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Soybean Seeding Rate Effects on Weed Management

Guillermo D. Arce, Palle Pedersen, and Robert G. Hartzler*

Studies were conducted in 2005 and 2006 at three Iowa locations to determine the effect of soybean seeding rate and glyphosate application timing on weed management and grain yields in glyphosate-resistant soybean. End-of-season weed populations were affected by soybean seeding rate at only one location, with higher weed densities present in the lowest seeding rate when glyphosate was applied at the V2 soybean growth stage. Although weed populations were not consistently affected by soybean population, weed biomass present at soybean harvest was inversely related to soybean population. At the location with the highest weed populations, no single glyphosate application provided yields equivalent to the weed-free control. At the other locations, glyphosate application timing did not affect soybean yield. Lower soybean yields occurred with 240,000 seed/ha compared with 420,000 seed/ha at all locations and with 300,000 seed/ha at two locations.

Nomenclature: Glyphosate; soybean, *Glycine max* L.

Key words: Plant population, glyphosate-resistant soybean, herbicide-tolerant crops.

The introduction of glyphosate-resistant (GR) soybean varieties in 1996 resulted in rapid changes in soybean production (Culpepper et al. 2000). In 2005, GR soybean accounted for more than 87% of the soybean planted in the Midwest United States (USDA 2006). The primary reason for the rapid adoption of GR soybean is the flexibility that glyphosate provides in controlling a broad spectrum of weeds with little risk of herbicide injury to the crop (Reddy and Whiting 2000). Glyphosate also controls larger weeds than alternative herbicides and may be applied from soybean emergence to the full flowering stage (Mulugeta and Boerboom 2000).

Cultural strategies, such as row spacing and seeding rate, influence the ability of the crop to compete with weeds for resources and, therefore, may affect weed management (Grichar et al. 2004; O'Donovan et al. 2001). More rapid closure of the soybean canopy can be obtained with a reduction in row spacing (Renner and Mickelson 1997; Wax and Pendleton 1968), an increase in seeding rate (Nice et al. 2001), and selection of varieties with traits that favor rapid canopy development (Bussan et al. 1997). Corrigan and Harvey (2000) and Wax and Pendleton (1968) found that rows of 38 cm or less could increase yields and reduce tillage and herbicide requirements because of faster canopy closure.

Renner and Mickelson (1997) found that a closed soybean canopy suppressed late-emerging weeds and any weeds that survived a POST herbicide. Kells et al. (2004) and Young et al. (2001) found that soybean planted in either 19-cm or 38-cm rows suppressed weed growth after glyphosate application more than soybean planted in 76-cm rows. More rapid canopy closure in narrow rows reduces weed germination and growth following herbicide application (Renner and Nelson 1999). Howe and Oliver (1987) found that soybean planted in 20-cm rows reduced pitted morningglory (*Ipomoea lacunosa* L.) leaf area index and seed production, compared with those growing in soybean planted in 1-m rows. In addition to shading weeds, changes in canopy characteristics can alter herbicide deposition on weeds. Hoverstad and Johnson (2002) stated that differences in weed control between narrow-row and wide-row corn (*Zea mays* L.) systems may be due to the greater herbicide interception by the corn canopy in narrow rows.

Crops seeded at high populations may have a competitive advantage over weeds because of rapid canopy development. Weiner et al. (2001) stated the crop fraction of the total plant biomass should increase with increasing crop populations, resulting in almost complete weed suppression at very high densities. Tharp and Kells (2001) found that increasing corn population from 60,000 to 73,000 plants/ha reduced common lambsquarters (*Chenopodium album* L.) biomass and fecundity and increased corn yield in the northern Corn Belt. Nice et al. (2001) found that increasing soybean populations from 245,000 plant/ha to 481,000 and 676,000 plants/ha coupled with reduced row spacing reduced sicklepod (*Senna obtusifolia* L.) density and growth.

High soybean seeding rates were commonly used in the past with conventional soybean cultivars, which frequently were established using saved seed, and thus, seeding rate did not significantly affect production costs (Kratochvil et al. 2004). Before increasing seeding rates to enhance weed suppression in GR cultivars, the economic benefit of higher seeding rates should be considered because increased seed fee costs may exceed the benefits in weed suppression (Nice et al. 2001; Renner and Nelson 1999). According to Norsworthy and Frederick (2002) the recommended seeding rate of GR soybean can be lowered without negatively affecting yield. Holshouser and Whittaker (2002) found that a population of 208,000 seeds/ha was adequate for maximizing yields. Kratochvil et al. (2004) found that yields from a seeding rate of 345,000 seeds/ha were not significantly different than the standard seeding rate of 432,500 seeds/ha. The reduction in seeding rates resulted in an additional profit ranging from $14 to $28/ha because of lower seed costs. Norsworthy and Oliver (2001) reported that the profit margin from weed management was optimized with a population of 185,000 seeds/ha. They stated that the savings in seeds costs was greater than the expenses for an additional glyphosate application.

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* Graduate Research Assistant, Assistant Professor, and Professor, Department of Agronomy, Iowa State University, Ames, IA 50010. Corresponding author's E-mail: hartzler@iastate.edu

Table 1. Date of soybean planting, herbicide application, harvest, and weed biomass assessment to evaluate the plant population effect on weed management at Boone, IA, 2005, and Kanawha and Ames, IA, 2006.

Operation	Boone	Kanawha	Ames
Soybean planting	May 5	May 8	May 11
Glyphosate timing			
V2 stage	June 10	June 11	June 9
V4 stage	June 17	June 20	June 19
V6 stage	June 24	June 28	June 28
Weed biomass harvest	September 7	September 11	September 8
Grain harvest	September 21	October 5	October 9

Table 2. Weed heights and weed densities at glyphosate application at Boone, IA, 2005, and Kanawha and Ames, IA, 2006.[a]

Glyphosate timing	Boone		Kanawha		Ames	
	Population	Ht	Population	Ht	Population	Ht
	plants/m^2	cm	plants/m^2	cm	plants/m^2	cm
V2[b]	69	5	197	5	19	8
V4	72	11	434	19	136	20
V6	88	22	219	46	89	34

[a] Values represent the average across soybean seeding rate.

[b] V2 data are pooled values of the V2 and the V2 + V6 treatments.

Recent research in Iowa found that economic returns did not differ among seeding rates between 185,300 and 556,000 seed/ha (De Bruin and Pedersen 2008). Yield increases from seeding rates higher than 185,300 seed were marginal and did not compensate for higher seed costs. Soybean populations required to achieve yields within 95% of the maximum ranged from 194,000 to 290,800 plants/ha. These harvest plant populations are considerably lower than previously recommended in Iowa, which ranged from 308,000 to 370,500 plants/ha depending upon row spacing (Whigham 1998). The purpose of this research was to determine whether reductions in seeding rates affect glyphosate efficacy and suppression of weeds in GR soybean.

Materials and Methods

During 2005, an experiment was conducted at the Iowa State University Agronomy Research Farm near Boone, IA. The soil was a Clarion (fine-loamy, mixed, superactive, mesic Typic Hapludoll), Nicollet (fine-loamy, mixed, superactive, mesic Aquic Hapludoll), and Webster (fine-loamy, mixed, superactive, mesic Typic Endoaquoll) with pH of 5.9 and 4.0% organic matter. In 2006, experiments were performed at the Iowa State University Northern Research Farm at Kanawha, IA, and at the Iowa State University Curtiss Farm at Ames, IA. The soil at the Kanawha, IA, site was a Canisteo (fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquoll) with pH of 7.0 and 6.3% organic matter. The soils at the Ames, IA, site were a Canisteo (fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquoll), Nicollet (fine-loamy, mixed, superactive, mesic Aquic Hapludoll), and Clarion (fine-loamy, mixed, superactive, mesic Typic Hapludoll) with a pH of 7.1 and 3.0% organic matter. Plots were chisel-plowed in the fall, and final seedbed preparation was completed with a field cultivator immediately before planting. The previous crop at all sites was corn.

A full-season GR soybean cultivar, Golden Harvest H-2162 RR,[1] was planted in 38-cm rows on May 5, 2005, at Boone, IA; May 8, 2006, at Kanawha, IA; and May 11, 2006, at Ames, IA, using a plot planter.[2] Plot size was 3.0 m (seven rows) by 7.6 m for all three locations. Dates for experimental procedures are provided in Table 1.

Seeding rate and glyphosate application timing were manipulated to evaluate the effect of soybean population on weed management systems relying on POST applications of glyphosate. The treatments were a two-way factorial of soybean seeding rates and glyphosate application timing arranged in a randomized complete-block design with four replications. Seeding rates were 240,000, 300,000, 360,000, and 420,000 seed/ha. Glyphosate was applied at the V2, V4, or V6 soybean growth stage (Fehr and Caviness 1977) and included a weed-free treatment (sequential application of glyphosate at V2 and V6 soybean stage) and a weedy control. Glyphosate[3] was applied at 1.00 kg ae/ha plus 1% wt/v of ammonium sulfate with a CO_2 backpack sprayer using 8002 flat fan nozzle tips,[4] delivering 140 L/ha at 275 kPa. The 1.00 kg/ha rate was used at all application timings to minimize the risk of weeds surviving application regardless of weed size.

Data collection included visual estimates of weed control on a scale of 0 (no control) to 100% (complete control) relative to the weedy control. Weed control was evaluated 14 and 21 d after application (DAA). Soybean injury was evaluated visually on a scale of 0 (no injury) to 100% (complete crop death) at 14 DAA.

Weed population and height were determined at the time of glyphosate application (Table 2). Four 0.093-m^2 quadrats were placed arbitrarily between rows three and four of each plot. Foxtail (*Setaria* spp.) and common waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] were the predominant weeds in 2005. During 2006, common lambsquarters (*Chenopodium album* L.) and foxtail were the predominant weeds at Kanawha, IA, whereas at Ames, IA, common lambsquarters, waterhemp, and foxtail were the primary weeds. End-of-season weed population and biomass were obtained by harvesting plant shoots at the soil line in early September from four 0.093-m^2 quadrats placed arbitrarily between rows three and four of each plot. Weed biomass was dried for 7 d at 65 C. Soybean plant counts were made immediately before the V2 application and on September 20, 2005, at Boone, IA, and September 13 and 14, 2006, at Kanawha and Ames, IA, respectively.

Soybean height was determined by measuring three arbitrarily selected plants per plot in September. Soybean grain was machine-harvested from the middle four rows for the entire length of each plot. Yield was adjusted to 13% moisture before analysis.

Statistical Analysis. Barlett's chi-square test for homogeneity of variance was tested, and data were combined over years and sites when appropriate. All data were subjected to ANOVA using PROG GLM of SAS.[5] The main effects and interaction of glyphosate application timing and soybean seeding rate were tested using ANOVA. Mean separation was conducted

Table 3. Mean monthly and 30-yr average rainfall for Boone, IA, 2005, and Kanawha and Ames, IA, 2006.

	Boone		Kanawha		Ames	
Month	2005	30-yr avg.	2006	30-yr avg.	2006	30-yr avg.
	cm					
April	8.0	7.9	11.4	7.9	11.5	9.1
May	11.8	12.0	2.2	8.9	6.1	12.0
June	12.2	14.0	8.2	12.1	1.9	11.9
July	9.8	8.5	6.5	11.9	13.0	9.6
August	17.2	8.5	8.0	9.7	17.5	12.1
September	10.5	7.3	15.2	7.2	14.5	7.1

Table 4. Effect of soybean seeding rate on final soybean density at Boone, IA, 2005, and Kanawha and Ames, IA, 2006.

Seeding rate	Soybean density[a,b] Boone	Kanawha	Ames
seed/ha	plants/ha		
240,000	250,112 ± 4,456	173,680 ± 10,841	179,687 ± 11,072
300,000	298,035 ± 9,406	209,180 ± 17,491	218,465 ± 9,739
360,000	340,805 ± 12,714	275,266 ± 16,887	263,796 ± 9,957
420,000	401,839 ± 12,177	305,851 ± 12,220	299,843 ± 17,216

[a] Plant counts were taken in mid-September. Data are pooled across the glyphosate timings at each soybean seeding rate.

[b] Data are means ± standard errors.

using Fisher's Protected $LSD_{0.05}$ test. Data from the weedy control were excluded from the analysis for grain yield, grain moisture, plant height, and end-season weed biomass because of the high degree of variability within the data. All the effects, except block, were considered fixed in determining the expected mean squares and the appropriate P value in the ANOVA. Regression analyses were performed using SAS REG procedures to evaluate the relationship between soybean population and weed biomass.

Results and Discussion

Environmental conditions and weed infestations varied considerably at the three locations. At Boone, IA, in 2005, monthly precipitation throughout the growing season was similar to, or greater than, the 30-yr average monthly rainfall (Table 3). In 2006, monthly precipitation at Kanawha, IA, was far below the 30-yr average from May to August. Ames, IA, monthly rainfall was below the 30-yr average in both May and June.

Final soybean populations were within 5% of targeted seeding rates at Boone, IA, in 2005 (Table 4). During 2006, soybean establishment was low, resulting in final soybean plant populations 24 to 30% below the seeding rate at both locations. The reductions in soybean population occurred before the V2 growth stage (data not presented). Below normal rainfall and temperatures during the first 6 wk after planting in 2006 may have been the cause of the low final populations compared with 2005. Current recommendations for Iowa are to target seeding rates that will provide 247,000 soybean plants at harvest (Pedersen 2008). This is a lower population than currently used by many farmers but is conservative to avoid increased risks of reduced economic returns (De Bruin and Pedersen 2008). At Boone, IA, all seeding rates exceeded the recommended population, whereas at Kanawha and Ames, IA, the two lowest seeding rates resulted in populations below recommended levels for optimum yields.

Weed Control. No soybean injury from glyphosate was observed at the Boone or Kanawha, IA, locations (data not shown). At Ames, IA, minor injury (< 15%) consisting of chlorosis of leaves initiated immediately following the V2 application was observed. Although most studies have not reported an adverse response to glyphosate in GR soybean (Culpepper et al. 2000; Kells et al. 2004), Pline et al. (1999) reported chlorosis under certain conditions. Seeding rate did not affect weed control 3 wk after application at any location (data not shown). Glyphosate efficacy was not affected by application timing at Boone, IA, but at Kanawha, IA, the V6 application provided less control (88%) than other application timings (> 97%). At Ames, IA, the V2 timing provided better control than the other application timings, although all timings provided greater than 95% control. The improved efficacy of early glyphosate applications compared with applications at the V6 stage at two locations was probably due to the treatment of smaller weeds and better coverage. Presence of large weeds at a late POST timing may reduce glyphosate efficacy (Young et al. 2001).

Glyphosate does not affect weeds that emerge after application because of adsorption to soil colloids (Sprankle et al. 1975); thus, the soybean canopy must suppress any late-emerging weeds to maintain full-season control. Soybean seeding rate did not affect late-season weed populations at Ames or Kanawha, IA, but at Boone, IA, both soybean seeding rate and application timing and also the seeding rate by application timing interaction were significant (Table 5). Weeds emerging following the V2 application resulted in end-of-season weed densities more than 10 times higher in the V2 timing treatment than in either the V4 or V6 timing at Kanawha, IA. At Boone, IA, weeds were only found in the combination of the lowest seeding rate sprayed at the V2 soybean stage, resulting in the significant seeding rate by application interaction (data not shown). Early applications of glyphosate increase the risk of late-season weeds because the crop canopy was not complete at the time of application. Reductions in soybean seeding rates resulted in increased late-season weed densities at only one of the three locations (Boone, IA), and at that location, weeds were present only after the earliest POST application. Seeding rate did not affect late-season weed populations at Kanawha, IA, where weed densities were at least twice as high as those at the other two locations (Table 2).

Although there was no consistent response in weed population to soybean populations, end-of-season weed biomass decreased linearly as plant population increased at all three locations (Figure 1). At the Ames, IA, site, only weedy control plots were infested with weeds at harvest, whereas at Boone, IA, the lowest seeding rate with the earliest glyphosate application plots and the control plots were infested with weeds at harvest. At Kanawha, IA, weeds were

Table 5. End-of-season weed density as affected by glyphosate timing and soybean seeding rate at Boone, IA, 2005, and Kanawha and Ames, IA, 2006.

Factor	Weed density[a] Boone	Kanawha	Ames
	——plants/m^2——		
Seeding rate[b] (seed/ha)			
240,000	5	46	1
300,000	0	37	0
360,000	0	19	0
420,000	0	39	0
$LSD_{0.05}$	4	NS	NS
Glyphosate timing[c]			
V2	5	125	1
V4	0	9	0
V6	0	7	0
$LSD_{0.05}$	4	30	NS
	——$P > F$——		
ANOVA			
Seeding rate (S)	0.040	NS	NS
Glyphosate timing (T)	0.040	< 0.0001	NS
S × T	0.007	NS	NS

[a] Abbreviation: NS, nonsignificant at the 0.05 level.
[b] Values represent the average across glyphosate timings.
[c] Values represent the average across soybean seeding rates.

Table 6. Effect of soybean seeding rate and glyphosate application timing on soybean grain yield at Boone, IA, 2005, and Kanawha and Ames, IA, 2006.

Factor	Grain yield[a] Boone	Kanawha	Ames
	——kg/ha——		
Seeding rate[b] (seed/ha)			
240,000	4,023	2,119	2,519
300,000	4,300	2,374	2,471
360,000	4,428	2,537	2,820
420,000	4,582	2,631	2,824
$LSD_{0.05}$	181	308	223
Glyphosate timing[c]			
V2	4,247	2,012	2,695
V4	4,283	2,521	2,613
V6	4,366	2,228	2,699
Weed free	4,398	2,900	2,627
$LSD_{0.05}$	NS	308	NS
Factor	——$P > F$——		
Seeding rate (S)	< 0.0001	0.0096	0.0017
Glyphosate timing (T)	NS	< 0.0001	NS
S × T	0.0059	NS	NS

[a] Abbreviation: NS, nonsignificant at the 0.05 level.
[b] Values represent the average across glyphosate timings.
[c] Values represent the average across soybean seeding rates.

present at harvest in all treatments except the weed-free treatment (Table 5). The reduction in weed biomass associated with increasing soybean population indicates that higher planting rates increased the competitiveness of the crop with weeds. In situations where glyphosate is effective in GR soybean, reductions in seeding rates may not be an issue in terms of weed management because there was no increase in late-season weed densities following the V4 or V6 applications typical of commercial production. However, the reduced competitiveness of lower soybean populations (Figure 1)

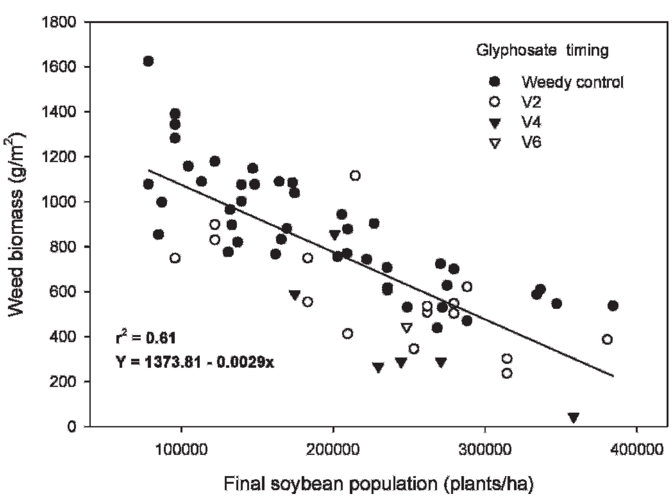

Figure 1. Relationship between final soybean population and end-of-season weed biomass at Boone, Kanawha, and Ames, IA (2005, 2006). Data were pooled across years, locations, herbicide application timing, and final soybean population and were regressed against final plant population, where x is the final soybean plant population/ha, and y is weed biomass. Herbicide application time is indicated by the symbol.

could increase problems in managing difficult-to-control weed species and GR weed biotypes (Legleiter and Bradley 2008; VanGessel 2001). Weed fecundity is directly related to biomass production (Conley et al. 2002; Hartzler et al. 2004), thus low seeding rates may result in an increase in the weed seed bank when glyphosate provides incomplete weed control.

Soybean Growth and Yield. Soybean seeding rate did not affect plant height at harvest (data not shown). Bertram and Pedersen (2004) also reported that plant population did not influence plant height in Wisconsin. The V6 application resulted in soybean heights that were 22 and 9% shorter than weed-free soybean at Kanawha and Ames, IA, respectively, possibly because of the relatively long period of early season weed competition. At Kanawha, IA, soybeans treated at V2 were taller than the weed-free soybeans. The competitive advantage for soybean provided by early removal of weeds may have allowed the soybean to compete effectively with the high densities of late-emerging weeds at this location via stem elongation.

Soybean seeding rate affected grain yield at all three locations, whereas glyphosate application timing was only significant at Kanawha, IA, the site with the highest weed densities (Table 6). The interaction between soybean population and application timing was significant only at Boone, IA. Regression analysis of soybean yield by final soybean population did not reveal statistically significant relationships, so treatment means are presented. Soybean at 240,000 seed/ha resulted in the lowest yields at all locations, and at Boone and Ames, IA, the two lowest seeding rates produced yields lower than the highest seeding rate (Table 6). These results are not surprising at Ames and Kanawha, IA, because the two lowest seeding rates resulted in final plant populations below 200,000 plants/ha, whereas minimum recommended final populations are 247,100 plants/ha (Pedersen 2008).

Glyphosate application timing only affected yields at Kanawha, IA, the site with the highest weed densities (Table 6). At this site, the three single-application treatments averaged 22% less grain than the sequential-application, weed-free treatment. Yield loss in the V2 treatment may have been due to late-season competition by weeds that emerged following glyphosate application (Table 5), whereas yield losses in the V4 and V6 treatment may have been due to the combination of both early and late-season competition.

Application timing was less critical at Boone and Ames, IA, sites with lower weed densities, than at Kanawha, IA. The significant interaction between seeding rate and glyphosate application timing at Boone, IA, was due to reduced yields in the 240,000 seeding rate with a V2 glyphosate application (data not shown). Yield in this treatment was reduced by more than 1,000 kg/ha compared with the weed-free treatment at this seeding rate. The combination of low seeding rate and early POST application resulted in this being the only treatment to have weeds present at harvest (Table 5), and weeds emerging after glyphosate application may be the cause of the yield loss. Soybean yields were not affected by glyphosate timing within the other seeding rates.

Recent reductions in soybean seeding rate recommendations have raised concerns regarding possible negative impacts on weed management. Similar to other research (Howe and Oliver 1987; Nice et al. 2001), our findings show that reducing crop population may provide a more favorable environment for weed growth (Figure 1). In these studies, when glyphosate was applied later than the V2 growth stage and controlled established weeds, the reduction in soybean population did not influence end-of-season weed densities. However, as weed shifts occur in response to prolonged reliance on glyphosate, weed escapes because of glyphosate-tolerant and GR weeds can be expected to increase (Owen 2008). Current GR weeds possess a moderate level of resistance to glyphosate (Powles and Preston 2006). Reduced soybean seeding rates may enhance the survival and spread of these weeds because the reduction in crop competitiveness (Figure 1) could enhance survival and fecundity of weeds suppressed, but not killed, by glyphosate. Thus, in fields where farmers have had difficulty in managing weeds, avoiding the low end of recommended seeding rates may improve the consistency of weed management.

Sources of Materials

[1] Syngenta Seeds, Golden Valley, MN 55427.

[2] Cone type planter, Almaco, Nevada, IA 50201.

[3] Roundup WeatherMAX, Monsanto Company, St. Louis, MO, 63167.

[4] Teejet XR8002 flat-fan nozzle tip, Spraying Systems Co., Wheaton, IL 60189.

[5] SAS statistical software, SAS Institute Inc., Cary, NC 27513.

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