would be a loss of about $297 per hectare ($120 per acre) with no control. In 2008, with the low, medium and high clethodim rates we used there would be a loss of soybean income of about $116, 149, 41 per hectare ($46, 60, and 17 per acre), respectively. This is a difference of $181, 148, 256 per hectare ($74, 60, and 103 per acre) compared with no control. The cost of chemical treatment would have been justified in this year as well.

These results differ from a study that found no differences in soybean yields with rates of 30 or 60 g a.i. ha\(^{-1}\) of clethodim tank-mixed with glyphosate at 0.9 kg ae ha\(^{-1}\) as long as a surfactant (0.5% v/v) was included (Deen et al. 2006). Their treatments were applied at the 5-7 leaf stage of volunteer corn. Our study was applied at about the same volunteer corn size and included the same rate of glyphosate. At similar rates, we did see a difference in yield loss from the 25.5 to 51 g a.i. ha\(^{-1}\) clethodim rate. The 25.5 g a.i. ha\(^{-1}\) rate resulted in 14-18% yield loss and the 51 g a.i. ha\(^{-1}\) rate resulted in only 5% yield loss. The same study (Deen et al. 2006) did see a reduction in yield during one year of each location with the low rate (30 g a.i. ha\(^{-1}\)) of clethodim when the surfactant was not included from 3.6-4.5 t/ha with surfactant to 2.5-4.0 t/ha without surfactant. Volunteer corn control without the surfactant was 0-48% and control with the surfactant was 71-99%.

The control of volunteer corn in our study was not consistent with another study that examined similar rates of clethodim (Currie et al. 2007). Their study reported that
6.8 and 13.6 g a.i. ha\(^{-1}\) of clethodim controlled 100% of the volunteer glyphosate-resistant corn at the 2-leaf and 3-leaf stages, respectively (Currie et al. 2007). The low rate was 50% lower than our lowest rate applied. In our study with 12.7 g a.i. ha\(^{-1}\) of clethodim the volunteer corn control was 16 and 12% in 2007 and 2008, respectively, at the V5-V7 growth stage. As corn grew, greater rates of clethodim were needed to provide complete control. Another part of the same study found 27.2 g a.i. ha\(^{-1}\) of clethodim provided 100% control of 3-leaf or 6-leaf volunteer corn (Currie et al. 2007). This rate was about equal to our mid-rate of 25.5 g a.i. ha\(^{-1}\) clethodim rate which gave 77 and 54% control of V5-V7 volunteer corn in 2007 and 2008. Volunteer corn density was not stated in the Currie et al. study (2007). Our results showed a higher clethodim rate (51 g a.i. ha\(^{-1}\)) resulted in the highest control (91-98%). Volunteer corn stage at time of application may be one explanation for the difference in control. The volunteer corn in our study was larger (V5-V7) than the V3-V6 stages that Currie et al. (2007) reported at the time of clethodim application.

A study by Marquardt and Johnson (2013) resulted in no difference in volunteer corn control (92-99%) or soybean yield when clethodim (79 g a.i. ha\(^{-1}\)) and glyphosate (840 g a.e. ha\(^{-1}\)) were applied to ≤ 30 cm or ≈ 90 cm volunteer corn at densities ranging from 0.5-16 plants m\(^{-2}\). This rate was 1.5X of our highest rate of clethodim. We did see a 5% yield loss at our high rate (51 g a.i. ha\(^{-1}\)) with similar (91-98%) control. The soybeans in this study (Marquardt and Johnson 2013) were drilled (19 cm rows) compared to our 76 cm rows which could account for the difference in soybean yield.
loss. Greater soybean yield loss due to weed competition was observed by Hock et al. (2006) in 76-cm rows versus 19-cm soybean rows.

**Volunteer Corn Control with Glufosinate**

Glufosinate plus a graminicide at a reduced rate may be an option for control of volunteer glyphosate-resistant corn in glufosinate-resistant (Liberty Link) soybean. Glufosinate alone provided greater control at the later timing both years; 30-46 cm or 61-91 cm volunteer corn in 2009 or 2010, respectively. (Table 1-3) Poor glufosinate control (33%) at the earliest corn growth stage (15 cm) in 2009 can be explained by a combination of factors including 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 glufosinate does not translocate from treated leaves (<1 to 15% of applied) (Steckel et al. 1997).

Including a graminicide with glufosinate improved volunteer corn control at both the early and late timings. When applied early in the season; glufosinate provided 33-73% volunteer corn control, whereas glufosinate with quizalofop or clethodim at that same time provided 90-100% control. When applied later in the season; 79-83% control was observed with glufosinate, but with the addition of quizalofop or clethodim control was 84-96%. This is contrary to a study that reported antagonism when clethodim and glufosinate were applied together to goosegrass versus clethodim applied alone (Burke et al. 2005). In 2009, there was no difference in volunteer corn control between graminicide rates at the early postemergence timing. The same year at the late postemergence timing, the higher rate of clethodim with glufosinate resulted in greater
volunteer corn control than the treatment with glufosinate plus the lower rate of clethodim. In 2010, the higher rate of quizalofop with glufosinate provided greater control of volunteer corn than the lower rate of quizalofop with glufosinate at the early postemergence timing. There were no differences in control between graminicide rates at the late postemergence timing in 2010. The size of the volunteer corn at the late postemergence timing in 2009 (30-46 cm) was close to the same as the early postemergence timing in 2010 (20-36 cm). These data imply that plant size may be critical to volunteer corn control with a reduced rate of graminicide. In addition, since glufosinate is generally most effective on broadleaf weeds when applied early postemergence, a graminicide may be needed to achieve complete volunteer corn control at this time.

The soybean yield in all herbicide treatments was greater than the untreated check in both years. In 2009, there was no difference in yield among any of the herbicide treatments at either timing. (Table 1-4) In 2010, there were differences among herbicide treatments. Of the treatments that included a graminicide in 2010, yield of the early postemergence treatments tended to be greater than the late postemergence treatments and of the early postemergence treatments the high rates of graminicide showed the highest yields. Of the treatments with a graminicide at the early postemergence timing, only the yield of the treatments with the high rate (38.6 g a.i. ha⁻¹) of quizalofop was greater than glufosinate alone. At the late postemergence timing, yield for all herbicide treatments were similar and much less compared to the early treatment. Our volunteer corn heights were 15 cm and 30-46 cm in 2009 and 20-36 cm and 61-91 cm in 2010.
This indicates the need to control volunteer corn earlier to prevent yield loss. Control at the 61-91 cm timing was between 93-96% with the graminicides, however there was still up to 15% yield loss compared with the earlier application indicating that timing may be of more importance than rate of graminicide.

In 2010 the yield of the glufosinate treatment at the early postemergence (20-36 inch volunteer corn) timing was 3031 kg ha$^{-1}$. With a soybean price of $0.37/kg ($10/bu) this would be an income of $1121 per hectare ($454 per acre). The high rate (38.6 g ai ha$^{-1}$) of quizalofop plus glufosinate at the same timing showed a 15% yield increase (3541 kg ha$^{-1}$) compared to glufosinate alone. This would be an income of $1310 per hectare ($530 per acre) with the addition of quizalofop. This is a difference of $189 per hectare ($76 per acre) compared to glufosinate alone. With the cost of quizalofop at this rate being an additional $9.90 per hectare ($4 per acre) the addition of the graminicide to glufosinate would be justified.

Results indicated that volunteer corn can cause substantial yield loss in soybean. With yield loss values as great as or greater than other weeds typically found in soybeans, volunteer corn proved to be a highly competitive weed in soybean. Reduced rates of clethodim resulted in partial control of volunteer corn, however, reduced rates had greater yield losses compared with the highest clethodim rate applied in this study. For the size of volunteer corn we were treating (51-61 cm) in this study the recommended labelled clethodim rate is 76.4 g a.i. ha$^{-1}$. The rates that we used were 1/6, 1/3, and 2/3 of this rate. The increase in yield and income from the clethodim treatments, compared to the treatment with no volunteer corn control, offset the cost of the additional herbicide.
Glufosinate with a reduced rate of graminicide proved to be an option for excellent (>90%) to good (>80%<90%) control of glyphosate-resistant volunteer corn in glufosinate-resistant soybean. All glufosinate treatments with a graminicide provided greater control than glufosinate alone. However, to prevent yield loss, this option worked best when volunteer corn height was 46 cm or less.
Figure 1-1. Yield loss curve for soybean yield loss as affected by volunteer corn density in 2007 and 2008 at Brookings, SD. These data were analyzed using the hyperbolic model equation: \( YL = \frac{I \times D}{1 + \frac{I \times D}{A}} \). YL is % yield loss, D is the density, I is a variable that describes incremental yield loss at low densities and A is the estimated maximum yield loss within the density values used, a 100% threshold was used for the A parameter, as soybean yield would be 0. The I value was 29.9, the A value was 100, with an \( R^2 = 0.89 \).
Figure 1-2. Plot containing a volunteer corn density of 0.6 plants m\(^{-2}\) in 2007. The observed yield loss at this density was about 10% and the predicted yield loss is about 15%.
Table 1-1. Details of herbicides and rates used for volunteer glyphosate-resistant corn control in glufosinate-resistant soybeans. The quizalofop and clethodim treatments included crop oil concentrate (COC) at a 1% v/v rate. All treatments included 1 kg ha\(^{-1}\) of ammonium sulfate (AMS).

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>trade name</th>
<th>Rate</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glufosinate</td>
<td>Liberty</td>
<td>450</td>
<td>Bayer Crop Science, Monheim, Germany; <a href="http://www.bayer.com">www.bayer.com</a></td>
</tr>
<tr>
<td>Glufosinate + quizalofop</td>
<td>Liberty + Assure II</td>
<td>450 + 38.6</td>
<td>Bayer Crop Science + E.I. du Pont de Nemours and Company, Wilmington, DE; <a href="http://www.dupont.com">www.dupont.com</a></td>
</tr>
<tr>
<td>Glufosinate + quizalofop</td>
<td>Liberty + Assure II</td>
<td>450 + 19.3</td>
<td>Bayer Crop Science + E.I. du Pont de Nemours and Company</td>
</tr>
<tr>
<td>Glufosinate + clethodim</td>
<td>Liberty + Select</td>
<td>450 + 105</td>
<td>Bayer Crop Science + Valent U.S.A. Corporation, Walnut Creek, CA; <a href="http://www.valent.com">www.valent.com</a></td>
</tr>
<tr>
<td>Glufosinate + clethodim</td>
<td>Liberty + Select</td>
<td>450 + 52.6</td>
<td>Bayer Crop Science + Valent U.S.A. Corporation</td>
</tr>
</tbody>
</table>
Table 1-2. Volunteer corn control and soybean yield loss due to partial volunteer corn control with three clethodim rates. Clethodim applied when volunteer corn was 51 cm (2007) or 61 cm (2008) and soybeans were 31 cm and 3-trifoliate (2007) or 36 cm and 4-5-trifoliate (2008). Visual estimate of volunteer corn control. 0 = no control and 100 = complete control. Control ratings taken 13 weeks after application in 2007 and 12 weeks after application in 2008a. Soybean yield in the weed-free treatment was 3138 kg ha\(^{-1}\) in 2007 and 2231 kg ha\(^{-1}\) in 2008a.

<table>
<thead>
<tr>
<th>Clethodim rate g a.i. ha(^{-1})</th>
<th>2007 Volunteer corn control</th>
<th>Soybean yield loss %</th>
<th>2008 Volunteer corn control</th>
<th>Soybean yield loss %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated check</td>
<td>--</td>
<td>0 c</td>
<td>--</td>
<td>0 a</td>
</tr>
<tr>
<td>12.7</td>
<td>16 c</td>
<td>21 a</td>
<td>12 c</td>
<td>14 a</td>
</tr>
<tr>
<td>25.5</td>
<td>77 b</td>
<td>14 ab</td>
<td>54 b</td>
<td>18 a</td>
</tr>
<tr>
<td>51</td>
<td>98 a</td>
<td>5 bc</td>
<td>91 a</td>
<td>5 a</td>
</tr>
</tbody>
</table>

a Means presented within each year with no common letter(s) are significantly different according to Fisher’s protected LSD test where \(P \leq 0.05\).
Table 1-3. Efficacy of herbicides for volunteer glyphosate-resistant corn control in soybean. Visual observations for % control where 0 is no control and 100 is complete control. An untreated control was rated at 0 each year. Control observations were taken July 9 and September 30, 2009 and July 27 and September, 16, 2010 with the later observations presented for each year.a

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate</th>
<th>2009 earlyb</th>
<th>2009 latec</th>
<th>2010 earlyb</th>
<th>2010 latec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glufosinate</td>
<td>450</td>
<td>33 e</td>
<td>79 d</td>
<td>73 f</td>
<td>83 e</td>
</tr>
<tr>
<td>Glufosinate + quizalofop</td>
<td>450 + 38.6</td>
<td>96 ab</td>
<td>86 d</td>
<td>100 a</td>
<td>94 bcd</td>
</tr>
<tr>
<td>Glufosinate + quizalofop</td>
<td>450 + 19.3</td>
<td>97 ab</td>
<td>84 c</td>
<td>90 d</td>
<td>93 cd</td>
</tr>
<tr>
<td>Glufosinate + clethodim</td>
<td>450 + 105</td>
<td>99 a</td>
<td>92 b</td>
<td>95 bc</td>
<td>96 abc</td>
</tr>
<tr>
<td>Glufosinate + clethodim</td>
<td>450 + 52.6</td>
<td>99 a</td>
<td>87 c</td>
<td>98 ab</td>
<td>95 bc</td>
</tr>
</tbody>
</table>

a Means presented within each year with no common letter(s) are significantly different according to Fisher’s protected LSD test where $P \leq 0.05$.

b Early treatments occurred when volunteer corn was 15 cm tall (June 16) in 2009 and 20-36 cm tall (June 18) in 2010.

c Late treatments of volunteer corn occurred when volunteer corn was 30 to 46 cm tall (June 25) in 2009 and 61 to 91 cm tall (July 6) in 2010.
Table 1-4. Soybean yield of treatments that were used to control volunteer glyphosate-resistant corn in glufosinate-resistant soybean.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Rate</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g ai ha\textsuperscript{-1}</td>
<td>early\textsuperscript{b}</td>
<td>late\textsuperscript{c}</td>
</tr>
<tr>
<td>Glufosinate</td>
<td>450</td>
<td>2604 a</td>
<td>2576 a</td>
</tr>
<tr>
<td>Glufosinate + quizalofop</td>
<td>450 + 38.6</td>
<td>2653 a</td>
<td>2618 a</td>
</tr>
<tr>
<td>Glufosinate + quizalofop</td>
<td>450 + 19.3</td>
<td>2562 a</td>
<td>2452 a</td>
</tr>
<tr>
<td>Glufosinate + clethodim</td>
<td>450 + 105</td>
<td>2673 a</td>
<td>2653 a</td>
</tr>
<tr>
<td>Glufosinate + clethodim</td>
<td>450 + 52.6</td>
<td>2846 a</td>
<td>2729 a</td>
</tr>
<tr>
<td>Untreated check</td>
<td></td>
<td>907 b</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{a} Means presented within each year with no common letter(s) are significantly different according to Fisher’s protected LSD test where P \textless 0.05.

\textsuperscript{b} Early treatments occurred when volunteer corn was 15 cm tall (June 16) in 2009 and 20-36 cm tall (June 18) in 2010.

\textsuperscript{c} Late treatments of volunteer corn occurred when volunteer corn was 30 to 46 cm tall (June 25) in 2009 and 61 to 91 cm tall (July 6) in 2010.
CHAPTER 2: VOLUNTEER CORN IN CORN

Introduction

Increased ethanol production has led to more corn-corn rotations. The habitual use of glyphosate-resistant crops and the application of only glyphosate as an herbicide option permit glyphosate-resistant volunteers to grow and compete (Thomas et al. 2007). Volunteer corn has been proven to reduce soybean yields due to competition (Andersen et al. 1982; Beckett and Stoller 1988) however; little research has been conducted to examine if corn yields are reduced due to volunteer corn competition. Volunteer corn in corn can be a challenge to control with the continuous use of glyphosate and Roundup Ready crops. Herbicides other than glyphosate will need to be considered for the control of volunteer Roundup Ready corn in corn.

Volunteer corn can compete with corn similar to other weeds; however, it is not known the density of volunteer corn required to cause a significant corn yield loss. The density of volunteer corn in corn fields can be quite diverse. In a previous study, volunteer corn densities have been found ranging from less than 30 plants ha\(^{-1}\) to more than 8000 plants ha\(^{-1}\) (Palaudelmàs et al. 2009). These densities are equivalent to 0.003 to 0.8 plants m\(^{-2}\). Additionally, it is not known if volunteer corn can contribute grain to the yield or if the need to control volunteer corn in corn is justified. The same study mentioned previously observed volunteer corn plants to be less vigorous than the corn crop and volunteer plants typically failed to produce a cob or produced cobs without grain (Palaudelmàs et al. 2009).
Corn yield loss due to competition with other grass weeds has been proven. Giant foxtail has been shown to cause a maximum yield loss of 30% or 61% yield loss over two different years in nonirrigated corn (Fausey et al. 1997). Deines et al. (2004) reported an $I$ value of 10.2 and a predicted maximum yield loss ($A$ value) of 32.1 for shattercane in corn. It is important to determine if volunteer corn in corn will cause similar yield loss results as other grass weeds in corn. If yield loss due to volunteer corn is significant, economical control options will need to be suggested.

One option to aide in controlling volunteer corn in corn would be to rotate between glyphosate-resistant and glufosinate-resistant corn varieties allowing more herbicide options. The results of a study by Corbett et al. (2004) demonstrated that glufosinate at either 291 or 409 g a.i. ha$^{-1}$ provided 100 percent control of volunteer glyphosate-resistant corn at 8-10 cm tall in fallow. In addition, crop rotation, with the use of different mode of action products, can be a strategic tool in some cropping systems.

The objectives of this study were to: 1) define the competitive ability of volunteer corn in corn by determining corn yield loss due to volunteer corn at different densities and 2) determine optimum application timing of glufosinate as an option for control of volunteer glyphosate-resistant corn in glufosinate-resistant corn. Each study was conducted during two field seasons in eastern South Dakota.

**Materials and Methods**

**Volunteer Corn Competition in Corn**

Studies were conducted at the South Dakota State University, Brookings Agronomy Farm in 2007 and 2008 on a Barnes loam soil (Fine-loamy, mixed,
superactive, frigid Calcic Hapludolls). Average volunteer corn densities (± 1 std dev) were established at 0, 0.2 (±0.17), 0.8 (±0.1), 1.2 (±0.28), 1.9 (±0.39), 2.5 (±0.29), 2.7 (±0.11), and 3.5 (±0.58) plants m⁻² in 2007 and 0, 1.3 (±0.28), 2.3 (±0.35), 3.4 (±0.3), 4.5 (±0.63), 5.3 (±0.51), 8.0 (±0.6), and 8.5 (±1.1) plants m⁻² in 2008. A treatment of volunteer corn planted in rows at the same density as the hybrid corn depending on the year was also included. The treatments were established in a randomized complete block design with four replications. Plots were 4 rows wide (76-cm row width) and 15 m long. While total precipitation for each growing season was similar (about 39 cm in 2007 and about 36 cm in 2008), in 2007 about half (16 cm) of the precipitation occurred in August during or just after pollination, whereas, in 2008 about 14 cm occurred in June during the early to mid-vegetative stages.

Both the 2007 and 2008 sites were planted to soybeans the year prior to the experiment. The 2007 site was fertilized with 100-30-0 NPK and the 2008 site was fertilized with 120-30-30 NPK. The source of the volunteer corn seed was collected the year prior to each study from plots near Beresford, SD. Seed from Dekalb Roundup Ready DKC 58-73 (a 108 d relative maturity hybrid) was collected in 2006 after physiological maturity and manually spread on the soil surface on May 14, 2007. Corn seed was collected from Dekalb Roundup Ready DKC 51-45 (a 101 d relative maturity hybrid) after physiological maturity in 2007 and manually spread on the soil surface on May 16, 2008. The volunteer corn seed was incorporated about 4 cm below the soil surface using a field cultivator each year. Roundup Ready Dekalb DKC 46-60 VT3 (a 96 d relative maturity hybrid) corn was planted at a rate of 74,000 plants h⁻¹ on May 14,
2007 and at a rate of 79,000 plants h\(^{-1}\) on May 16, 2008. After volunteer corn emergence, manual counts were completed across each plot to quantify volunteer corn densities. The plots were kept weed-free with an application of Harness (acetochlor) at 3920 g a.i. ha\(^{-1}\) and Roundup Weathermax (glyphosate) at 870 g a.e. ha\(^{-1}\) in 2007 and Harness Xtra (acetochlor + atrazine) at 2415 + 955 g a.i. ha\(^{-1}\) in 2008.

Volunteer corn was manually harvested from the center 1.5 m of each 3 m wide plot and weighed and the planted corn was harvested with a plot combine from the same area on November 10, 2007. After harvest volunteer corn grain was mechanically shelled, separated and weighed. Due to lodging, volunteer corn and planted corn were harvested at the same time in 2008 with a plot combine from the center 1.5 m of each 3 m wide plot on November 5, 2008. Corn grain yield was recorded and adjusted to 15.5% moisture.

**Control of Volunteer Corn in Corn with Glufosinate**

Studies were conducted at the South Dakota State University, Brookings Agronomy Farm on Barnes loam soil (Fine-loamy, mixed, superactive, frigid Calcic Hapludolls) in 2007 and 2008. Volunteer corn was established at an average density of 3.5 plants m\(^{-2}\) in 2007 and 7 plants m\(^{-2}\) in 2008. The treatments were established in a randomized complete block design with four replications. Plots were 4 rows wide (76-cm row width) and 15 m long.

Volunteer corn seed was collected in the fall the year prior to each study from the same varieties as described above and seeded on May 14, 2007 and on May 22, 2008. The volunteer corn seed was incorporated about 4 cm below the soil surface using a field
cultivator each year. Pioneer 38H72 RR/LL (a 98 d relative maturity hybrid) corn was planted at a rate of 74,000 plants h\(^{-1}\) on May 14, 2007 and Pioneer 37Y14 HXX LL RR2 (a 97 d relative maturity hybrid) corn was planted at a rate of 79,000 plants h\(^{-1}\) on May 22, 2008. After volunteer corn emergence, manual counts were completed across each plot to quantify volunteer corn densities. The plots were kept weed-free both years with an application of Harness Xtra (acetochlor + atrazine) at 2534 + 1002 g a.i. ha\(^{-1}\) applied preemergence at planting. Liberty (glufosinate) was applied at 482 g a.i. ha\(^{-1}\) when volunteer corn was approximately 13, 18, 28, or 46 cm tall in 2007 and 15, 30, 61, or 91 cm tall in 2008. All treatments were applied using 187 L ha\(^{-1}\) at 207 kPa and TeeJet 8003XR nozzles. Treatments were applied with a bicycle sprayer for the earlier two applications each year and with a backpack sprayer for the later two applications each year. The later timings were sprayed with a backpack sprayer to avoid breakage of the taller corn.

Control of volunteer corn was visually rated on a scale of 0 (no control) to 100% (complete control) on July 16, 2007 and October 15, 2008. The corn was harvested with a plot combine from the center 1.5 m of each 3 m wide plot on October 23, 2007 and November 3, 2008. Corn grain yield was recorded and adjusted to 15.5% moisture.

**Statistical Analysis**

Corn density was used as an independent variable and corn yield was used as the dependent variable. An F-test determined yield loss in the competition study was not statistically different between years; therefore, data were pooled between the years. Corn density data versus corn yield was fit to the hyperbolic yield equation (Cousens 1985):
YL = \( (I*D)/(1+(I*D)/A) \) using iterative methods in the “Solver” add-on in Microsoft Excel (2013). YL is % yield loss, D is the density, I is a variable that describes incremental yield loss at low densities and A is the estimated maximum yield loss within the density values used, a 100% threshold was used for the A parameter, as cash crop corn yield would be 0.

Herbicide control treatment means were analyzed by ANOVA and compared with the Student Newman Keuls test at the 0.05 level of probability using ARM (2015). Random effect was years, in all studies, and the fixed effect was treatment. In the competition study volunteer corn density was the fixed effect and in the control study, glufosinate rate and application timing were the fixed effects.

**Results and Discussion**

**Volunteer Corn Competition in Corn**

In both years, corn yield loss ranged from 0-41%. Fitting all the data (including crop increases) to the Cousens yield loss model resulted in an \( R^2 \) value of 0.4 (Figure 2-1) with an I value (incremental yield loss) calculated to be 5.6 (A value set to 100). A greater yield loss was seen in 2008 versus 2007 due, on a large part, to higher volunteer corn densities in 2008. Volunteer corn densities were purposely increased due to minimal yield loss response in 2007.

One reason for minimal yield loss response of corn to volunteer corn in this field study may be that volunteer corn seed contributed to grain yield. Scattered volunteer corn plants grown alone yielded 5700 kg ha\(^{-1}\) at 1.6 plants m\(^{-2}\) in 2007 and 4800 kg ha\(^{-1}\) at 3.4 plants m\(^{-2}\) in 2008 (Figure 2-2). Intraspecific competition may explain the lower
yield at the higher density; however, we did see a lower yield in general in 2008 versus 2007. Competition may explain the lower yields for 2008 as all of the densities were higher in 2008 versus 2007 including the hybrid planting density. In 2007 volunteer corn growing in competition with planted corn yielded from 170 to 1400 kg ha\(^{-1}\) with volunteer corn densities of 0.2 to 3.5 plants m\(^{-2}\), respectively (Table 2-1). Due to lodging volunteer corn was not hand-harvested separately from the hybrid corn in 2008.

Another treatment was included in the study comprised of volunteer corn planted in rows at the same density as the hybrid corn depending on the year (74,000 plants ha\(^{-1}\) in 2007 or 79,000 plants ha\(^{-1}\) in 2008). The planted volunteer corn yielded 7772 kg ha\(^{-1}\) in 2007 and 5767 kg ha\(^{-1}\) in 2008 versus the hybrid corn with no volunteer corn which yielded 11388 kg ha\(^{-1}\) in 2007 and 8825 kg ha\(^{-1}\) in 2008 (Table 2-2). This demonstrates that volunteer corn had about a 30% reduction in yield compared with the hybrid corn. Because of this the removal of volunteer corn may be justified to avoid hybrid corn yield loss due to competition.

A study in Indiana reported that volunteer corn competition resulted in reduced corn yield, however when the yield of the volunteer and hybrid corn were added together there was no difference among treatments (Marquardt et al. 2012). Conversely another study reported a 16.8% reduction in hybrid corn yield with a volunteer corn density of 0.5 plants m\(^{-2}\) (Shauck et al. 2009). This study also found a corn yield loss range of 40-62% with a volunteer corn density of 3.4 plants m\(^{-2}\) (Shauck et al. 2009). Our results differed considerably from this study; we would expect a 23% yield loss with 3.4 plants m\(^{-2}\) using our yield loss equation.
The corn yield loss observed in our study was quite variable. For example, volunteer corn densities of 5 plants m$^{-2}$ or less yield ranged from a 27% yield gain to a 64% yield loss (Figure 2-1). Results from Palaudelmàs et al (2009) determined that local density influenced development of volunteer corn. They found that about 80% of volunteer corn growing individually produced a tassel but if grown in clusters less than 50% of the volunteer corn tasseled. Hybrid corn development can also be manipulated by planting density. Corn yield will increase with increased planting density up to a point where competition among plants is great enough to decrease development (Clay et al. 2009), consequently affecting ear and grain development. Liu et al. (2004) concluded that corn responded more to plant emergence variability than plant spacing variability. With non-uniform plant spacing and uneven plant emergence stands, a decreased yield was more dependent on uneven plant emergence (Liu et al. 2004). Plants with delayed emergence produced less grain yield than plants that emerged uniformly due to a number of factors including: less leaf area and dry matter accumulations, high leaf-to-stem ratios, and low harvest index (Liu et al. 2004). With a two-leaf stage delay in emergence a 35 to 47% per plant yield decrease was observed and with a four-leaf stage delay in emergence a 72 to 84% per plant yield decrease was observed (Liu et al. 2004). When there was uneven emergence, the earlier emerged plants were not able to compensate for the yield decrease seen in late emerged plants (Liu et al. 2004). Liu et al. (2004) concluded that an individual corn plant’s yield is influenced by directly adjacent plants as well as a second adjacent plant. This study was examining hybrid corn and it is not known if we can expect to see the same results between volunteer corn and hybrid corn, however we
would expect it to be similar. Volunteer corn may not emerge at the same time as the hybrid corn therefore one may not be able to rely on the contribution of seed from the volunteer corn plants to compensate for the hybrid corn yield loss due to competition.

A study that was examining control of remaining corn from freeze damage before replanting corn found the threshold to reduce replanted corn yield was two or more plants m$^{-2}$ (Steckel et al. 2009). They reported that a treatment with nine corn plants m$^{-2}$ remaining resulted in a corn yield loss of 1000 kg ha$^{-1}$ (15.9 bu/A). This would be about a 12% loss of a 8486 kg ha$^{-1}$ (135 bu/A) yield. The estimated yield loss at 9 plants m$^{-2}$ using the yield loss equation for our data would be about 34%.

Although corn competition with volunteer corn has not been thoroughly studied, there have been numerous studies on corn competition with other weeds. Clay et al. (2012) summarized the results of numerous grass weeds in corn and found the maximum yield loss ($A$) to be 28-49% for green foxtail, 42-75% for yellow foxtail ($Setaria pumila$), and 24-60% for giant foxtail.

Full-season interference due to volunteer proso millet at 125 plants m$^{-2}$ in corn caused an 85% reduction in corn yield (Anderson 2000). With full-season interference our study saw a corn yield loss of 8.3% in 2007 and 25.7% in 2008. The densities that we studied were considerably lower than the volunteer proso millet density therefore it is not known if volunteer corn would have as great of an impact as volunteer proso millet at that high of density. Using the yield loss equation we would estimate yield loss to be about 88% with 125 volunteer corn plants m$^{-2}$. Researching barnyardgrass densities of 0 to 800 seedlings m$^{-2}$ Bosnic and Swanton (1997) predicted a maximum corn yield loss
(A) of 38%, with one barnyardgrass per m of corn row (I) predicted to cause 0.3% yield loss when it emerged with the corn. The effect of barnyardgrass on corn yield was associated more with emergence time of barnyardgrass than weed density (Bosnic and Swanton 1997). Clay et al. (2005) observed a 30% corn yield loss from barnyardgrass that was planted before corn emergence, however, those planted at crop emergence, at V1, or at V2 did not cause yield loss. Volunteer corn had a similar or greater effect on corn yield as many common grass weed species.

Volunteer corn may be as competitive as some broadleaf weeds, such as waterhemp and velvetleaf, in corn. Knezevic et al. (1994) observed a yield loss of 5-34% with redroot pigweed densities of 2-32 plants m$^{-2}$ when pigweed was planted and emerged at the same time as the corn. A maximum corn yield loss of 74% was observed with season-long common waterhemp interference over two years (Steckel and Sprague, 2004). Palmer amaranth, which may be more competitive than waterhemp or volunteer corn, has been revealed to cause corn yield losses ranging from 11-91% with densities of 0.66-10.5 Palmer amaranth plants m$^{-2}$ (Massinga et al. 2001). Liphadzi and Dille (2006) revealed an $I$ value of 24% and an $A$ value of 82% with Palmer amaranth interference in corn. The same study reported an $I$ and $A$ value of 11 and 41%, respectively, for velvetleaf ($Abutilon theophrasti$) interference in corn (Liphadzi and Dille, 2006). Scholes et al. (1995) found the predicted maximum ($A$) corn yield loss due to velvetleaf to be 33.1% and the loss per unit velvetleaf density ($I$) to be about 4.67%.
**Control of Volunteer Corn in Corn**

Data between the two years of the glufosinate study were not pooled due to different application heights and different volunteer corn densities. In each year, volunteer corn control was greatest when glufosinate was applied at 18 – 30 cm tall volunteer corn and control was slightly less when applied earlier or later. Volunteer corn control was approximately 85% when glufosinate was applied to volunteer corn 13 – 15 cm tall, control increased to 93 – 97% when applied to 18 – 30 cm tall volunteer corn, and then control declined to 71 – 91% when volunteer corn was 46 – 91 cm tall. These results indicated that glufosinate alone may not provide complete volunteer corn control when applied early-postemergence in corn, which happens to be the time when glufosinate is most effective on weeds.

Treatments that received glufosinate applications showed variable yield loss results. Corn yield loss was not significant ($P > 0.05$) among glufosinate treatments in 2007, but ranged up to a 23% yield loss in 2008 (Table 2-3). A higher volunteer corn density of 7 plants $m^{-2}$ in 2008 (Figure 2-3) versus 3.5 plants $m^{-2}$ in 2007 may help explain the greater yield loss in 2008 than in 2007.

Although volunteer corn control was not optimal when glufosinate was applied at earlier application times, the hybrid corn yield was not significantly affected. However, corn yield declined at later application times in 2008 which may be largely due to early-season competition between hybrid corn and volunteer corn and reduced control from glufosinate. Volunteer corn control ranged from 80-97% in 2007 and 71-96% in 2008 (Table 2-3). Although volunteer corn control was less than 100% (85 & 96%) at the
earlier timings (15cm & 30cm) in 2008, yield loss was not significant ($P>0.05$) compared to a weed-free treatment. However, control ratings of 91 & 71% at the later timings in 2008 did result in about 20% yield loss. For example, in 2008 the 61 and 91 cm application timings reduced yield by 23% and 19% respectively. In each of the years, control of volunteer corn with glufosinate was greatest when applied to 18-30 cm tall volunteer corn. With little or no corn yield loss when glufosinate was applied to volunteer corn that was 30 cm tall or less, results indicate the need for glufosinate herbicide treatments to be applied when volunteer corn was 18-30 cm tall in order to optimize volunteer corn control and minimize corn yield loss.

While examining giant foxtail, common lambsquarters (*Chenopodium album*), Pennsylvania smartweed (*Polygonum pensylvanicum*), and common cocklebur (*Xanthium strumarium*) at 5, 10, and 15 cm tall without a crop; Steckel et al. (1997) reported the optimal control with glufosinate application at 10 cm tall plants with application rates of 420 and/or 560 g ai ha$^{-1}$. Carey and Kells (1995) found interference from weeds treated with bromoxynil + nicosulfuron (0.42 + 0.035 kg/ha) at 15 and 20 cm tall reduced both corn height and corn grain yield whereas application to 5 and 10 cm tall weeds did not reduce yield. This same study suggested that with high weed populations; applications to weeds 10 cm tall or greater may result in yield loss even with complete weed control. Results from our study do not completely agree with these suggestions. In 2008 yield loss was significant at the 61 and 91 cm application timings however a significant yield loss was not observed at the 15 and 30 cm application timings.
Another study researching volunteer proso millet at a density of 125 plants m$^{-2}$ in corn observed a 48% yield loss when proso millet was removed at 4 weeks of interference, due to late flushes emerging and not controlled, however, when the proso millet was removed at 5 or 6 weeks of interference no reduction in corn yield was noted as no later plants emerged (Anderson 2000). Our volunteer corn density was much lower at 3.5 or 7 plants m$^{-2}$. In our study we observed no yield loss at the low density but a yield loss of 7% when volunteer corn was sprayed at 30 cm which was approximately 5 or 6 weeks after corn planting. The 13 to 15 cm application time corresponds to nearly 4 weeks after corn planting and at that time we observed no yield loss in either year at either density. The yield loss difference between the proso millet and volunteer corn at 4 weeks may be due to the difference in densities and the fact that there was late emerging proso millet and not volunteer corn.

Previously it has been shown that weed control early in the season is necessary to reduce yield loss in corn. Volunteer corn typically emerges relatively close to the same time as the hybrid corn allowing control at an early stage to be permissible with minimal corn yield loss. Field preparation just prior to planting destroys all plants growing in the field and the remaining corn seeds (volunteer corn) germinate at virtually the same time as planted seeds (Palau delimàs et al. 2009). Other weeds typically emerge over a longer time period; consequently, with an early herbicide application time, weeds can emerge after non-residual herbicide applications and cause additional interference. The emergence time indicates that competition of volunteer corn can have more of an impact early in the season. Our results support this suggestion, with minimal yield loss seen
when volunteer corn was sprayed at 30 cm or less. This was also seen in a study, which was supported by previous research, examining weed management in glufosinate-resistant corn that found delayed post applications of glufosinate provided better weed control but weed competition prior to the application caused yield reductions (Bradley et al. 2000). Glufosinate lacks residual activity and a single early glufosinate application will not adequately control weeds that emerge later. This is one reason glufosinate may be an option to control volunteer corn although a tank mix or another spray application may be needed if other weeds are present or emerge later.

According to Hamill et al. (2000) in a study on weed control in glufosinate-resistant corn, no corn yield loss was observed when weeds were controlled between the V2 to V8 corn growth stages. Crop yield loss as a result of competition until the V8 stage has been observed in other studies (Hamill et al. 2000; Bosnic and Swanton 1997; Hall et al. 1992; Knezevic et al. 1994). Due to the emergence patterns of the weeds tested and the nonresidual trait of glufosinate it suggests glufosinate weed control was increased at the later growth stages of corn (Hamill et al. 2000). Under conditions of early weed competition, the same study recommends the V3 to V5 stage of corn may be the optimum timing for weed control when applying glufosinate with residual herbicides (Hamill et al. 2000). With proper application timing, glufosinate in glufosinate-resistant corn is an acceptable alternative to traditional herbicide options for volunteer glyphosate-resistant corn control. Results from our study support this statement. Glufosinate provided acceptable control either year ranging from 71-97% over all of the application
timings and both years. Application timing proved to be a crucial factor regarding glufosinate control of volunteer corn and corn yield loss.

Results indicated that volunteer corn caused yield loss in corn. However, yield loss was minimal and grain from the volunteer corn may offset the effect. Results suggest that glufosinate is an acceptable option for volunteer glyphosate-resistant corn control in glufosinate-resistant corn. However the volunteer corn would have to be only glyphosate resistant and not stacked glyphosate and glufosinate resistant. Our results also demonstrated that the timing of volunteer corn control in corn may be critical. Control of volunteer corn was greatest when glufosinate was applied to 18-30 cm tall volunteer corn. Corn yield loss was minimized with glufosinate applications to volunteer corn that was 30 cm tall or less.
Figure 2-1. Yield loss curve for corn yield loss as affected by volunteer corn density in 2007 and 2008 at Brookings, SD. These data were analyzed using the hyperbolic model equation: 

$$YL = \frac{I*D}{1+I*D/A}.$$ 

YL is % yield loss, D is the density, I is a variable that describes incremental yield loss at low densities and A is the estimated maximum yield loss within the density values used, a 100% threshold was used for the A parameter, as corn yield would be 0. The I value was 5.6, the A value was 100, with an $R^2 = 0.40$. 

R2=0.40

2007 yield loss
2008 yield loss
estimated yield loss

Corn yield loss (%)
Volunteer corn density (plants m$^{-2}$)
Figure 2-2. Plot of scattered volunteer corn plants grown at 1.6 plants m$^{-2}$ without a crop in 2007. Average yield of this treatment was 5700 kg ha$^{-1}$. 
**Figure 2-3.** Volunteer corn in corn at 7 plants m$^{-2}$ in 2008. This density was used for the volunteer corn control with glufosinate experiment for 2008.
Table 2-1. Yield of corn in 2007 with and without the addition of the volunteer corn seed.

<table>
<thead>
<tr>
<th>Volunteer corn density (plants m(^{-2}))</th>
<th>Hybrid corn yield without volunteer corn (kg ha(^{-1}))</th>
<th>Total corn yield (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11387.8 a</td>
<td>11387.8 a</td>
</tr>
<tr>
<td>0.2</td>
<td>11182.8 a</td>
<td>11346.4 a</td>
</tr>
<tr>
<td>0.5</td>
<td>10950.0 a</td>
<td>11396.1 a</td>
</tr>
<tr>
<td>1.2</td>
<td>9685.0 a</td>
<td>9875.1 a</td>
</tr>
<tr>
<td>1.9</td>
<td>10144.4 a</td>
<td>10866.2 a</td>
</tr>
<tr>
<td>2.5</td>
<td>9383.0 a</td>
<td>10267.1 a</td>
</tr>
<tr>
<td>2.7</td>
<td>9666.2 a</td>
<td>10655.4 a</td>
</tr>
<tr>
<td>3.5</td>
<td>9961.9 a</td>
<td>11282.2 a</td>
</tr>
</tbody>
</table>

\( ^a \) Means presented within each year with no common letter(s) are significantly different according to Fisher’s protected LSD test where \( P < 0.05. \)
Table 2-2. Yield of hybrid corn and volunteer corn planted with similar equipment at 74,000 plants ha\(^{-1}\) in 2007 and 79,000 plants ha\(^{-1}\) in 2008.

<table>
<thead>
<tr>
<th></th>
<th>Hybrid corn yield (kg ha(^{-1}))</th>
<th>Volunteer corn yield (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>11388 ± 1509.9</td>
<td>7772 ± 408.7</td>
</tr>
<tr>
<td>2008</td>
<td>8825 ± 1558.3</td>
<td>5767 ± 627.5</td>
</tr>
</tbody>
</table>
Table 2-3. Volunteer glyphosate-resistant corn control in corn with glufosinate (482 g a.i. ha\(^{-1}\)) applied at various volunteer corn heights and corn yield loss associated with each application for 2007 and 2008\(^a\). Volunteer corn density was 3.5 plants m\(^{-2}\) in 2007 and 7 plants m\(^{-2}\) in 2008. Visual observations for % control where 0 is no control and 100 is complete control. All treatments included ammonium sulfate (AMS) at 470 g ai/ha.

\(^a\) Means presented within each year with no common letter(s) are significantly different according to Fisher’s protected LSD test where P ≤ 0.05.

<table>
<thead>
<tr>
<th></th>
<th>Volunteer corn height (cm)</th>
<th>Volunteer corn control (%)</th>
<th>Corn yield loss (%)</th>
<th>Corn yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>85</td>
<td>b</td>
<td>0.43 a</td>
<td>10792.6 a</td>
</tr>
<tr>
<td>18</td>
<td>93</td>
<td>a</td>
<td>1.45 a</td>
<td>10704.5 a</td>
</tr>
<tr>
<td>28</td>
<td>97</td>
<td>a</td>
<td>0.50 a</td>
<td>10824.1 a</td>
</tr>
<tr>
<td>46</td>
<td>80</td>
<td>b</td>
<td>8.84 a</td>
<td>9943.1 a</td>
</tr>
<tr>
<td>Untreated</td>
<td>--</td>
<td>--</td>
<td>8.27 a</td>
<td>9993.4 a</td>
</tr>
<tr>
<td>2008</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>85</td>
<td>c</td>
<td>-1.18 b</td>
<td>10748.6 a</td>
</tr>
<tr>
<td>30</td>
<td>96</td>
<td>a</td>
<td>6.97 b</td>
<td>9886.4 a</td>
</tr>
<tr>
<td>61</td>
<td>91</td>
<td>b</td>
<td>22.67 a</td>
<td>8218.7 b</td>
</tr>
<tr>
<td>91</td>
<td>71</td>
<td>d</td>
<td>18.63 a</td>
<td>8646.7 b</td>
</tr>
<tr>
<td>Untreated</td>
<td>--</td>
<td>--</td>
<td>25.75 a</td>
<td>7891.5 b</td>
</tr>
</tbody>
</table>
CHAPTER 3: VOLUNTEER SOYBEANS IN CORN

Introduction

The continuous use of glyphosate-resistant crops has caused volunteer crops that have the same resistance mechanism as the cash crop to become an increasing weed problem. Volunteer corn at 1 plant m\(^{-2}\) has been proven to cause 30% soybean yield loss. However, there has been little research on the effect of volunteer soybeans in corn. The lack of research on volunteer soybeans may be due to the fact that there have been many options for control of volunteer soybeans. Many broadleaf postemergence herbicides for corn will control volunteer soybeans. With the adoption of glyphosate-resistant and glufosinate-resistant soybeans and the introduction of other resistant traits, producers will need to be aware of the type of soybeans present and select appropriate herbicides.

Volunteer soybeans may become an increasing concern in corn in the near future with the release of different genetically modified soybeans that are resistant to more than one herbicide. Currently there is research being conducted on soybeans resistant to: dicamba and glyphosate; 2,4-D, glyphosate, and glufosinate; isoxaflutole and glyphosate; isoxaflutole, glyphosate, and glufosinate; and mesotrione, glufosinate, and isoxaflutole. With the introduction of either single or multi trait soybeans, control options may be limited. It will also be important to know which type of volunteer soybeans are present in the field to determine proper herbicide options for control.

There are several factors that can contribute to the presence of volunteer soybeans. Volunteer soybeans can be the result of seed shatter, lodging, or harvest loss (Tsuchiya 1987; Weber and Fehr 1966; Philbrook and Oplinger 1989). Delayed soybean
harvest can lead to increased yield losses with increased volunteer plants the following season. Harvest losses also can be due to missed plants or to equipment inefficiencies.

Soybean pod shattering (dehiscence) can be due to genetic and environmental factors. Soybean varieties have different levels of resistance to pod dehiscence with some varieties being more susceptible and some varieties being more resistant. Some common factors that may induce soybean pod shattering include; low humidity, high temperature, rapid temperature changes, and alternating wetting and drying of plants (Tsuchiya 1987). Tsuchiya (1987) researched shattering of susceptible and resistant varieties and discovered susceptible varieties began to shatter at 10-15% pod moisture and at 5% moisture nearly 100% had shattered whereas the resistant varieties had 10% shattering at 5% moisture. Tukamuhabwa et al. (2002) observed a maximum soybean yield loss between 57-175 kg ha\(^{-1}\) as a result of pod shattering. Assuming 6000 seeds kg\(^{-1}\) and 100% germination, this would be equivalent to a maximum of 34-105 volunteer soybean plants m\(^{-2}\). Their results (Tukamuhabwa et al. 2002) also observed that high temperatures increased shattering whereas high humidity reduced pod shattering. A study by Caviness (1965) found that when soybean pods were subjected to alternate wetting and drying periods at relative humidity levels of 30 and 40% the rate of pod dehiscence increased slightly, and pod dehiscence rate also increased slightly when the pods remained dry at relative humidity levels of 10 and 20% compared to moistened pods.

One study determined that shatter losses accounted for 37% of total soybean losses with total losses averaging 10% of potential yield (Philbrook and Oplinger 1989).
Philbrook and Oplinger (1989) also found soybean shatter losses to increase with delays in harvest after soybean maturity with the greatest increases with a 14 day to 28 day harvest delay. Tsuchiya (1987) recommends harvesting varieties that are more susceptible to shattering in early morning when the humidity is higher. Soybean losses, due to shattering and other factors, remain in the field and are potential volunteer soybean plants the following season.

Corn yield loss due to competition with other broadleaf weeds has been studied and proven. Velvetleaf at about 3 plants m$^{-2}$ resulted in about 10% corn yield loss (Scholes et al. 1995). Beckett et al. (1988) found a maximum yield loss of 27% with 6.2 plants m$^{-2}$ of common cocklebur. Palmer amaranth at densities of 0.66-10.5 plants m$^{-2}$ resulted in 11-91% yield loss (Massinga et al. 2011). Corn yield loss as a result of volunteer soybean competition needs to be quantified to determine if an herbicide application to control volunteer soybeans is profitable.

Herbicides are available for the control of volunteer soybeans in corn. Some post-emergence options for volunteer soybean control include: dicamba + diflufenzopyr (Status), clopyralid (Stinger), topramezone (Armezon/Impact), mesotrione (Callisto), tembotrione (Laudis), flumetsulam + clopyralid (Hornet), and acetochlor + flumetsulam + clopyralid (Tripleflex/Surestart) (Jhala et al. 2013).

The objectives of this study were to evaluate corn yield loss due to volunteer soybean competition and to determine effective herbicide control options for volunteer glyphosate-resistant soybeans in glyphosate-resistant corn. Each study was conducted during two field seasons in eastern South Dakota.
Materials and Methods

Volunteer Soybean Competition in Corn

Studies were conducted at the South Dakota State University, Brookings Agronomy Farm in 2011 on a Barnes loam soil (Fine-loamy, mixed, superactive, frigid Calcic Hapludolls) and Volga Research Farm in 2012 on a Brandt silt clay loam soil. In 2011, average volunteer soybean densities were established at 0, 1.8, 3.7, 18.5, 37, and 111 plants m$^{-2}$. In 2012, average volunteer soybean densities (± 1 std dev) were established at 0, 2.3 (±0.33), 4.2 (±1.0), 12.9 (±2.9), 41 (±18.9), and 90 (±19.1) plants m$^{-2}$. The treatments were established in a randomized complete block design with four replications. Plots were 4 rows wide (76-cm row width) and 15 m long. Total precipitation for the growing season was about 33 cm for 2011 and about 35 cm for 2012.

Commercial Roundup Ready soybean seed was used to establish volunteer soybean densities. Asgrow 1230 (relative maturity 1.2) was manually spread on the soil surface on May 16, 2011 and Asgrow 1431 (relative maturity 1.4) was manually spread on the soil surface on April 25, 2012. The soybean seed was incorporated about 4 cm below the soil surface using a field cultivator each year. Roundup Ready Dekalb 43-27 (a 93 d relative maturity hybrid) corn seed was planted on May 16, 2011 and Roundup Ready Dekalb 45-51 (a 95 d relative maturity hybrid) corn seed was planted on April 25, 2012 at a rate of 76,100 plants h$^{-1}$ each year. Conditions were ideal in 2011 and we expected uniformity among volunteer soybean densities, however, in 2012, there was heavy rainfall shortly after planting that may have influenced the densities, consequently stand counts were taken. The plots were kept weed-free both years with an application of
glyphosate (Roundup Weathermax) at 870 g a.i. ha\(^{-1}\) and ammonium sulfate at 2.8 kg ha\(^{-1}\) applied on June 14, 2011 and June 1, 2012.

Corn was harvested with a plot combine from the center 1.5 m of each 3 m wide plot on October 14, 2011 and September 28, 2012. Corn yields were determined and adjusted to 15% moisture.

**Volunteer Soybean Control in Corn**

Studies were conducted at the South Dakota State University, Brookings Agronomy Farm in 2011 on a Barnes loam soil (Fine-loamy, mixed, superactive, frigid Calcic Hapludolls) and Volga Research Farm in 2012 on a Brandt silty clay loam soil. The treatments were established in a randomized complete block design with four replications. Plots were 4 rows wide (76-cm row width) and 15 m long.

Volunteer soybeans were established at an average density of 10 plants m\(^{-2}\) by manually spreading the same varieties as described above seeded on the same dates as the competition study. The soybean seed was incorporated about 4 cm below the soil surface using a field cultivator each year. Corn was planted at a rate of 76,100 plants h\(^{-1}\) each year using Roundup Ready Dekalb 43-27 (a 93 d relative maturity hybrid) corn seed on May 16, 2011 and Roundup Ready Dekalb 45-51 (a 95 d relative maturity hybrid) corn seed on April 25, 2012.

Herbicide treatments were applied on June 25, 2011 and June 12, 2012 at full and 1/2X recommended label rates. Treatments included tembotrione (Laudis) at 30.6 or 15.3 g a.i. ha\(^{-1}\), dicamba+diflufenzopyr (Status) at 56 + 22 (78.5) or 28 + 11.2 (39.2) g a.i. ha\(^{-1}\), atrazine at 1120 or 560 g a.i. ha\(^{-1}\), dicamba (Clarity) at 280 g a.e. ha\(^{-1}\) and rimsulfuron
(Resolve) at 8.8 g a.i. ha⁻¹ (Table 3-1). The tembotrione, atrazine and rimsulfuron treatments included nonionic surfactant at 0.25% v/v. All treatments included glyphosate (Roundup Weathermax) at 870 g a.i. ha⁻¹ and ammonium sulfate at 470 g a.i. ha⁻¹ to control weeds other than volunteer soybean. Treatments were applied with a bicycle sprayer using 187 L ha⁻¹ at 207 kpa and TeeJet 8003XR nozzles. At the time of application corn was approximately 25 cm tall and at the V5 stage in 2011 and the volunteer soybeans were approximately 10-15 cm tall and 2-trifoliate. In 2012, corn was approximately 30-36 cm tall and at the V4-V5 stage and soybeans were approximately 15-20 cm tall and 3-4-trifoliate. Control of volunteer soybeans was visually rated on a scale of 0 (no control) to 100% (complete control). Control ratings were taken on August 23, 2011 and July 11, 2012.

**Statistical Analysis**

Soybean density was used as an independent variable and corn yield was used as the dependent variable. An F-test determined yield loss in the competition study was not statistically different between years; therefore, data were pooled between the years. Soybean density data versus corn yield was fit to the hyperbolic yield equation (Cousens 1985): \( YL = \frac{(I \times D)}{(1 + (I \times D)/A)} \) using iterative methods in the “Solver” add-on in Microsoft Excel (2013). YL is % yield loss, D is the density, I is a variable that describes incremental yield loss at low densities and A is the estimated maximum yield loss. The \( R^2 \) value for the equation that had the lowest sum of squares for error was also calculated.

Herbicide control treatment means were analyzed by ANOVA and compared with the Student Newman Keuls test at the 0.05 level of probability using ARM (2015).
Random effect was years, whereas the fixed effect was herbicide treatment which resulted in variable volunteer soybean control.

**Results and Discussion**

**Volunteer Soybean Competition in Corn**

The average corn yield of the treatment with no volunteer soybeans was 11,054 kg ha\(^{-1}\) (164.5 bu/A) in 2011 and 8796 kg ha\(^{-1}\) (130.9 bu/A) in 2012. Corn yields were reduced by volunteer soybeans. Averaged over treatments corn yield loss ranged from 0-46% in 2011 and 0-53% in 2012. (Figure 3-1) Using the hyperbolic model, incremental yield loss \(I\) at low densities of volunteer soybean plants was 3.2% and the maximum yield loss \(A\) at high densities was 56%. The \(R^2\) value for the equation was 0.78, indicating that 78% of the yield loss variability was explained in the equation. We observed an average soybean stand establishment of about 30% based on the seeded density. Using the maximum yield loss due to shattering of 57-175 kg ha\(^{-1}\) reported by Tukamuhabwa et al. (2002) this would be equivalent to 34-105 seeds m\(^{-2}\). Based on 30% emergence, the expected density range of plants would be 10.2-31.5 plants m\(^{-2}\). Based on the incremental values, maximum yield loss (55%) would occur at about 1000 volunteer soybean plants m\(^{-2}\). All of the average densities in this study were below this value. The highest densities were necessary to create a full yield loss curve.

When compared with the weed-free control, yield was reduced when volunteer soybean densities were 12.9 plants m\(^{-2}\) or greater in 2012 and 18.5 plants m\(^{-2}\) or greater in 2011. The yield of the treatment in 2012 with 12.9 plants m\(^{-2}\) was 6895 kg ha\(^{-1}\) (102.6 bu/A) and the yield of the treatment in 2011 with 18.5 plants m\(^{-2}\) was 7338 kg ha\(^{-1}\) (109.2 bu/A).
bu/A). This amounts to a 34% yield loss in 2011 and a 21% yield loss in 2012. If the price of corn is $0.16/kg ($4/bu) this amounts to a loss of about $594 per hectare ($221 per acre) in 2011 and about $304 per hectare ($113 per acre) in 2012. Densities of this amount would justify herbicide application to control the volunteer soybeans, however it is unlikely that such densities would be seen uniformly across an entire field. It is more likely that higher densities would be seen in patches. In South Dakota, the 5-yr average corn yield (2008-2012) is reported to be 8486 kg ha\(^{-1}\) (135 bu/A) (NASS 2013), assuming a 3% yield loss (255 kg/ha (4 bu/A)) with 1 volunteer soybean plant and a corn price of $0.16/kg ($4/bu), this would be a $41 loss per ha ($16 loss per acre). As the volunteer soybean density increases, the yield loss increases and the breakeven point for herbicide costs can be calculated.

The volunteer soybean yield loss results in our study are comparable to previous studies with other broadleaf weeds in corn. For example, Scholes et al. (1995) found velvetleaf densities of about 3 plants m\(^{-2}\) reduced corn yield by 10%. This is comparable to our study where we saw about 10% yield loss with an average density of 3.7 soybean plants m\(^{-2}\) in 2011. The same study (Scholes et al. 1995) reported the predicted maximum (A) corn yield loss due to velvetleaf to be 33.1% and the loss at low velvetleaf densities (I) to be 4.67%. Liphadzi and Dille (2006) found an I and A value of 11 and 41%, respectively, for velvetleaf interference in corn. Our results indicated an A value of 56% and an I value of 3.2% with volunteer soybean in corn. Velvetleaf may be more competitive than volunteer soybeans at lower densities although, volunteer soybeans appears to be more competitive at higher densities. Knezevic et al. (1994) observed a
yield loss of 5-34% with redroot pigweed densities of 2-32 plants m$^{-2}$ when pigweed was planted and emerged at the same time as the corn. This is similar to our study in which we observed a soybean density of 1.8-2.3 soybean plants m$^{-2}$ resulted in corn yield loss from 3-6% and with a density of 37 soybean plants m$^{-2}$ in 2011 corn yield loss averaged 30%.

Studies have found other broadleaf weeds to be more competitive than volunteer soybeans in corn. Harrison et al. (2001) reported giant ragweed (*Ambrosia trifida*) to have an *I* value of 13.6% and an *A* value of 90% when competing with corn. Other research also found corn yield loss to be 13% with 1 giant ragweed plant m$^{-2}$ (OMAF, 2009). The same research reported common lambsquarters to cause 12% corn yield loss with 1 plant m$^{-2}$. Deines et al. (2004) reported that common sunflower (*Helianthus annuus*) had an *I* value of 49% in corn. Beckett et al. (1988) reported the predicted maximum yield loss from common cocklebur in corn to be 27% at 6.2 plants m$^{-2}$. Common cocklebur therefore was more competitive than volunteer soybeans which reduced corn yield loss by about 30% in 2011 with 37 volunteer soybean plants m$^{-2}$. Densities of volunteer soybeans need to be six times greater than that of the common cocklebur to cause similar corn yield loss.

Corn yield losses associated with Palmer amaranth have been revealed to range from 11-91% with densities of 0.66-10.5 Palmer amaranth plants m$^{-2}$ (Massinga et al. 2001). Results from Liphadzi and Dille (2006) support the high yield loss of corn due to Palmer amaranth with an *I* value of 24% and an *A* value of 82%. The yield loss from Palmer amaranth was about 10 times greater than volunteer soybean densities. Season-
long interference with common waterhemp was observed to cause a maximum corn yield loss of 74% over two years (Steckel and Sprague 2004).

Beckett et al. (1988) found the predicted maximum yield loss to be 12% at 6.4 plants m$^{-2}$ from common lambsquarters interference in corn. The common lambsquarters in their study was less competitive than volunteer soybeans, as we observed a similar yield loss (about 10%) with a density of 3.7 plants m$^{-2}$ in 2011 which is nearly half the common lambsquarters density (Figure 3-2). This suggests that volunteer soybeans may be more competitive than some other broadleaf weeds in corn.

Volunteer soybeans in corn appear to be more competitive than grass weeds in corn at low densities. Clay et al. (2012) summarized the results of several studies in corn and reported the I values to range between 0.32-2.04% for green foxtail, 0.11-2.9% for yellow foxtail, 1.29-2.69% for giant foxtail, and 2.15% for barnyardgrass for each weed m$^{-2}$. All of these values are below our I value of 3.2%. However the maximum yield loss was greater than our results (A value of 56%) with volunteer soybeans in some instances. They reported the A values in corn to be 30.1-52.7% with green foxtail, 45.2-80.6% with yellow foxtail, 25.8-64.5% with giant foxtail, and 33.3% with barnyardgrass. This suggests that volunteer soybeans may be more competitive than many grass weeds at lower densities but with higher densities some grass weeds may be more competitive than volunteer soybeans. Another study found the I value of giant foxtail interference in nonirrigated corn to be 2.0 with an A value of 38% (Fausey et al. 1997).

**Volunteer Soybean Control in Corn**
The results of our volunteer soybean control study varied greatly each year. Control of volunteer soybeans ranged from 65-99% in 2011 and from 48-96% in 2012. (Table 3-2) Several treatments provided 90% control or better. In 2011, the lower rate of tembotrione (15.3 g ai ha\(^{-1}\)) and the rimsulfuron (8.8 g ai ha\(^{-1}\)) were the only two treatments that did not provide control above 90% evaluated 8 weeks after application. All other treatments provided 91-99% control. Control in 2012 when evaluated 4 weeks after application was much more variable with only three treatments providing greater than 90% control. In 2012, all treatments, except for atrazine, were not significantly (P=0.05) different and provided 87-96% control. The atrazine treatments applied POST resulted in the poorest control (48-59%) in 2012. One reason that we may have seen better volunteer soybean control in 2011 is that the soybeans were treated at different times as the treatments were applied later in 2012 (V3-4) than in 2011 (V2).

The herbicide treatments we used had an estimated 2015 cost of $5-20 per hectare ($2-8 per acre) in addition to the glyphosate application (Johnson, 2015). Based on the estimated loss of $304-594 per hectare ($113-221 per acre) with 12.9-18.5 soybean plants m\(^{-2}\) and the amount of control received with the herbicide treatments it would be justifiable to include the additional herbicide to control the volunteer soybeans. With a corn price of $0.16 kg\(^{-1}\) ($4/bu) a yield loss of only 126 kg h\(^{-1}\) (2 bu per acre) would offset the additional cost of the herbicide. This would only be about a 1.5% yield loss of a 8500 kg ha\(^{-1}\) (135 bushel per acre) yielding corn crop which could be caused by about 0.5 soybean plants m\(^{-2}\). The decision to include additional herbicides for volunteer
soybean control will depend on the density of the volunteer soybeans, the cost of the herbicide, and the price of the crop and all of these will vary from year to year.

One study showed 99% control of volunteer soybeans at the V2-V3 stage with 140 or 175 g ae ha\(^{-1}\) dicamba with petroleum oil concentrate (Zollinger and Ries 2004). We observed similar control (96-99%) with 280 g ai ha\(^{-1}\). This may indicate that volunteer soybeans can be controlled with a lower rate however we did not have an adjuvant included in our treatment since we tank-mixed each treatment with a glyphosate product formulated with an adjuvant. Zollinger and Ries (2004) also found increased volunteer soybean control with most treatments when treating at the V2-V3 versus the V4-V6 soybean. We did not have two application timings however, our data indicated greater control with most of the treatments of 2-tri (V2) soybeans in 2011 than 3-4-tri (V3-4) soybeans in 2012. Gunsolus (2010) also recommended applying herbicides to V2-V3 soybeans versus V4-V6 for more effective control of volunteer soybeans. Excellent control (90-99%) of V2-V3 soybeans was observed with atrazine, dicamba, bronate, Hornet (flumetsulam + clopyralid), Permit (halosulfuron), Status (dicamba + diflufenzopyr), Stinger (clopyralid) (Zollinger, 2015).

Knezevic et al. (2014) also found that volunteer soybeans were easier to control at V2-V3 versus V4-V6. At one location, the study revealed 100% control two weeks after application with glufosinate (594 g ai ha\(^{-1}\)), mesotrione+atrazine (105 + 560 g ai ha\(^{-1}\)), tembotrione + atrazine (92 + 560 g ai ha\(^{-1}\)) and topramezone + atrazine (24.5 + 560 g ai ha\(^{-1}\)) when applied to V2-V3 volunteer Roundup-Ready soybeans. The same treatments applied at V4-V6 resulted in 85, 66, 69, and 68% control, respectively. Knezevic et al.
(2014) observed 88-100% control with the tembotrione + atrazine (92 + 560 g ai ha\(^{-1}\)) application at the V2-V3 volunteer soybean stage. Our results were similar with 89-94% control using a reduced rate of tembotrione (30.6 g ai ha\(^{-1}\)) alone applied to V2-V4 volunteer soybeans. This suggests that a reduced rate of tembotrione may effectively control volunteer soybean.

Previous research at South Dakota State University looked at some of the same treatments as we examined for volunteer soybean control in corn (Wrage et al. 2004). Their study looked at two locations applied to V2-V3 soybeans. Wrage et al. (2004) observed 88-92% volunteer soybean control with dicamba + diflufenzopyr at 56 + 22 (78.5) g a.i. ha\(^{-1}\). Using the same rate, our results showed 94-99% control. Atrazine at 1120 g a.i. ha\(^{-1}\) resulted in 85-99% control (Wrage et al. 2004) whereas we saw 59-98% control with the same rate. One reason for the low control (59%), which was seen during 2012, may be that is was applied to more mature (V3-V4) soybeans. They also used a crop oil concentrate whereas we used a non-ionic surfactant with our atrazine treatment. Wrage et al. (2004) reported that dicamba at 140 g a.e. ha\(^{-1}\) had 45-75% control. Our dicamba rate was twice their rate (280 g a.e. ha\(^{-1}\)) and we saw 96-99% control. The 140 g a.e. ha\(^{-1}\) rate is half the registered recommended rate of dicamba, this suggests that a full rate may be necessary to control volunteer soybeans. However, dicamba may cause crop injury to corn if it is applied to corn past 20 cm (8 inches) tall. Dicamba + diflufenzopyr, atrazine, and dicamba proved to be options for volunteer soybean control. South Dakota State University (Wrage et al. 2004) also found dicamba + diflufenzopyr at 112 + 45
(157) g a.i. ha\(^{-1}\), atrazine at 2240 g a.i. ha\(^{-1}\), and dicamba + atrazine at 1120 or 2240 g a.i. ha\(^{-1}\) to provide excellent (99%) volunteer soybean control at both locations.

Our results indicate that volunteer soybean in corn can cause significant corn yield loss with the densities we used in this experiment. Densities of 12.9 soybean plants m\(^{-2}\) or greater resulted in significant corn yield loss. Volunteer soybeans can be equally competitive in corn compared with other broadleaf weeds. Compared to grass weeds, volunteer soybeans proved to be more competitive at lower densities although some grasses have the potential to be more competitive at higher densities. Results from this study indicate that there are herbicide options available to adequately control volunteer soybeans in corn. Based on other research it is evident that timing of volunteer soybean control is important. Other research found volunteer soybean control to work better earlier with soybeans at about the V2-V3 stage. We also saw better control in 2011 when we applied the treatments to V-2 soybeans compared to 2012 when we made the applications to V3-V4 soybeans.
Figure 3-1. Yield loss curve for corn yield as affected by volunteer soybean density in 2011 near Brookings, SD and in 2012 near Volga, SD, with each data point representing the density and yield loss in an individual plot. These data were analyzed using the hyperbolic model equation: \( YL = \frac{I*D}{1+(I*D)/A} \). \( YL \) is % yield loss, \( D \) is the density, \( I \) is a variable that describes incremental yield loss at low densities and \( A \) is the estimated maximum yield. The \( I \) value was 3.2, the \( A \) value was 56, with an \( R^2 = 0.78 \).
Figure 3-2. Volunteer soybeans at 3.7 plants m\(^{-2}\) in 2011. Observed and estimated yield loss at this density was about 10\%.
Table 3-1. Herbicides and rates used for volunteer glyphosate-resistant soybean control in glyphosate-resistant corn. Tembotrione, atrazine, and rimsulfuron treatments included non-ionic surfactant (NIS) at 0.25% v/v. All treatments included glyphosate at 870 g ai/ha and ammonium sulfate (AMS) at 470 g ai/ha.

<table>
<thead>
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<th>Herbicide</th>
<th>Trade Name</th>
<th>Rate (g ai/ha)</th>
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<tr>
<td>Rimsulfuron</td>
<td>Resolve</td>
<td>8.8</td>
<td>E.I. du Pont de Nemours and Company, Wilmington, DE; <a href="http://www.dupont.com">www.dupont.com</a></td>
</tr>
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Table 3-2. Volunteer soybean control in 2011 near Brookings, SD and in 2012 near Volga, SD. Visual observations for % control where 0 is no control and 100 is complete control. Applications were applied to V2 soybeans (June 25) in 2011 and V3-4 soybeans (June 12) in 2012. Control ratings were recorded 8 weeks after application (August 23) in 2011 and 4 weeks after application (July 11) in 2012. Tembotrione, atrazine, and rimsulfuron treatments included non-ionic surfactant (NIS) at 0.25% v/v. All treatments included glyphosate at 870 g ai/ha and ammonium sulfate (AMS) at 470 g ai/ha.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Voluntary Soybean Control (%)</th>
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<th>2012</th>
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<td>Chemical name</td>
<td>Trade Name</td>
<td>Rate (g ai/ha)</td>
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<tr>
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<td>0 f</td>
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<tr>
<td>Tembotrione+NIS</td>
<td>Laudis</td>
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<td>Tembotrione+NIS</td>
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<td>Dicamba+diflufenzopyr</td>
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<td>98 a</td>
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*Means presented within each year with no common letter(s) are significantly different according to Fisher’s protected LSD test where P ≤ 0.05.
Conclusions

Competition

The results of the three competition studies demonstrated that volunteer corn in soybeans was more competitive than volunteer corn in corn or volunteer soybeans in corn. According to the hyperbolic yield loss equation used, the incremental yield loss ($I$ value) was 29.9 for volunteer corn in soybeans, 5.6 for volunteer corn in corn, and 3.2 for volunteer soybeans in corn. These data indicate that competition of volunteer corn in soybean was six times greater than volunteer corn in corn and about ten times greater than volunteer soybean in corn.

On a per plant basis per area, volunteer soybeans in corn proved to be much less competitive in corn than volunteer corn in corn. Our highest density of volunteer soybeans (111 plants m$^{-2}$) was about 13 times greater than our highest density of volunteer corn (8.5 plants m$^{-2}$) to have similar corn yield loss.

Our studies demonstrated that volunteer corn is not as competitive in corn as it is in soybeans. In fact, yield loss was minimal with volunteer corn in corn and grain from the volunteer corn may offset hybrid yield reduction. The quality of the volunteer corn grain may be poorer, although this was not examined in this study. We saw a lower yield loss in corn due to volunteer corn with a maximum density (8.5 plants m$^{-2}$) that was almost double the maximum density (4.4 plants m$^{-2}$) of volunteer corn in soybean.

Control of Volunteer Plants

Unless extremely low volunteer densities are encountered, in almost all cases, it appears to be economically sensible to control volunteer corn and soybean with an
herbicide application.

Glufosinate with a reduced rate of a graminicide proved to be an option for glyphosate-resistant volunteer corn control in soybeans. The addition of the graminicide provided greater control of volunteer corn than glufosinate alone. This option worked best when the height of the volunteer corn was 46 cm or less in order to prevent yield loss.

Glufosinate was also demonstrated as an acceptable option for volunteer glyphosate-resistant corn control in glufosinate-resistant corn. However, the timing of the volunteer corn control may be critical for efficacy and to minimize competition with the crop. Corn yield loss was minimized when glufosinate applications were made when the height of the volunteer corn was 30 cm or less.

Several herbicides tank-mixed with glyphosate provided adequate control of volunteer soybeans in corn. Dicamba+diflusenzopyr or dicamba provided excellent (>90%) control both years. Tembotrione provided good (>80%<90%) to excellent control both years. The control results for the treatments of atrazine or rimsulfuron varied by year. Overall control was better in 2011 when treatments were applied to V-2 soybeans compared to 2012 when they were applied to V3-V4 soybeans.

Future work may include a study with different application timings to determine optimum soybean size for best control. Typical soybean yield losses have been determined, however a study to determine typical volunteer soybean stands in the field the following year may be considered. A study on the quality of the grain obtained from volunteer corn in corn would also be useful. Other work may include control of
volunteers from the different herbicide-tolerant crops that are going to be released in the near future.
References


South Dakota Agriculture 2013 USDA NASS SD Field Office Bulletin No 73. Sioux Falls, SD


