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Volunteer Corn (*Zea mays*) Interference in Dry Edible Bean (*Phaseolus vulgaris*)

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Volunteer corn can affect dry bean by reducing yields; expanding the life cycle of insects, mites, and pathogens; interfering with harvest; and contaminating bean seed. Field studies were conducted at Lingle, WY, and Scottsbluff, NE, to determine the relationship between volunteer corn density and dry bean yield, establish the proper time of volunteer corn removal, and determine whether dry bean yield was affected by the method used to remove volunteer corn. Volunteer corn reduced dry bean yields, as recorded in other crops. Growing conditions for each location were different, as indicated by the accumulated growing degree days (GDD): Lingle 2008 (990), Lingle 2009 (780), and Scottsbluff 2009 (957). No difference in dry bean yields was observed between hand removal of volunteer corn and herbicide application. Dry bean yield loss increased with longer periods of volunteer corn competition and ranged from 1.2 to 1.8% yield loss for every 100 GDD that control was delayed. Control measures should be implemented 15 to 20 d after planting when volunteer corn densities are close to 1 plant m^{-2}. Dry bean yield losses also increased as volunteer corn densities increased, with losses from 6.5 to 19.3% for 1 volunteer corn plant m^{-2}. Based on 2015 prices, the cost of controlling volunteer corn would be the equivalent of 102 kg ha^{-1} of dry bean, and potential losses above 4% would justify control and should not be delayed beyond 15 to 20 d after planting
Nomenclature: Dry bean, *Phaseolus vulgaris* L.; volunteer corn, *Zea mays* L.
Key words: Competition, critical time of removal, volunteer corn density, yield loss.

El maíz voluntario puede afectar al frijol común al reducir su rendimiento, al expandir el ciclo de vida de insectos, ácaros y patógenos, al interferir con la cosecha, y al contaminar la semilla de frijol. Se realizaron estudios de campo en Lingle, Wyoming, y en Scottsbluff, Nebraska, para determinar la relación entre la densidad de maíz voluntario y el rendimiento del frijol, para establecer el momento apropiado de remoción del maíz voluntario, y para determinar si el rendimiento del frijol fue afectado por el método usado para remover el maíz voluntario. El maíz voluntario redujo los rendimientos del frijol como ha sido documentado en otros cultivos. Las condiciones de crecimiento fueron diferentes para cada localidad, como lo indicó el acumulado de grados día de crecimiento (GDD): Lingle 2008 (990), Lingle 2009 (780), and Scottsbluff 2009 (957). No se observó ninguna diferencia en el rendimiento del frijol entre la remoción manual del maíz voluntario o con aplicaciones de herbicida. La pérdida en el rendimiento del frijol aumentó con períodos más largos de competencia con el maíz voluntario y varió desde 1.2 a 1.8% de pérdida de rendimiento por cada 100 GDD de retraso en el control. Las medidas de control deberían ser implementadas 15 a 20 d después de la siembra cuando las densidades del maíz voluntario están cerca de 1 planta m^{-2}. Las pérdidas de rendimiento también incrementaron al aumentarse la densidad del maíz voluntario, con pérdidas desde 6.5 a 19.3% para 1 planta de maíz voluntario m^{-2}. Con base en los precios de 2015, el costo de controlar maíz voluntario sería equivalente a 102 kg ha^{-1} de frijol, y pérdidas potenciales superiores a 4% justificarían el control y este no debería ser retrasado más allá de 15 a 20 d después de la siembra.

Volunteer corn can be a troublesome weed in regions where corn is a rotational crop (Andersen and Geadelman 1982; Becket and Stoller 1988; Deen et al. 2006). Dry bean often follows corn in western Nebraska and eastern Wyoming crop rotations. As a consequence, corn seed that remains in the field as a result of ear or kernel losses during crop harvest (e.g., caused by mechanical problems, stalk lodging, and pests) will often germinate in dry bean fields the following growing season. Volunteer corn competes with the dry bean crop for moisture, nutrients, and light in the same way as other weeds, and substantial crop yield loss has been reported in soybean [*Glycine max* (L.) Merr.], corn, and sugar beet (*Beta vulgaris* L.) (Becket and Stoller 1988; Kniss et al. 2012; Marquardt et al. 2012). Heavy infestations can occur when large amounts of corn seed remain in the field after a corn crop because of excessive stalk lodging and ear loss (Becket and Stoller 1988). Reduced tillage (chisel plow or no-

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till) can exacerbate volunteer corn problems more than conventional moldboard tillage because more of the corn seed remains near the soil surface where germination and successful emergence occurs more readily (Becket and Stoller 1988). Volunteer corn can be found as both isolated plants and clumps of many plants (Becket and Stoller 1988). Volunteer corn can also affect the quality of the harvested crop (Deen et al. 2006), in addition to hosting insect pests and crop disease pathogens that can become the source of infestation for the next crop in the rotation (Summers et al. 2004). The use of corn hybrids with insecticidal traits has created a new concern regarding volunteer corn plants. Target insects can feed on volunteer corn plants, thereby affecting insect resistance management for the field (Krupke et al. 2009).

Crop yield reduction caused by interference from weeds is a function of weed density and duration of the interference (Froud-Williams 2002). In the case of volunteer corn, yield loss up to 25% has been reported in soybean when volunteer corn plants growing in clumps reached a density of 5,380 clumps ha^{-1} (Beckett and Stoller 1988). Alms et al. (2007) reported corn yield reduction of 9% caused by volunteer corn densities of 3.5 plants m^{-2}. In a study by Kniss et al. (2012) in western Nebraska and eastern Wyoming, volunteer corn densities of 1 plant m^{-2} reduced sugar beet sucrose yield by 19%.

Apart from the magnitude of yield loss caused by volunteer plant densities, the critical time of removal of competing plants is also important. The critical time of removal is defined as the period of time in which the weed competition can result in yield loss (Zimdahl 2013). For example, Burnside et al. (1998), working with wild mustard (*Sinapis arvensis* L.), green foxtail [*Setaria viridis* (L.) Beauv.], and redroot pigweed (*Amaranthus retroflexus* L.) as the major weedy species, determined that the critical period for weed control in dry bean was 3 to 6 wk after planting. In western Nebraska, Wilson (1993) reported that a period of 4 wk free of weeds was required to avoid the competitive effects of wild-proso millet (*Panicum miliaceum* L.).

Selective POST herbicides such as quizalofop-p-ethyl, clethodim, and fenoxaprop-p-ethyl can provide effective weed control before yield is substantially affected by interference in other crops (Becket and Stoller 1988; Deen et al. 2006; Kniss et al. 2012). Hand weeding may not be practical over vast acreages but can be an option on small farms or at low weed densities. If removed by hand, volunteer corn will typically stop intercepting light immediately. When volunteer corn is sprayed with a herbicide, it may continue to intercept light for some time after application; therefore, the critical time of weed removal may differ for herbicide application compared with hand weeding.

Although yield reduction in dry bean competing with other grassy weeds has been extensively reported in the literature, competitive effects of volunteer corn in dry bean have not yet been adequately documented. Also, no information is available comparing herbicides to hand labor as a means of controlling volunteer corn. This information is important to enable growers dealing with volunteer corn in dry bean to make informed decisions on the most efficient way to manage crop rotations. The objectives of this study were, therefore, to characterize the relationship between volunteer corn density and dry bean yield, establish the critical time of volunteer corn removal, and determine whether dry bean yield was affected by the method used to remove volunteer corn.

Materials And Methods

Site Description. Field experiments were conducted at the Sustainable Agriculture Research and Extension Center (SAREC) near Lingle, WY, and the Panhandle Research and Extension Center (PREC) in Scottsbluff, NE, in 2008 and 2009 to evaluate the effects of volunteer corn time of removal, density, and method of removal on dry bean yield. Soil at SAREC was Haverson and McCook loams (mesic Aridic Ustifluvents) with pH 7.8 and 1.4% organic matter. At Scottsbluff, soil was Glenberg loamy sand (Ustic Torrifluvents) with pH 7.9 and 1% organic matter. Dry bean variety used at both locations was Great Northern 'Orion' (Rogers®, Syngenta Seeds Inc., P.O. Box 4188, Boise, ID 83711). Grown under sprinkler irrigation at each site, dry bean was planted at a seeding rate of approximately 150,000 seeds ha^{-1}, in 76-cm-wide rows in Lingle and in 56-cm-wide rows in Scottsbluff, in keeping with the customary practice at both research centers. The experimental design for both the volunteer corn density and time of removal studies at both locations was a randomized complete block with four replications. Plots at

Table 1. Dry bean plant stand, planting dates, harvest date, and growing degree days (GDD) for the years 2008 and 2009 at both locations.

Operation	Lingle, WY 2008	Lingle, WY 2009	Scottsbluff, NE 2009
Dry bean plant stand (plants ha^{-1})	140,000	110,000	91,000
Dry bean planting date	June 16	May 29	June 5
Volunteer corn planting date	June 16	June 8	June 5
Harvest date	September 18	September 10	September 24
Accumulated GDD 50 d after planting	990	780	957
Accumulated GDD at harvest	1,640	1,700	2,004

SAREC were 3.1 by 10 m consisting of four rows, whereas those at PREC measured 3.4 by 10 m and consisted of six rows. Experimental sites were kept free of weeds by preplant-incorporated application of trifluralin (Trifluralin 4EC®, Agri Star®, Albaugh Inc., 1525 NE 36th Street, Ankeny, IA 50021) at 0.54 kg ha^{-1} and weekly hand weeding until the end of the season.

In 2008 at Scottsbluff, dry bean was replanted because of soil crusting. Uneven crop emergence after replanting continued to be a problem and resulted in variable plant stand and crop maturity, which affected dry bean seed yields. Consequently, data from Scottsbluff in 2008 was removed from all analyses. Dry bean yield was measured from a harvested area of 2.3 m^{-2} at SAREC and 3.4 m^{-2} at PREC from the center two rows of each plot. Crop growth and development conditions during the study were characterized by estimating growing degree days (GDD) for each location based on local weather data. GDD was calculated as

$$\mathrm{GDD} = \left[\sum (T_{\max} + T_{\min})/2\right] - T_{\mathrm{b}}, \qquad [1]$$

where $T_{\max}$ and $T_{\min}$ are daily maximum and minimum air temperatures (C), and T_{b} is the base or threshold temperature below which physiological activities are inhibited. A corn base temperature of 10 C was used to estimate the GDD for each site. Dry bean plant density, planting dates, harvest dates, and GDD are described in Table 1.

Time of Volunteer Corn Removal. Previous studies conducted in the study area showed no difference in competitive effects of F1 and F2 generations of hybrid corn seeds (Kniss et al. 2012). On the basis of those results, individual F1 hybrid corn seeds were hand planted soon after dry bean planting and placed in the dry bean row at a density of 1.2 plants m^{-2} in all plots. Corn plants were then removed at 0, 2, 4, 6, and 8 wk after bean emergence to establish varying volunteer corn interference periods; a season-long interference treatment was also included. At each removal timing, corn plants were either cut at the soil level and removed by hand or sprayed with quizalofop (Assure II®, Dupont™, E.I. du Pont de Nemours and Company, Agricultural Products, Wilmington, DE 19898) at 0.067 kg ai ha^{-1} plus crop oil concentrate at 0.5% by volume. Herbicide was applied with a CO_2-pressurized sprayer delivering a volume of 180 L ha^{-1} at a pressure of 275 kPa. In plots where volunteer corn was cut and removed, corn regrowth was removed by weekly hand weeding when necessary.

Volunteer Corn Density. In a similar manner as the volunteer corn removal study, individual F1 hybrid corn seeds were planted next to the dry bean row at densities of 0, 0.2, 0.6, 1.2, and 2.4 plants m^{-2}. This was achieved by hand hoeing corn seed holes at the designated densities.

Statistical Analysis. ANOVA was used to determine the effects of site, removal method, and removal time on dry bean yield in the time of removal study. Linear regression was then used to quantify the effect of removal time on dry bean yield. A similar approach was used for the density study, using ANOVA to determine the effect of site and density on dry bean yield, and the linear regression to quantify the effect of volunteer corn density on dry bean yield. For both studies, nonlinear regression models were tested but did not significantly improve model fit compared with linear regression models, so the simpler linear regression models were used. Comparisons between sites were made by calculating 95% confidence intervals for slope and y-intercept estimates. All data analysis was conducted using the R language version 3.2.3 (R Core Team 2015).

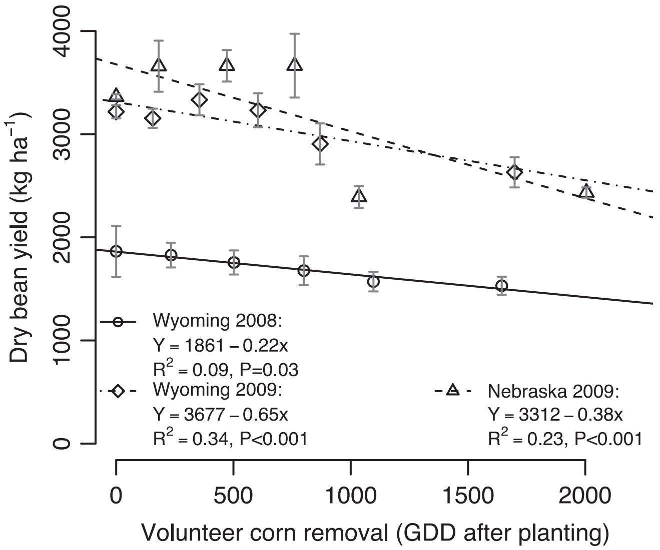

Figure 1. Dry bean yield loss as a function of volunteer corn time of removal measured as growing degree days (GDD) after planting for a 1.2 plants m^{-2} volunteer corn density interference at Scottsbluff, NE, and Lingle, WY, during the 2008 and 2009 growing seasons. Linear regression equations: dry bean yield Wyoming 2008 $= 1{,}861 - 0.22x$ ($R^2 = 0.09$); dry bean yield Wyoming 2009 $= 3{,}677 - 0.65x$ ($R^2 = 0.34$); dry bean yield Nebraska 2009 $= 3{,}312 - 0.38x$ ($R^2 = 0.23$).

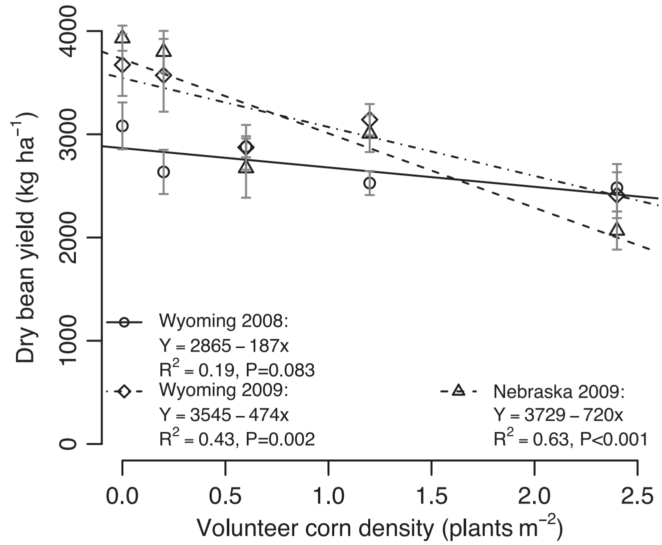

Figure 2. Dry bean yield loss as a function of volunteer corn density in 2008 and 2009 at Lingle, WY, and in 2009 at Scottsbluff, NE. Linear regression equations: dry bean yield Wyoming 2008 $= 2{,}865 - 187x$ ($R^2 = 0.19$); dry bean yield Wyoming 2009 $= 3{,}545 - 474x$ ($R^2 = 0.43$); dry bean yield Nebraska 2009 $= 3{,}729 - 720x$ ($R^2 = 0.63$).

Results And Discussion

Time of Volunteer Corn Removal. Dry bean yield was not significantly different whether volunteer corn was removed by hand or with herbicide ($P > 0.37$), indicating that both methods were equally appropriate. A significant site by time of removal interaction was observed ($P = 0.04$), suggesting that the yield effect of duration of volunteer corn interference was driven by growing conditions for each site (Figure 1). In 2008 at the Wyoming site, dry bean yield was estimated to decline by 0.22 kg ha^{-1} per GDD of interference. However, yield potential (estimated by the *y*-intercept) was significantly lower at that site than either site in 2009. As a percentage, dry bean yield was reduced by 1.2% per 100 GDD of interference at the Wyoming site in 2008, compared with 1.8% and 1.2% per 100 GDD at Wyoming and Nebraska, respectively, in 2009. By midseason (approximately 1,000 GDD), this would result in between 12 and 18% dry bean yield loss if volunteer corn were left uncontrolled.

Dry bean plant stands in 2009 for Wyoming and Nebraska were 110,000 and 91,000 plants ha^{-1}, which is below the optimum of 150,000 plants ha^{-1} recommended for Great Northern varieties in the area (Schwartz et al. 2004). In 2008, the Wyoming site had a dry bean stand of 140,000 plants ha^{-1}. Resources such as light, water, and nutrients are more available to other species in crops with low plant stands. However, percent yield loss from duration of volunteer corn interference was similar among the three sites regardless of plant stand. Good growing conditions early in the season, as indicated by the cumulative GDD for the first 50 d at Wyoming in 2008 (Table 1) and a high dry bean plant stand, helped to establish a competitive crop. The cumulative GDD were lower during the pod formation and filling stages in Wyoming for 2008, which may partially explain the overall lower yields for this location.

Volunteer Corn Density. A significant interaction between site and volunteer corn density was observed ($P = 0.02$), and although dry bean yield decreased as volunteer corn densities increased, rate of the reduction (slope) as well as yield without volunteer corn (*y*-intercept) differed among sites (Figure 2). Greater yield reductions were observed in Wyoming and Nebraska in 2009 compared with Wyoming in 2008. For each volunteer corn plant per square meter, dry bean yield was reduced 6.5, 13.4, and 19.3% for the Wyoming 2008, Wyoming

2009, and Nebraska 2009 studies, respectively. Dry bean plant stand followed a similar pattern, being greatest in Wyoming in 2008 (140,000 plants ha^{-1}) and lowest in Nebraska in 2009 (91,000 plants ha^{-1}) (Table 1). Although the bean stand difference did not greatly affect yield loss because of duration of interference, it seems to have played a larger role in season-long dry bean yield loss in response to volunteer corn density.

Volunteer corn growing in dry bean reduced yields as reported in other crops. Results from these studies can serve as a basis for an economic decision to control volunteer corn. The cost of the herbicide for volunteer corn control used in this study was \$39.50 ha^{-1} or \$58 ha^{-1} if custom application cost is included (UNL Extension 2015; Wilson 2014). For a dry bean price of \$0.57 kg^{-1} (USDA Economic Research Service 2015), the cost of controlling volunteer corn represents 102 kg ha^{-1} of dry bean. Given that average dry bean yield for eastern Wyoming and western Nebraska is 2,460 kg ha^{-1} (NASS et al. 2015), yield losses above 4% would exceed herbicide control costs, thereby justifying control. Using equations from linear regressions (Figure 2), 102 kg ha^{-1} yield loss was predicted to occur at volunteer corn densities of 0.6, 0.2, and 0.1 plants m^{-2} at Wyoming 2008, Wyoming 2009, and Nebraska 2009, respectively. As a conservative estimate, volunteer corn should be controlled at densities greater than 0.1 plants m^{-2} in dry bean.

On the basis of the regression equations for time of removal (Figure 1) the duration of interference that caused 102 kg ha^{-1} loss measured was 463, 157, and 268 GDD after planting for Wyoming 2008, Wyoming 2009, and Nebraska 2009, respectively. These GDD were recorded 26, 15, and 19 d after planting at the Wyoming 2008, Wyoming 2009, and Nebraska 2009 sites, respectively. These estimates are similar to recommendations for sugar beet, where volunteer corn densities as low as 0.03 plants m^{-2} caused economic yield loss calling for removal before 3.5 wk after planting (Kniss et al. 2012). These data suggest that very low volunteer corn densities warrant control from an economic perspective and that control measures should not be delayed beyond 20 d after planting, or earlier (15 d after planting) if volunteer corn densities are near 1 plant m^{-2}. Furthermore, a competitive crop plant stand and conditions during the growing season are important factors determining the effects of volunteer corn on dry bean.

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