Influence of soybean population on the efficacy of glyphosate

by

Guillermo D. Arce Reyes

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Crop Production and Physiology

Program of Study Committee:
Robert G. Hartzler, Major Professor
Micheal D.K. Owen
Palle Pedersen
Matthew O'Neal

Iowa State University

Ames, Iowa

2006

UMI Number: 1439905

UMI

UMI Microform 1439905

ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

To my parents: Guillermo E. Arce and Ana V. Reyes

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

I would like to extend my gratitude to my thesis committee members: Robert Hartzler, Micheal Owen, Palle Pedersen, and Matthew O'Neal. Their continual support and suggestions throughout this process and my personal struggles have made it a much more pleasant experience, and it has enabled me to finish this *thesis* that is before you.

I would also like to extend my gratitude to the personal staff of the Illinois Natural History Survey, especially to John Shaw for helping me to start this journey, as well to Abelino Pitty for his help during my career.

I would also like to thank my family and friends for always encouraging me and helping me stay on track, and for their love and support always. In addition, specials thanks to Philip Dixon, Jim Lux, Damian Franzenburg, and Ian Zelaya for all their advice. Finally, tremendous thanks to Jason De Bruin, Jodee Roland, Santiago Ulloa, Dorivar Ruíz-Díaz, Adriana Murillo-Williams, Andres Egas, David Rueber, José Gómez for all their generous help in the field and laboratory experiments.

ABSTRACT

Studies were conducted at three Iowa locations in 2005 and 2006 to test if a reduction in soybean seeding rate would reduce weed suppression and increase glyphosate efficacy. The cultivar H-2162 RR was planted at four seeding rates (240,000, 300,000, 360,000, and 420,000 seed ha^{-1}) for both experiments. In the first experiment, treatments included glyphosate applied at V2, V4, V6, and V2+V6 soybean stage at Boone, Hancock and Story. Weed control efficacy was influenced more by application timing than by soybean seeding rate, while grain yield was influenced more by soybean population than application timing. Weed control was almost 100% at Boone and Story, while at Hancock delaying application until V6 weed control was only 88%. At the highest seeding rate compared to the lowest seeding rate at Boone, Hancock, and Story soybean yield increased 11, 20, and 11% respectively. In the second experiment, treatments included application of two glyphosate rates 0.5 and 1.0 kg ae ha^{-1} when common lambsquarters was 10 cm tall and soybean was at V6 stage. Herbicide interception was affected by plant population, whereas weed control was not affected. Common lambsquarters control was 100% at 21 DAA for both glyphosate rates. These results suggest that soybean population influenced grain yield under favorable or drought conditions. Soybean population also did not affect the efficacy of glyphosate. At places with high weed densities no single glyphosate application guarantees high grain yield. Under these conditions a second glyphosate application may be needed to protect yields.

Key words: soybean stage, seeding rate, herbicide interception, glyphosate rate.

Abbreviation: DAA, days after application; ae, acid equivalent.

CHAPTER I

General Introduction

Introduction

Weeds and crops compete for the same resources: sunlight, mineral nutrients, and for space to grow and acquire resources (Guveritch et al. 2002). When one of these resources becomes limited, crop growth may be negatively affected. The competitive stress created by neighboring plants may result in an increase in crop plant mortality, reduction in growth rate, and a reduction in seed production (Monks and Oliver, 1988). Weed competition in soybean (*Glycine max* L.) may start near the beginning of the growing season and persist through the end of the cropping season (Mulugeta and Boerboom, 2000).

Weed communities are frequently a mixture of different weed species at different stages of maturity and different densities. Due to the complexity of weed communities, a single control tactic may provide inconsistent control. An early application of glyphosate can be ineffective on late-emerging weeds. However, if the glyphosate application is delayed the herbicide effectiveness on the early-emerging weeds will decrease because weeds will become larger and will require higher than recommended rates for satisfactory control (VanGessel *et al.* 2000). Weed density may also influence the optimum application timing. Fields with higher weed densities competing with soybean at early growing stages will require an early application and probably a late application to obtain adequate control, while at fields with lower densities; herbicide application may be delayed if yield is not compromised. It is critical to determine the optimum time for herbicide application to optimize weed control and profits. New technology in agriculture has provided new options for weed control in corn and soybean. One of these technologies was the development of glyphosate-resistant crops (Culpepper *et al.* 2000) which allows the use of glyphosate for weed control throughout the cropping season with little risk of crop injury.

Cultural practices such as narrow rows (≤ 38 cm) and soybean population may affect weed control and maximum economic return in glyphosate-based systems. Bradley (2006), Burnside and Moomaw (1977), Howe and Oliver (1987), Nice *et al*. (2001) Renner and Mickelson (1997), Renner and Nelson (1999), and Wax and Pendleton (1968) stated that planting soybean in narrow rows improved weed control without requiring more time and cultivation. In addition, Norsworthy (2004) and Renner and Nelson (1999) found that weed emergence and growth in narrow rows was less than emergence in wide rows. Control of common ragweed (*Ambrosia artemisiifolia* L.), redroot pigweed (*Amaranthus retroflexus* L.), and velvetleaf (*Abutilon theophrasti* Medik.) was greater in narrow rows than in wide-rows using the recommended postemergence herbicide rate (Renner and Nelson, 1999). Curran *et al*. (2001) stated that row spacing may help reduce the growth of late-emerging burcucumber (*Sicyos angulatus* L.). Pitted morningglory (*Ipomoea lacunosa* L.) seed production was lower in narrow soybean rows than conventional wide rows (Howe and Oliver, 1987). Renner and Mickelson (1997) stated that planting soybean in 19 cm rows resulted in 30% less weed biomass and 14% greater soybean yield compared with soybean planted in 76 cm rows. The major influence of narrow soybean spacing is the reduction in the amount of light that reaches plants below the canopy and the reduction of time to reach full canopy closure (Bradley, 2006). Regnier and Stoller (1989) found that soybean is an effective shade producer. Soybean planted in 19 or 38 cm rows suppressed weed growth after glyphosate application more than soybean in 76 cm rows (Kells *et al.* 2004; Young *et al.* 2001).

Increased soybean density may promote early canopy closure to provide advantages over late-emerging weeds, therefore increasing herbicide effectiveness (Norsworthy, 2005). However, the benefits of increasing the seeding rate in glyphosate-resistant crops may be surpassed by seed costs due to the technology fee associated with the glyphosate-resistant trait (Norsworthy and Oliver, 2001). Thus, soybean producers may lower soybean seeding rates to reduce seed costs if there are no effects on grain yield. Norsworthy and Frederick (2002) stated that the seeding rate in glyphosate-resistant soybean can be lowered without negatively affecting seeding yields.

This thesis is composed of two experiments focusing on the effect of soybean densities on weed management in glyphosate-resistant soybean in Iowa. The first manuscript reports on the effect of soybean seeding rate and glyphosate application timing on soybean yield and weed control. The second manuscript deals with the impact of soybean seeding rates on common lambsquarters control with glyphosate.

References

Bradley, K.W. 2006. A review of the effects of row spacing on weed management in corn and soybean. [Online]. Available at www.plantmanagementnetwork.org/cm/. Crop Manage. DOI 10.1094/CM-2006-0227-02-RV.

Burnside, O.C. and R.S. Moomaw. 1977. Control of weed in narrow-row soybean. Agron. J. 69:793−796.

Culpepper, A.S., A.C. York, R.B. Batts, and K.M. Jennings. 2000. Weed management in glufosinate and glyphosate-resistant soybean (*Glycine max*). Weed Technol. 14:77−88.

Curran, W.S., W.R. Esbenshade, G.W. Roth, N.L. Harting, and M.D. Orzolek. 2001. Effect of tillage, row spacing, and herbicide on the emergence and control of burcucumber (*Sicyos angulatus*) in soybean (*Glycine max*). Weed Technol. 15:229−235.

Gurevitch J., S.M. Scheiner, and G.A. Fox, eds. 2002. The ecology of plants. Massachusetts: Sinauer Associates, Inc. Pp. 106−107.

Howe, O.W. and L.R. Oliver. 1987. Influence of soybean (*Glycine max*) row spacing on pitted morningglory (*Ipomoea lacunose*) interference. Weed Sci. 35:185−193.

Kells, J.J., C.D. Dalley, and K.A. Renner. 2004. Effect of glyphosate application timing and row spacing on weed growth in corn (*Zea mays*) and soybean (*Glycine max*). Weed Technol. 18:177−182.

Monks, D.W. and L.R. Oliver. 1988. Interaction between soybean (*Glycine max*) cultivar and selected weeds. Weed Sci. 36:770−774.

Mulugeta, D. and C.M. Boerboom. 2000. Critical time of weed removal in glyphosate-resistant *Glycine max.* Weed Sci. 48:35−42.

Nice, G.R., N.W. Buehring, and D.R. Shaw. 2001. Sicklepod (*Senna obtusifolia*) response to shading, soybean (*Glycine max*) row spacing, and population in three management systems. Weed Technol. 15:155−162.

Norsworthy, J.K. 2005. Optimizing glyphosate timing in a mixed stand of glyphosate-resistant/conventional, drill-seeded soybean. Weed Technol. 19:942−946.

Norsworthy, J.K. 2004. Soybean canopy formation effects on pitted morningglory (*Ipomoea lacunose*), common cocklebur (*Xanthium strumarium*), and sicklepod (*Senna obtusifolia*) emergence. Weed Sci. 52:954−960.

Norsworthy, J.K. and J.R. Frederick. 2002. Reduced seeding rate for glyphosate resistant, drilled soybean on the Southeastern coast plain. Agron. J. 94:1282−1288.

Norsworthy, J.K. and L.R. Oliver. 2001. Competitive potential and economic analysis of glyphosate-tolerant/conventional soybean (*Glycine max*) mix. Weed Technol. 15:177−183.

Regnier, E. R. and E.W. Stoller. 1989. The effect of soybean (*Glycine max*) Interference on the canopy architecture of common cocklebur (*Xanthium strumarium*), jimsonweed (*Datura atramoniun*), and velvetleaf (*Abutilon theophrasti*). Weed Sci. 37:187−195.

Renner, K.A. and K.A. Nelson. 1999. Weed management in wide and narrow row glyphosate resistant soybean. J. Prod. Agric. 12:460−465.

Renner, K.A. and J.A. Mickelson. 1997. Weed control using reduced rates of post-emergence herbicides in narrow and wide row soybean. J. Prod. Agric. 10:431−437.

VanGessel, M.J., A.O. Ayeni, and B.A. Majek. 2000. Optimum glyphosate timing with or without residual herbicides in glyphosate-resistant soybean (*Glycine max*) under full-season conventional tillage. Weed Technol. 14:140−149.

Wax, L.M. and J.W. Pendleton. 1968. Effect of row spacing on weed control in soybean. Weed Sci. 16:462−465.

Young, B.G., J.M. Young, L.C. Gonzini, S.E. Hart, L.M. Wax, and G. Kapusta. 2001. Weed management in narrow and wide row glyphosate-resistant soybean (*Glycine max*) Weed Technol. 15:112−121.

CHAPTER II

Soybean Plant Density Effects on Weed Management

A paper to be submitted to Weed Technology

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

Department of Agronomy, Iowa State University, Ames, IA 50010

Abstract

Studies were conducted in 2005 and 2006 at three Iowa locations to determine the effect of soybean seeding rate and glyphosate application timing on soybean yield and weed control. The cultivar H-2162 RR was planted at four seeding rates (240,000, 300,000, 360,000, and 420,000 seed ha^{-1}). Final soybean population varied at the three locations. During 2005 soybean population was within 95% of target seeding rate, while during 2006 at both locations soybean population was 24 to 30% below the seeding rates. *Setaria* spp. and *Amaranthus* spp. were the predominant species in 2005, while in 2006 *Chenopodium album*, *Setaria* spp., and *Amaranthus* spp. were the predominant species. Weed control was influenced more by application timing than by soybean population, while grain yield was influenced by soybean population. Weed control was almost 100% at Boone and Story, while at Hancock delaying application until V6 decreased weed control to 88%. At the highest seeding rate compared to the lowest seeding rate at Boone, Hancock and Story soybean yield increased 11, 20, and 11% respectively. The results indicate that soybean populations influence grain yield under favorable or drought conditions.

Application timing becomes critical at places with high weed densities. Late-emerging weeds may warrant a second glyphosate application under this condition.

Key words: Soybean growth stage, common lambsquarters, foxtail, pigweed.

Introduction

The adoption of new technology has resulted in significant changes in soybean (*Glycine max*. L.) production in the last decade. One example is the introduction of glyphosate-resistant soybean varieties in 1996 (Culpepper *et al*. 2000). In 2005, glyphosate resistant soybean accounted for over 87% of the hectares planted in the Midwest USA and the adoption is increasing (USDA, 2006). A primary reason for the rapid adoption is the flexibility that glyphosate provides in controlling a broad spectrum of weed with little risk of herbicide injury to the crop (Reddy and Whithing, 2000). Glyphosate also provides a wide application window from emergence to the full flowering stage (Mulugeta and Boerboom, 2000).

Cultural strategies such as row spacing, seeding rate, and fertilizer placement may alter the ability of the crop to compete with weeds for resources such as light, reduce weed seed production and, by inference, dependence on herbicides for weed control (Grichar *et al*. 2004; O'Donovan *et al.* 2001). Corrigan and Harvey (2000) and Wax and Pendleton (1968) found that narrow rows (≤ 38 cm) may increase yields and reduce the need for tillage and herbicide use since they allow a faster canopy closure.

A faster closure in soybean canopy can be obtained with a reduction in row spacing (Renner and Mickelson 1997 and 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). Renner and Mickelson (1997) found that a closed soybean canopy suppressed late emerging weeds and weeds that survive a postemergence herbicide application. Kells *et al.* (2004) and Young *et al.* (2001) found that soybean planted in either 19 or 38 cm rows suppressed weed growth after glyphosate application more than soybean in 76 cm rows. More rapid canopy closure in narrow rows reduces weed germination and growth following herbicide application (Renner and Nelson 1999). In addition to shading weeds, changes in canopy characteristics might alter herbicide deposition on weeds. Hoverstad and Johnson (2002) stated that differences in weed density between narrow and wide row corn systems may be due to the greater herbicide interception by corn canopy in narrow than in wide row system.

Crops seeded at high densities may have a competitive advantage over weeds due to rapid canopy development. Therefore, increasing the degree of size-asymmetric competition in the crop-weed community should benefit the crop at expense of the weed (Weiner *et al.* 2001). Schwinning and Weiner (1998) stated that size-asymmetry competition occurs when larger plants get the majority of the contested resources, consequently suppressing the growth of smaller neighbors. Weiner *et al*. (2001) stated the crop fraction of the total plant biomass should increase with increasing crop density, resulting in almost complete weed suppression at very high density. Tharp and Kells (2001) found that increasing corn population from 60,000 to 73,000 plants/ha reduced common lambsquarters 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 improved sicklepod (*Senna obtusifolia* L.) vegetative and reproductive suppression.

Manipulating densities has been used as a method to control weeds. Howe and Oliver (1987) found that soybean population of 500,000 plants ha^{-1} in 20 cm row reduced pitted morningglory (*Ipomoea lacunosa* L.) leaf area index and seed production. Nice *et al.* (2001) found also a reduction in sicklepod population up to 80% with 19 and 38 cm rows and a high soybean population compared with low soybean population and 76 cm row spacing.

High soybean seeding rates were commonly used in the past with conventional soybean cultivars which frequently were saved seed and thus did not significantly increase production costs (Kratochvil *et al.* 2004). Before increasing planting densities to enhance weed suppression in glyphosate resistant cultivars, trade-offs of additional seed costs have to be considered (Nice *et al.* 2001; Renner and Nelson 1999). Reddy and Whithing (2000) stated that seed cost, including any associated technology fee and herbicide cost will be an important item to consider for selecting the most profitable cropping system. Seed and technology fee costs (on average \$20 to \$25 ha^{-1}) may prohibit the use of high seeding rates. Increasing seed cost may actually result in seeding rates below currently recommended standards (Kratochvil *et al.* 2004). According to Norsworthy and Frederick (2002) the recommended seeding rate of glyphosate resistant soybean can be lowered, without negative effects in yields. Holshouser and Whittaker (2002) found that a population of 208,000 seeds ha^{-1} was adequate for maximizing yields at a site with a brief period of drought stress. Kratochvil *et al.* (2004) found that yields from a seeding rate of 345,000 seeds ha^{-1} was not significantly different than the standard seeding rate of 432,500 seed ha^{-1}, which resulted in an additional profit ranging from $14.30 to $27.72 ha^{-1}. However, a population of 259,000 seeds ha^{-1} had significantly lower yield than the recommended populations, even during years with little or no drought stress. Norsworthy and Oliver (2001) also found that the profit margin from weed management was optimized with a low population of 185,000 seeds ha^{-1}. They stated that saving in seeds costs were greater than expenses for an additional glyphosate application.

To test the hypothesis that reduction in soybean seeding rate will reduce weed suppression, we perform field experiments with glyphosate-resistant soybean, in which we varied the seeding rate and different glyphosate timing applications.

Materials and Methods

Experimental Design

Field studies were conducted in 2005 and 2006. During 2005, the experiment was conducted at the Iowa State University Agronomy Research Farm in Boone County, Iowa. 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 the second year, the experiment was performed at the Iowa State University Northern Research Farm in Hancock County, Iowa and at the Iowa State University Curtiss Farm in Story County, Iowa. The soil of the Northern

Research Farm was a Canisteo (fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquoll) with pH 7.0 and 6.3% organic matter. The soils of the Curtiss Farm 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 7.1 and 3.0% organic matter. Plots in both years were chisel plowed in the fall and final seedbed preparation was completed with a field cultivator. The previous crop at all sites was corn.

A full season soybean glyphosate-resistant cultivar Golden Harvest H-2162 RR was planted on May 5, 2005 at Boone and on May 8, 2006 at Hancock and May 11, 2006 at Story using an Almaco grain drill (Almaco, Nevada, IA) (Table 1).

To evaluate the effect of plant density on weed management, seeding rates and glyphosate application timings (weed management tactics) were used to accomplish the objective. A two-way factorial experiment arranged in a randomized complete block design with four replications was used. Seeding rate (240,000, 300,000, 360,000 and 420,000 seed ha^{-1} in 38 cm rows) was the first factor. The second factor was weed control tactic, including weedy control (nontreated check), weed free (sequential application of glyphosate at V2 and V6 soybean stage), and glyphosate applied at V2, V4, or V6 (Fehr and Caviness, 1977).

Plot size was 3.0 m by 7.6 m for all three locations. Glyphosate[1] was applied at 1.00 kg a.e. ha^{-1} plus 1% w/v of ammonium sulfate with a CO_2 backpack sprayer

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

using Teejet[2] 8002 flat fan nozzle tips calibrated to deliver 140 L ha^{-1} at 275 kPa (Table 1).

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

Weed density and height were obtained at the time of the application for all three locations (Table 2). Four 0.093 m^2 quadrats were placed arbitrarily along the center two rows of each plot. *Setaria* spp. and *Amaranthus* spp. were the predominant weeds infesting Boone in 2005. During 2006, *Chenopodium album* and *Setaria* spp. were the predominant weeds at Hancock. Story presented *Chenopodium album*, *Amaranthus* spp. and *Setaria* spp. as the predominant weeds. End of season weed density and biomass were obtained by harvesting plants at soil line in early September at each location from four 0.093 m^2 quadrats placed arbitrarily along the center two rows of each plot. Soybean stand counts were obtained on September 20 2005 at Boone and on September 13 at Hancock and September 14 2006 at Story.

Two meters of soybean plants were harvested from the sixth row in each plot in September for the three locations (Table 1). Three soybean plants were selected randomly from the sample. Plant height and number of nodes were determined from these plants. Mature pods and stems of the three plants were separated and placed

[2] Teejet 8002 flat fan nozzle tip, Spraying Systems Co., Wheaton, IL 60189.

in paper bags, and then returned to the sample. The samples were dried in an oven for three days at 60 C. Weight of the mature pods, stems, and the whole sample was recorded. Finally, seed weight and seed count were measured from the selected plants. Soybean grain was machine harvested from the middle four rows for the entire length of each plot. Yield was adjusted to 13% moisture prior to analysis.

Statistical Analysis

Barlett's chi- square test for homogeneity of variance was tested and data combined over years and sites when appropriate.

All data were subjected to analysis of variance using PROG GLM of SAS. Mean separation was conducted using Fisher's protected $LSD_{0.05}$ test. Weed density, weed height, weed control and final plant population mean separation was made either by weed control tactic or by seeding rate factor. Variables obtained at harvest such as grain yield, moisture, plant height, seed weight, and end-season weed biomass were mean separated for both factors and data from weedy plot was not included in the analysis. Data from the weedy control was excluded 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 analysis of variance. In addition, contrasts were conducted for each location to test grain yield in the weed free treatment (sequential application) vs. the average grain yield in the other three glyphosate treatments (single application average) at 240,000, 300,000, 360,000, and 420,000 seed ha^{-1} and the average grain yield in 420,000 seed ha^{-1} within glyphosate treatments (sequential + single application average) vs. the average grain yield in 240,000, 300,000 or 360,000 seed ha^{-1} within glyphosate treatment.

Regression analyses were performed using SAS REG procedures. The first regression analysis was used to determine the grain yield response to weed competition. Grain yield from the plots where weed biomass was collected at the end of season was adjusted to the yield of the 'weed-free' treatment in each of the four soybean densities at the three experimental locations and then pooled across locations. Weed biomass also, was regressed on final plant population. Regression analysis was used to observe the relationship between weed biomass harvested at the end of the season and final soybean plant population for the three locations. Finally, grain yield was regressed on final plant population. Regression analysis was used to examine the relationship between grain yield and plant density for the different weed management treatments. Regression coefficient was described when significant at $P \leq 0.05$.

Results and Discussion

The environmental conditions and weed densities varied considerably over the two years and locations, therefore influencing soybean yields. During 2005, monthly rainfall precipitation throughout the growing season (April to September) was similar or above the 30-year average monthly rainfall for Boone County (Figure 1). In 2006, monthly rainfall precipitation at the Hancock was far below the 30-year average for Hancock County from May to August (Figure 1). Story County monthly rainfall was below the 30-year average in May and June (Figure 1).

Because of the good weather conditions in 2005, weeds and soybean emerged satisfactorily at Boone. During 2006, soybean establishment was low at both locations giving a final soybean plant population 24 to 30% below the targeted plant population across the four seeding rates for both locations (Table 3). Dry conditions and high temperatures during the first 6 weeks after planting may have been the cause of the reduced establishment compared to 2005.

No visible soybean injury was recorded from glyphosate at 14 DAA in Boone 2005. Soybean injury due to glyphosate application during 2006 at Story was not greater than 15% in average 14 DAA when glyphosate was applied at V2 soybean stage. Soybean injury ranging from 0 to 4% was noted when glyphosate was applied at V4 and V6 soybean stage (data not shown) (Fehr and Caviness, 1977). Soybean at Hancock did not show visible injury from any glyphosate timing application treatment at 14 DAA.

Weed Control

Seeding rate did not affect weed control at any location (Table 4). Weed control was not affected by application timing at Boone, but at Hancock the V6 application provided less control than other application timings. At Story a significant difference was found between V2 and the other application timings, although all timings provided greater than 95% control. Glyphosate applied at V2 and V2+V6 stage gave complete weed control at the three locations at 21DAA (Table 4) even though weed density varied (Table 2). Glyphosate at V4 stage resulted in 97 to 100% control 21 DAA across locations. The better efficacy of glyphosate applied at

V2 and V4 soybean stage compared to V6 was probably due to the treatment of smaller weeds and better coverage (Mulugeta and Boerboom, 2000). Weed control at V6 soybean stage at Boone was complete (100%) even though weeds were 22-cm tall (Table 2). Glyphosate at the Hancock location provided 88% weed control 21 DAA (Table 4). Less effective control for this application may be due to large weed height (46-cm tall in average) (Table 2). Presence of large weeds at a late postemergence timing may reduce glyphosate efficacy (Young *et al*. 2001; Franzenburg *et al*. 1998). Glyphosate application at Story provided weed control greater than 97% at all timings. These results agree with other studies comparing weed control at different soybean stages (Mulugeta and Boerboom 2000; Myers *et al*. 2005; VanGessel *et al*. 2000).

Because glyphosate exhibits no residual activity, weeds emerging after application are not controlled. Applications made early in the season may allow weed emergence and growth after application which compete with soybean for the remainder of the growing season. Soybean density did not affect late-season weed density at Story or Hancock, but at Boone late-season weeds were only present in the lowest seeding rate (Table 5). At Hancock, weeds were present following V2, V4, and V6 applications. However, the weeds present after V2 application were more than 10x greater that at the other application timings. At Boone, weeds were only present in the V2 treatment.

End of season weed biomass decreased linearly as plant population increased at all three locations (Fig. 2). At the Story site only control plots were infested with weeds at the end of the season, whereas at Boone one V2 plot and the control plots had weeds present. At the Hancock location late-emerging weeds were found in all weed management treatments (Table 5). The reduction in end-of-season weed biomass associated with increasing soybean density indicates that higher planting rates increased the competitiveness of the crop with weeds (Norsworthy and Oliver 2002). In situations where postemergence herbicides are effective, the reduction in competitiveness associated with low planting rates may not influence weed management. However, when herbicides fail to control existing weeds, or conditions favor weed establishment after weed application, reduction in planting rates provide a more favorable environment for weed survival.

Grain Yield

Soybean density affected grain yield at all three locations. Weed management effects were not significant at Story and Boone but at Hancock. The interaction between soybean density and weed management was significant only at Boone (Table 6). Differences in grain yield among seeding rates were consistent for the three locations, whereas weed management was inconsistent. Grain yield at 240,000 seed ha^{-1} had the lowest value at all locations (Table 7). The difference represented 13, 24, and 12% less grain yield than 420,000 seed ha^{-1} at each location. However, no differences in grain yield were found between 360,000 and 420,000 seed ha^{-1} at the three locations (Table 7 and 8). Bertram and Pedersen (2004) also found no response of grain yield to plant population between an optimum plant population of 300,000 and 410,000 plants ha^{-1}.

Weed management tactics did not affect yield at Boone and Story (Table 7). However, weed management at Hancock was significant and resulted in reductions of 30, 44, and 15% between the V2, V4, and V6 application and the weed free control respectively. No single application of glyphosate provided yields equivalent to the weed free treatment. Yield losses in the V2 treatment may have been due to late-season competition by the high weed densities that emerged after glyphosate application (Table 5), whereas losses in the V4 and V6 treatment may have been due to combination of early-season and late-season competition. Orthogonal contrasts showed that at places with high weed densities such as Hancock no single application of glyphosate provided grain yield as high as in the weed free treatments. However al places with low weed densities, such as Story (Table 5), grain yield in the weed free treatment was not statistically different from any single application (Table 8).

Regression analysis of grain yield vs. final plant population was conducted for all glyphosate applications treatments at the three locations. The relationship between grain yield and plant density was best explained using a quadratic equations in Boone and Hancock for all the weed management tactics (Table 10). However, at the Story site only the weed free treatment showed a quadratic relationship, whereas at V2, V4 or V6 no relationships were found between grain yield and plant populations. Holshouser (2003) and Norsworthy and Oliver (2001) found also a quadratic response of soybean grain yield to plant population.

Yield losses in the weedy control compared to the weed-free treatment ranged from 63% at Hancock to 42% at Boone (Table 9). Relative yield losses at the three locations were correlated with the weed densities, with Hancock having higher weed densities than the other sites (Table 2). Soybean seeding rate did not affect yield losses in the absence of weed control.

Regression analysis for weed biomass over the relative soybean yield indicated a linear response in yield to end-of-season weed biomass for all four soybean densities (Fig. 3). Arce and Hartzler (2005), Burnside and Moomaw (1977), and Harrison (1990) also found that weed biomass is inversely proportional to soybean grain yield. Similar results have been obtained for other crops. For instance, Burnside and Wicks (1969) and Myers *et al*. (2005) found that weed biomass is inversely proportional to sorghum and corn yield respectively.

Grain Moisture

Weed management tactic and soybean density did not affect grain moisture at Boone and Story, but was significant at Hancock (Table 7 and 9). The interaction between soybean density and weed management was also found only at Hancock. Bertram and Pedersen (2004) found no difference in grain moisture among soybean population and weed management systems. The differences observed at this location were unexpected and inconsistent and can not be explained. Finally, there were no differences in soybean moisture in the untreated control at the three locations (data not shown).

Plant Height

No differences in soybean height were found at any location due to soybean densities (Table 7). Bertram and Pedersen (2004) found that plant population did not influence plant height in Wisconsin and support the results obtained in this experiment. Differences in height were found at Hancock and Story due to the weed management systems. The V6 application soybean plant heights were 29 and 10% shorter than plants at weed free plots, possibly because soybean plants were less vigorous after a long period of early weed competition.

Soybean plant height in the weedy control across soybean densities (data not shown) was less than 10% smaller than the soybean height in weed free plots at each location. Krausz *et al*. (2001) found similar result in soybean height reduction when weeds compete with the crop throughout the growing season. Soybean height at the weedy control was similar to the height of the weed free and that was likely due to the allocation of more resources to the stem to reach a height that enabled the plant to compete with weeds for light. Gurevitch *et al*. 2002 stated that a typical response to crowding in plants is stem elongation.

Seed Weight

Weed management tactics and soybean densities both influenced seed weight at Boone. At Hancock weed management and at Story soybean density affected seed weight. The interaction of factors was not significant at any location (Table 6).

Soybean density and weed management influenced seed weight inconsistently at the three locations. At Boone the lowest seed weights were found at 240,000 plants ha^{-1} (14.7 g 100 seed $^{-1}$) and at the V4 application (14.6 g 100 $seed^{-1}$). At Hancock no differences were found across soybean densities and the lowest weight was at V4 weed management tactic (13.2 g 100 seed $^{-1}$). Finally, at Story the lowest value was found at 240,000 seed ha^{-1} (14.7 g 100 seed $^{-1}$) and no differences in seed weight were found among weed management tactics (Table 7).

Conclusions

This study showed that where the common annual weeds, particularly common lambsquarters, foxtail, pigweed, are a problem, the window of application of glyphosate to obtain optimum weed control in glyphosate resistant system is between V2 and V4 soybean stage independent of soybean density. While application at the V2 stage provided optimum efficacy (Table 4), early treatment increased the risk of late-emerging weed survival (Table 5).

Soybean yield at the lowest seeding rate (240,000 seed ha^{-1}) was reduced compared to higher densities at all three locations (Table 7). Even though soybean was planted in narrow rows (38 cm), the lack of early canopy development allowed weed emergence and competition the remainder of the season. Yield losses at this seeding rate varied among locations and may depend on density and type of weeds (e.g. broadleaves and grasses) competing with soybean. Dry conditions may also influence yield at this seeding rate. This response is probably due to a restrictive vegetative growth which allows that grain yield respond negatively to low plant populations (Holshouser and Whittaker, 2002).

Seeding rate did not affect the efficacy of glyphosate, however, at one of three locations end-of-season weed densities were higher in the low seeding rate compared to higher seeding rates (Table 5). This response is probably due to the effect of seeding rate on canopy development and ability to suppress late-emerging weeds.

In the absence of weed control, soybean seeding rate did not influence yield losses associated with weed competition (Table 9). However, at all locations the amount of weed biomass produced was indirectly related to soybean population. This suggests that higher seeding rates enhance interespecific competition, but the benefits may not always result in reduction in yield losses.

Timing of weed control only influenced soybean yield at the location with the highest weed densities (Table 7). At this site, no single application provided yield equivalent to the weed-free treatment. Therefore a second glyphosate application may be needed to guarantee maximum yield at sites with high weed densities.

References

Arce, G.D. and R.G. Hartzler. 2005. Effect of preemergence herbicide on the critical period in glyphosate resistant corn and soybean. North Cent. Weed Sci. Soc. Abstract 60:43. [CD-ROM Computer File]. North Cent. Weed Sci. Soc., Champaign, IL.

Bertram, M.G. and P. Pedersen. 2004. Adjusting management practices using glyphosate-resistant soybean cultivars. Agron. J. 96:462−468.

Burnside, O.C. and R.S. Moomaw. 1977. Control of weed in narrow-row soybean. Agron. J. 69:793−796.

Burnside, O.C. and G.A. Wicks. 1969. Influence of weed competition on sorghum growth. Weed Sci. 17:332−334.

Bussan, A.J.,O.C. Burnside, and K.J. Puettmann. 1997. Field evaluation of Soybean (*Glycine max*) genotypes for weed competitiveness. Weed. Sci. 45:31−37.

Corrigan, K.A. and R.G. Harvey. 2000. Glyphosate with and without residual herbicides in no-till glyphosate resistant soybean (*Glycine max*). Weed Technol. 14:569−577.

Culpepper, A.S., A.C. York, R.B. Batts, and K.M. Jennings. 2000. Weed management in glufosinate and glyphosate-resistant soybean (*Glycine max*). Weed Technol. 14:77−88.

Franzenburg, D.D., M.D.K. Owen, J.F. Lux, and K.W. Adam. 1998. Herbicide application strategies for weed control in glyphosate tolerant soybean. Proc. North Cent. Weed Sci. Soc. 53:27−28.

Fehr, W.R. and C.E. Caviness. 1977. Stages of soybean development. Spec. Rep. 80. Iowa Agric. Home Econ. Exp. Stn., Iowa State Univ., Ames.

Grichar, W.J., B.A. Bessler, and K. D. Brewer. 2004. Effect of row spacing and herbicide dose on weed control and grain sorghum yield. Crop Prot. 23:263−267.

Gurevitch J., S.M. Scheiner, and G.A. Fox, eds. 2002. The ecology of plants. Massachusetts: Sinauer Associates, Inc. Pp. 106−107.

Harrison, S.K. 1990. Interference and seed production by common lambsquarters (*Chenopodium album*) in soybean (*Glycine max*). Weed Sci. 38:113-118.

Holshouser D.L. 2003. Early-maturing double crop soybean requires higher plant soybean density to meet leaf area requirements. [Online]. Available at www.plantmanagementnetwork.org/cm/. Crop Manage. DOI 10.1094/CM-2003-0408-01-RS.

Holshouser, D.L. and J.P. Whittaker. 2002. Plant population and row-spacing effects on early soybean production systems in the Middle-Atlantic USA. Agron. J. 94:603−611.

Hoverstad, T.R. and G.A. Johnson. 2002. Effect of row spacing and herbicide application timing on weed control and grain yield in corn (*Zea mays*). Weed Technol. 16:548−553.

Howe, O.W. and L.R. Oliver. 1987. Influence of Soybean (*Glycine max*) row spacing on pitted morningglory (*Ipomoea lacunose*) interference. Weed Sci. 35:185−193.

Kratochvil, R.J., J.T. Pearce, and M.R. Harrison Jr. 2004. Row spacing and seeding rate effects on glyphosate-resistant soybean for Mid-Atlantic production systems. Agron J. 96:1029−1038.

Krausz, R.F., B.G. Young, G. Kapusta, and J.L. Matthews. 2001. Influence of weed competition and herbicide on glyphosate-resistant soybean (*Glycine max*) Weed Technol. 15:530−534.

Kells, J.J., C.D. Dalley, and K.A. Renner. 2004. Effect of glyphosate application timing and row spacing on weed growth in corn (*Zea mays*) and soybean (*Glycine max*). Weed Technol. 18:177−182.

Mulugeta, D. and C.M. Boerboom. 2000. Critical time of weed removal in glyphosate-resistant *Glycine max.* Weed Sci. 48:35−42.

Myers, M.W., W.S. Curran, M.J. VanGessel, B.A. Majek, B.A. Scott, D.A. Mortensen, D.D. Calvin, H.D. Karsten, and G.W. Roth. 2005. The effect of weed density and application timing on weed control and corn grain yield. Weed Technol. 19:102−107.

Nice, G.R., N.W. Buehring, and D.R. Shaw. 2001. Sicklepod (Senna obtusifolia) response to shading, soybean (*Glycine max*) row spacing and population in three management systems. Weed Technol. 15:155−162.

Norsworthy, J.K. and L.R. Oliver. 2001. Effect of seeding rate of drilled glyphosate resistant soybean (*Glycine max*) on seed yield and gross profit margin. Weed Technol. 15:284−292.

Norsworthy, J.K. and J.R. Frederick. 2002. Reduced seeding rate for glyphosate resistant, drilled soybean on the southeastern coast plain. Agron. J. 94:1282−1288.

Norsworthy, J.K. and L.R. Oliver. 2002. Effect of irrigation, soybean (*Glycine max*) density, and glyphosate on hemp sesbania (*Sesbania exaltata*) and pitted morningglory (*Ipomoea lacunosa*) interference in soybean. Weed Technol. 16:7−17.

O'Donovan, J.T., K.N. Harker, G.W. Clayton, J.C. Newman, D. Robinson, and L.M. Hall. 2001. Barley seeding rate influence the effects of variable herbicide rates on wild oat. Weed. Sci. 49:746−754.

Reddy, K.N. and K. Whiting. 2000 Weed control and economic comparisons of glyphosate-resistant, sulfonylurea-tolerant, and conventional soybean (*Glycine max*) systems. Weed Technol. 14:204−211.

Renner, K.A. and J.A. Mickelson. 1997. Weed control using reduced rates of post-emergence herbicides in narrow and wide row soybean. J. Prod. Agric. 10:431−437.

Renner, K.A. and K.A. Nelson. 1999. Weed management in wide and narrow row glyphosate resistant soybean. J. Prod. Agric. 12:460−465.

Schwinning, S. and J. Weiner. 1998. Mechanisms determining the degree of size asymmetry in competition among plants. Oecologia 113:447−455.

[USDA] United States Department of Agriculture, National Agricultural Statistics Service. 2006. Adoption of genetically engineered crops in the U.S.:Soybeans. 2006 genetically engineered soybean varieties summary: web page: http://www.ers.usda.gov/. Accessed: October 2006.

Tharp, B.E. and J.J. Kells. 2001. Effect of glufosinate-resistant corn (*Zea mays*) population and row spacing on light interception, corn yield, and common lambsquarters (*Chenopodium album*) growth. Weed Technol. 15:413−418.

VanGessel, M.J., A.O. Ayeni, and B.A. Majek. 2000. Optimum glyphosate timing with or without residual herbicides in glyphosate-resistant soybean (*Glycine max*) under full-season conventional tillage. Weed Technol. 14:140−149.

Wax, L.M. and J.W. Pendleton. 1968. Effect of row spacing on weed control in soybean. Weed Sci. 16:462−465.

Weiner, J. H. Griepentrog, and L. Kristensen. 2001. Suppression of weed by spring wheat *Triticum aestivum* increases with crop density and spatial uniformity. J Applied Ecol. 38:784−790.

Young, B.G., J.M. Young, L.C. Gonzini, S.E. Hart, L.M. Wax, and G. Kapusta. 2001. Weed management in narrow and wide row glyphosate-resistant soybean (*Glycine max*) Weed Technol. 15:112−121.

Table 1. Date of soybean planting, herbicides application, harvest, and weed biomass assessment to evaluate the plant density effect on weed management at Boone, Hancock and Story, IA, in 2005 and 2006.

Procedure	2005	2006	
	Boone	Hancock	Story
Soybean planting	May 5	May 8	May 11
Weed management[1]			
V2 stage	Jun 10	Jun 11	Jun 9
V4 stage	Jun 17	Jun 20	Jun 19
V6 stage	June 24	Jun 28	Jun 28
V2 + V6 stage	Jun 10, 24	Jun 9, 28	Jun 9, 28
Weed biomass harvest	Sep 7	Sep 11	Sep 8
Soybean plant harvest	Sep 13	Sep 25	Sep 20
Grain harvest	Sep 21	Oct 5	Oct 9

[1] Weed management refers to soybean stage at the time of herbicide application.

Table 2. Weed heights and weed densities at application at Boone, Hancock and Story, IA, in 2005−2006[1].

Soybean stage	Boone		Hancock		Story	
	Density	Height	Density	Height	Density	Height
	(plants m^{-2})	(cm)	(plants m^{-2})	(cm)	(plants m^{-2})	(cm)
V2[2]	69	5	197	5	19	8
V4	72	11	434	19	136	20
V6	88	22	219	46	89	34

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

[2] V2 data are pooled values of V2 and V2+V6 treatment.

Table 3. Seeding rate and final soybean population at Boone, Hancock and Story, IA, in 2005 and 2006.

Soybean seeding rate (seed ha^{-1})	Soybean population (plants ha^{-1})[1]		
	Boone	Hancock	Story
240,000	250,112 ± 4,456[2]	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

[1] Data are pooled across the herbicides treatments at each soybean seeding rate.

[2] Data are means ± standard errors.

Table 4. Weed control at Boone, Hancock and Story, IA with 1.0 kg ha^{-1} glyphosate as affected by application timing in 2005 and 2006.

	Weed control (%)[1]		
	Boone	Hancock	Story
Seeding rate (seed ha^{-1})[2]			
240,000	100	97	98
300,000	100	96	99
360,000	100	96	99
420,000	100	96	99
$LSD_{0.05}$	NS	NS	NS
Weed management[3]			
V2	100	100	100
V4	100	97	97
V6	100	88	97
Weed free	100	100	100
$LSD_{0.05}$	NS	4	2

[1] Visual ratings made 21 days after application.

[2] Values represent the average across weed management treatments.

[3] Values represent the average across soybean seeding rates.

Table 5. End of season weed densities as affected by glyphosate timing and soybean density at Boone, Hancock and Story, IA, in 2005 and 2006.

	Weed density (plants m^{-2})		
	Boone	Hancock	Story
Seeding rate (seed ha^{-1})[1]			
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
Weed management[2]			
V2	5	125	1
V4	0	9	0
V6	0	7	0
$LSD_{0.05}$	4	30	NS
ANOVA			
Seeding rate (S)	0.040	NS	NS
Weed management (W)	0.040	<.0001	NS
S × W	0.007	NS	NS

[1] Values represent the average across weed management treatments.

[2] Values represent the average across soybean seeding rates.

NS, nonsignificant at the 0.05 level.

Table 6. Significance of *p*-values from analysis of variance of soybean grain yield, grain moisture, plant height and seed weight from Boone, Hancock and Story, IA, in 2005 and 2006.

Factor	Grain yield (kg ha^{-1})	Moisture (%)	Height (cm)	Seed weight (g 100 seed^{-1})
Boone				
Seeding rate (S)[1]	<.0001	NS	NS	0.0044
Weed management (W)[2]	NS	NS	NS	0.0437
S × W[3]	0.0059	NS	NS	NS
Hancock				
Seeding rate (S)	0.0096	0.0001	NS	NS
Weed management (W)	<.0001	0.0500	<.0001	0.0122
S × W	NS	<.0001	NS	NS
Story				
Seeding rate (S)	0.0017	NS	NS	0.0288
Weed management (W)	NS	NS	0.0016	NS
S × W	NS	NS	NS	NS

[1,2] Degrees of freedom for seeding rate or weed management factor = 3.

[3] Degrees of freedom for seeding rate and weed management interaction = 9.

NS, nonsignificant at the 0.05 level.

Table 7. Weed management and seeding rate effect on grain yield, grain moisture, plant height, seed weight at Boone, Hancock and Story, IA, in 2005 and 2006.

	Grain yield (kg ha^{-1})	Moisture (%)	Height (cm)	Seed weight (g 100 seed^{-1})
		Boone		
Seeding rate[1] (seed ha^{-1})				
240,000	4023	10.4	68.4	14.7
300,000	4300	10.4	66.8	14.8
360,000	4428	10.4	69.2	15.5
420,000	4542	10.5	67.8	15.6
$LSD_{0.05}$	181	NS	NS	0.6
Weed management[2]				
V2	4247	10.4	68.1	15.1
V4	4283	10.4	66.8	14.6
V6	4366	10.4	68.6	15.3
Weed free	4398	10.5	68.7	15.5
$LSD_{0.05}$	NS	NS	NS	0.6
		Hancock		
Seeding rate (seed ha^{-1})				
240,000	2119	11.2	65.1	13.5
300,000	2374	10.7	63.9	13.7
360,000	2537	10.6	65.3	13.7
420,000	2631	11.2	66.1	13.9
$LSD_{0.05}$	308	0.3	NS	NS
Weed management				
V2	2012	10.7	75.1	13.4
V4	2521	11.1	69.2	13.2
V6	2228	10.9	53.8	14.1
Weed free	2900	10.9	69.2	14.2
$LSD_{0.05}$	308	0.3	4.1	0.6
		Story		
Seeding rate (seed ha^{-1})				
240,000	2519	7.9	69.7	14.7
300,000	2471	7.9	70.5	15.6
360,000	2820	7.9	71.8	15.0
420,000	2824	7.9	71.2	15.4
$LSD_{0.05}$	223	NS	NS	0.6
Weed management				
V2	2695	7.9	72.3	15.0
V4	2613	7.9	70.3	15.0
V6	2699	7.9	67.1	15.2
Weed free	2627	7.9	73.5	15.4
$LSD_{0.05}$	NS	NS	3.2	NS

[1] Values represent the average across weed management treatments.

[2] Values represent the average across soybean seeding rates.

NS, nonsignificant at the 0.05 level.

Table 8. Significance of contrasts at seeding rate and weed management factors for Boone, Hancock and Story, IA, in 2005 and 2006.

Contrasts		Grain yield (kg ha^{-1})		
		Boone	Hancock	Story
		p-values		
Seeding rate (seed ha^{-1})				
240,000	Sequential[1] vs. Single[2]	0.0039	0.0052	NS
300,000	Sequential[1] vs. Single[2]	NS	0.0059	NS
360,000	Sequential[1] vs. Single[2]	NS	0.0349	NS
420,000	Sequential[1] vs. Single[2]	NS	0.0235	NS
Weed management				
Glyphosate treatments[3]	420,000 vs. 240,000	<.0001	0.0017	0.0084
	420,000 vs. 300,000	0.0102	NS	0.0026
	420,000 vs. 360,000	NS	NS	NS

[1] Sequential refers to sequential glyphosate application (Weed free treatment).

[2] Single refers to the average of the V2, V4, and V6 glyphosate application stage.

[3] Glyphosate treatments refer to the average of V2, V4, V6, and weed free.

NS, nonsignificant at the 0.05 level.

Table 9. Soybean relative yield for untreated plots at Boone, Hancock and Story, IA, in 2005 and 2006.

Seeding rate (seed ha^{-1})	Soybean relative yield (%)[1]		
	Boone	Hancock	Story
240,000[2]	60	32	35
300,000	58	36	49
360,000	54	43	40
420,000	59	37	58
Mean	58	37	45
$LSD_{0.05}$	NS	NS	NS

[1] Relative yield = (yield weedy control / yield weed free) × 100.

[2] Data represent the mean value from four replications.

NS, nonsignificant at the 0.05 level.

Table 10. Regression equations for soybean yield in four weed management tactics in Iowa (2005-2006). Data were pooled across seeding rates and regressed against harvest plant population.

Weed management[1]	Regression equation	R^2
Boone		
V2	$Y = -3.4E\text{-}08x^2 + 0.0296x – 1839.9$	0.62
V4	$Y = -1.3E\text{-}08x^2 + 0.0112x – 2112.4$	0.62
V6	$Y = -8.3E\text{-}09x^2 + 0.0091x – 2253.5$	0.73
Weed free	$Y = -2.9E\text{-}09x^2 + 0.0046x – 3200.1$	0.66
Hancock		
V2	$Y = -2.0E\text{-}08x^2 + 0.0143x + 190.70$	0.68
V4	$Y = -2.2E\text{-}08x^2 + 0.0165x – 293.90$	0.68
V6	$Y = -6.2E\text{-}08x^2 + 0.0360x – 2868.2$	0.60
Weed free	$Y = -2.2E\text{-}08x^2 + 0.0142x + 819.10$	0.64
Story		
V2	nonsignificant coefficients	–
V4	nonsignificant coefficients	–
V6	nonsignificant coefficients	–
Weed free	$Y = -1.9E\text{-}08x^2 + 0.0147x + 215.70$	0.66

[1] Weed management refers to soybean stage at the time of herbicide application.

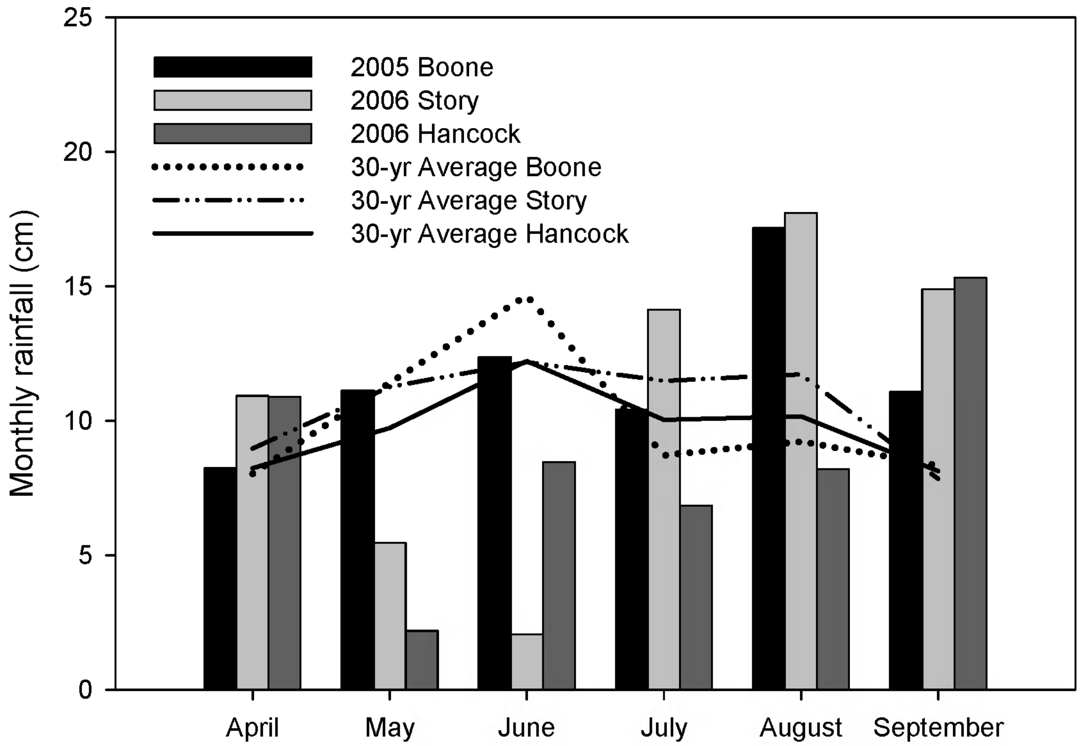

Figure. 1 Mean monthly rainfall for Boone 2005 and Story and Hancock 2006 and 30-yr- average rainfall for Boone, Story and Hancock County, Iowa.

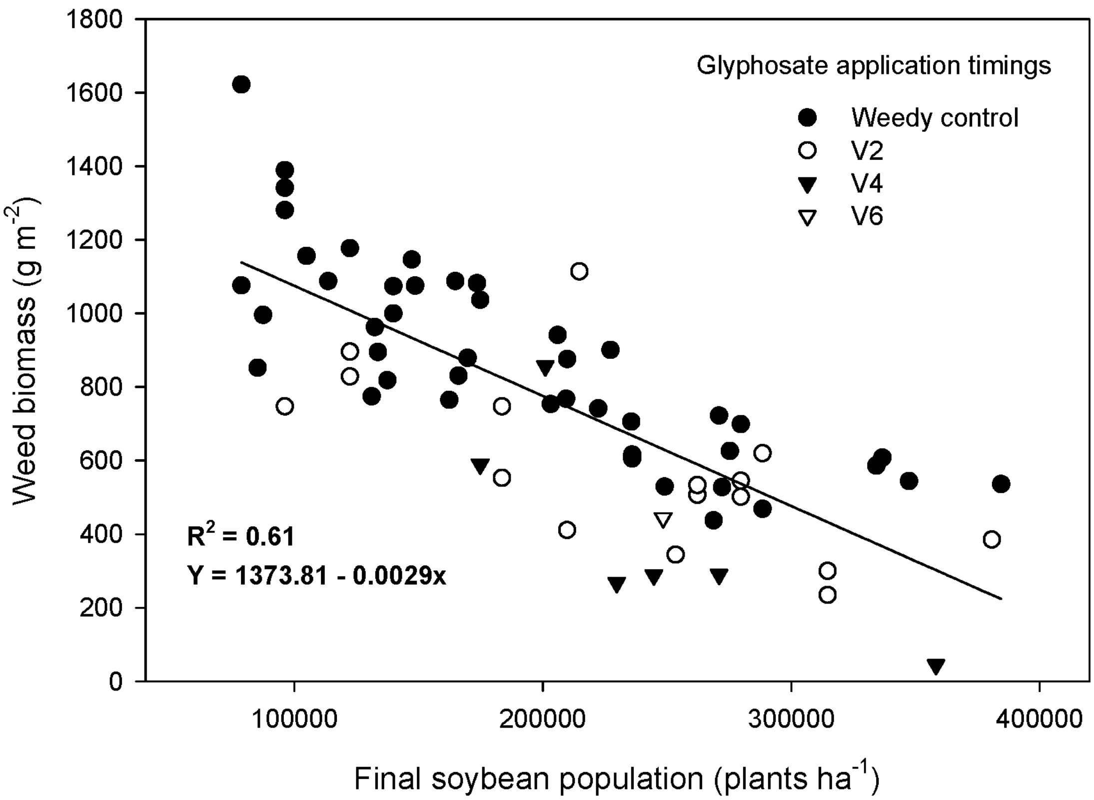

Figure 2. Relationship between final plant population and end-of-season weed biomass at Boone, Hancock, and Story, Iowa (2005−2006). Data were pooled across years, locations, herbicide application timing, and soybean densities and regressed against final plant population; where x = final soybean plant population ha^{-1}.

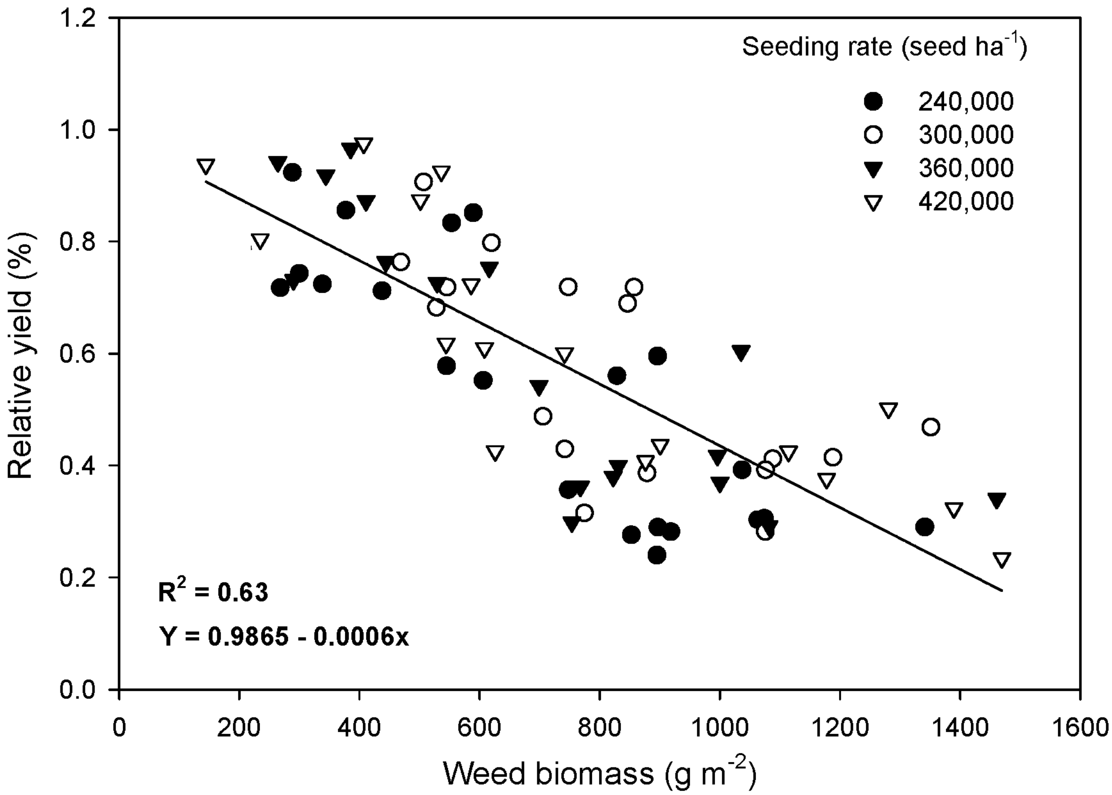

Figure 3. Relationship between weed biomass and soybean yield loss within four soybean seeding rates in Iowa (2005−2006). Data were pooled across year, location, herbicide application timing and regressed against weed biomass; where x = g weed biomass m^{-2}.

CHAPTER III

Effect of Soybean Population on Glyphosate Performance

Abstract

A study was conducted in 2005 at Agronomy Farm, Boone County to determine the impact of soybean seeding rates on common lambsquarters control with glyphosate. The cultivar H-2162 RR (glyphosate-resistant) was planted at four seeding rates (240,000, 300,000, 360,000, and 420,000 seed ha^{-1}). Glyphosate was applied at 0.5 and 1.0 kg ae ha^{-1} when common lambsquarters were 10 cm tall and soybean was at V6 stage. Unwanted weeds were controlled by handweeding. Herbicide interception by weeds was affected by soybean plant population, whereas weed control was not affected. There was no interaction between glyphosate rate and seeding rate for any of the parameters evaluated. Glyphosate rate significantly affected common lambsquarters control at 14DAA, but did not affect grain yield. Common lambsquarters control was 100% at 21 DAA for both glyphosate rates. The results suggest that under favorable conditions for soybean growth and small lambsquarters the use of reduced glyphosate rates can provide excellent weed control and protect crop yields, while reducing production costs.

Key words: Seeding rates, herbicide interception, reduce glyphosate rates.

Abbreviation: DAA, days after application; ae, acid equivalent.

Introduction

The introduction of glyphosate resistant soybean (*Glycine max* L.) in 1996 dramatically changed weed management systems in soybean. The new technology allows producers to apply a broad-spectrum herbicide over the top of soybean with excellent crop safety (Culpepper *et al.* 2000; Norsworthy and Oliver, 2001). Glyphosate allows a wide window of application from emergence to the fully flowered stage (Mulugeta and Boerboom, 2000). Weed control with glyphosate is affected by application timing (Mulugeta and Boerboom 2000; Myers et al. 2005; Young *et al*. 2001), glyphosate rate (Koger *et al*. 2004), and the susceptibility of target weed species (Corrigan and Harvey 2000). It is important to match application rates to weed size. Application timing is critical when problematic weeds such as common lambsquarters (*Chenopodium album* L.) and velvetleaf (*Abutilon theophrasti* Medik.) are present. Control of these species with glyphosate is recommended at early stages since glyphosate effectiveness declines as these weeds become taller (Payne and Oliver, 2000).

Cultural practices such as row spacing, seeding rate, crop rotation and fertilizer placement may alter the ability of the crop to compete with weeds, reduce weed seed production and, by inference, alter dependence on herbicides for weed control (Grichar *et al*. 2004; O'Donovan *et al.* 2001). Early soybean canopy closure as a result of increases in seeding rate may improve weed control by suppressing late-emerging weeds and weeds not completely killed by the herbicide application (Renner and Mickelson, 1997).

Increasing soybean density is another cultural practice that may directly reduce weed growth (Howe and Oliver, 1987; Nice *et al.* 2001; Norsworthy, 2005). Pitted morningglory LAI (leaf area index) and seed production was reduced by the presence of a high density of soybean (Howe and Oliver, 1987). Norsworthy (2005) stated that an increase in soybean seeding rate increased soybean biomass, while decreasing Palmer amaranth (*Amaranthus palmeri* S. Wats.) and Florida pusley (*Richardia scabra* L.) biomass. The reduction in weed biomass and growth was a result of reduced emergence and increased weed mortality below the soybean canopy. Nice *et al.* (2001) found fewer sicklepod (*Senna obtusifolia* L.) plants in either 38 or 19 cm row spacing and a high soybean population of 481,000 and 676,000 plants ha^{-1} than 245,000 plant ha^{-1} and 76 cm row spacing. The increased competition from soybean with narrow row spacing and high soybean population reduced sicklepod population by 80%. Before increasing planting rates to enhance weed suppression, trade-offs of additional seed costs need to be considered (Nice *et al.* 2001; Norsworthy and Frederick, 2002; Renner and Nelson, 1999). Reddy and Whiting (2000) stated that when weed control for conventional and glyphosate-resistant soybean are similar, soybean producers have to consider seed cost, including any associated technology fee, to select the cropping system that will maximize yield and net return. Technology fees added to the cost of glyphosate-resistant soybean seed result in seed costs averaging \$20 to \$25 ha^{-1} more than conventional seed (Kratochvil *et al.* 2004; Norsworthy, 2003). One way to reduce weed management costs in glyphosate-resistant soybean would be to lower seeding rates (Norsworthy, 2003). Norsworthy and Frederick (2002) found that some cultivars provide excellent yields using lower seeding rates when plants are not subjected to periods of stress during vegetative development. Norsworthy and Oliver (2001) also found that reducing the seeding rate from 432,000 to 185,000 seed ha^{-1} reduced expenses and increased gross profit margin. Holshouser and Whittaker (2002) found that a soybean density of 208,000 plants ha^{-1} was adequate for maximum yields at sites with short periods of moisture stress.

In competitive crops and low weed pressures, it may be possible to spray herbicides at lower than the label rate and maintain effective weed control and satisfactory yield (Boström and Fogelfors, 2002). Blackshaw *et al.* (2006) stated that there is a good potential to reduce both herbicide rate and the number of herbicide applications in competitive cropping systems. Weed control equal to spraying a full rate has been reported using sequential applications of low herbicides doses (Renner and Mickelson, 1997). Prostko and Meade (1993) stated that post-emergence herbicides applied at reduced rates provide acceptable weed control. Culpepper *et al.* (2000) reported that glyphosate applied sequentially was more effective than a single glyphosate application on broadleaf signalgrass (*Brachiaria platyphylla* (Griseb.) Nash) due to control of plants emerging after the early postemergence application.

Common lambsquarters (*Chenopodium album* L.) is one of the most widely distributed weeds in the world (Colquhoun *et al.* 2001; Crook and Renner, 1990; Harrison, 1990; Shropshire *et al.* 2004). The success and persistence of common lambsquarters is due to many factors such as germination under a wide range of environmental conditions (Basset and Crompton, 1978), early germination during the crop season (Ogg and Dawson, 1984), presence of large reserves of seed in soil due to prolific seed production (Harrison, 1990), and a waxy covering on leaves that may reduce effectiveness of postemergence herbicides (Taylor *et al.* 1981).

In soybean, common lambsquarters has been reported to reduce yield by 20% if weed control is delayed until the fifth week after the weed emergence (Crook and Renner, 1990). Interference has resulted in 36% yield reductions in tomato with 64 common lambsquarters per1 m of row (Bhowmik and Reddy, 1988), and a 10% yield reduction in lettuce with 1.5 weeks of interference with a density of 4 common lambsquarters per 6 m of row (Santos *et al*. 2004). Research was conducted to test the hypothesis that seeding rate will increase glyphosate efficacy. We performed a field experiment with glyphosate-resistant soybean, in which we varied soybean seeding rate and glyphosate rate applied at postemergence.

Materials and Methods

Experimental Design

An experiment was conducted in 2005 at the Iowa State University Agronomy Research Farm in Boone County, Iowa. 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. Plots were chisel plowed in the fall and final seedbed preparation was completed with a field cultivator. The previous crop was corn.

To evaluate the effect of plant density on common lambsquarters control with glyphosate[1], soybean (Golden Harvest H-2162 RR) was planted May 5, 2005. The experimental design was a randomized complete block with a factorial arrangement of seeding rates (240,000, 300,000, 360,000 and 420,000 seed ha^{-1}) and glyphosate (0, 0.5 and 1.0 kg ae ha^{-1}) with three replications. Plot size was 3.0 m by 7.6 m.

Common lambsquarters was planted 5 cm north of the three middle soybean rows at two different dates (Table 1) at a spacing of 30 cm. Unwanted weeds were controlled by handweeding. Glyphosate was applied when lambsquarters from the first planting date reached 10 cm and soybeans were at V6 stage (Fehr and Caviness, 1977), whereas common lambsquarters from the second planting date was 4 cm in height. The postemergence herbicide was applied in water with a CO_2 backpack sprayer using 8002 Teejet flat fan nozzle tips[2] at 275 kPa. The application included 1% w/v of ammonium sulfate.

To estimate the amount of herbicide intercepted by common lambsquarters at the time of application, water was applied to 5 cm × 2.5 cm water-sensitive cards[3] using the sprayer equipment previously described. Nontreated check units from each soybean seeding rate were used for this objective (four seeding rates × three replications). Each card was bonded to a wire stake, so the card surface was parallel to the ground. Cards were placed 5 cm above the ground level at the same position to the row as common lambsquarters. Twelve water-sensitive cards were placed in each nontreated check unit.

---

[1] Roundup WeatherMAX® Monsanto Company, St. Louis, MO, 63167.
[2] Teejet 8002 flat fat nozzle tip, Spray Systems Co., Wheaton, IL, 60189.
[3] Water-sensitive paper, Spray Systems Co., Wheaton, IL, 60189

Control of common lambsquarters was rated visually [scale of 0% (no control) to 100% (complete control)] relative to the untreated control. Common lambsquarters control was measured 14 and 21 days after application (DAA). Soybean injury was evaluated visually on a scale of 0 (no injury) to 100% (complete crop death) 14 DAA. The water-sensitive cards were scanned using a color computer vision system and were analyzed using image processing with Sigma Scan® Pro 5 software[4]. Percent coverage (PC) was obtained as the output from the software. Soybean grain was machine harvested from the middle three rows (Table 1) for the entire length of each plot. Yield was adjusted to 13% moisture prior to analysis.

Control of common lambsquarters, soybean yield, and PC were subjected to analysis of variance, and means were separated at the 5% level of significance by Fisher's protected LSD test.

Results and Discussion

There was no visible soybean injury from glyphosate (data not shown) 14 DAA. Glyphosate rate significantly affected common lambsquarters control, but did not affect grain yield. Soybean density was not significant for either parameter. There was not a significant interaction between soybean density and glyphosate rate for these parameters.

[4] Sigma Scan Pro 5.0 Systat Sfotware Inc., Point Rich, CA, 94804.

Herbicide Interception

Weed control with foliar-applied herbicides requires spray droplet contact with the weed foliage, and the crop canopy may interfere with spray coverage. (Knoche, 1994). There was a significant effect of soybean density on the interception of water by the water sensitive cards. Soybean density of 240,000 seed ha^{-1} allowed greater (%) coverage compared to the other three soybean densities (Fig. 1). High seeding rates allow a faster and early canopy development (Ball *et al*. 2000) and less herbicide was intercepted by weeds.

Common Lambsquarters Control

Visual estimates of common lambsquarters control were similar across soybean densities at 14 DAA with a rate of 1.0 kg ha^{-1} of glyphosate. Control of common lambsquarters with 0.5 kg ha^{-1} glyphosate was affected by soybean densities for the first planting date at 14 DAA (Table 2). Control of common lambsquarters with 0.5 kg ha^{-1} glyphosate could have resulted due to favorable environmental conditions before and after the 10-cm height application. Mulugeta and Boerboom (1996) found that the timing of application was more important than the rate of glyphosate. Reduced rates of postemergence herbicides may provide good weed control if herbicides are applied early to weeds (DeFelice *et al*. 1989). Common lambsquarters were dead by 21 DAA, providing 100% common lambsquarters control (Table 2). Despite reduced coverage with soybean densities of 360,000 and 420,000 seed ha^{-1}, excellent control was obtained with glyphosate at all soybean densities. VanGessel *et al.* (2003) found that differences in spray coverage did not affect weed control.

Low common lambsquarters emergence occurred for the second planting date. Taylorson and Borthwick (1969) found that the presence of a crop canopy inhibited germination of common lambsquarters seed. Lambsquarters were killed by both rates of glyphosate (data not shown).

Soybean Yield

Soybean yield was reduced in control plots when common lambsquarters competed for the entire season compared with plots sprayed with 0.5 and 1.0 kg ha^{-1} of glyphosate (Fig.2). A 19, 21, 12, and 11% reduction in soybean yield occurred in the control plots with 240,000, 300,000, 360,000 and 420,000 soybean seed ha^{-1} respectively, compared to the plots with 1.0 kg ha^{-1} application when 15 common lambsquarters per 5.5 m of row were present all season. A similar reduction in soybean yield was found by Crook and Renner (1990) when 32 common lambsquarters/10 m of row were present. Even though yield reduction in control plots was higher in soybean densities of 240,000 seed ha^{-1} than 420,000 seed ha^{-1}, soybean density effect was not significant.

Conclusions

This study showed that there is some potential for the use of reduced herbicide rates to provide common lambsquarters control when weather conditions did not affect soybean growth and weeds are small. In this study at 0.5 kg ae ha^{-1} total weed control was achieved at 21 DAA (Table 2).

Seeding rate did not affect the efficacy of glyphosate. However, the lowest seeding rate allowed a higher herbicide interception than the highest seeding rate (Fig. 1). Despite the difference in spray coverage, excellent common lambsquarters control was achieved at all soybean seeding rates. Koger *et al.* (2004) found that pitted morningglory control was not influenced by the degree of spray coverage.

In the absence of weed control, soybean seeding rate did not influence yield losses associated with common lambsquarters competition. However, the highest seeding rate yielded 12% more than the lowest seeding rate (Fig. 2). Data suggest that higher seeding rates used in the experiment may improve inter specific competition.

Farmers have to consider that using low rate can achieve an excellent weed control under favorable conditions. However farmers must take a long term approach to weed management because weed control tactics in one year may affect weed management strategies in future years.

References

Ball, R.A., L.C. Purcell, and E.D. Vories. 2000. Optimizing soybean plant population for a short-season production system in the Southern USA. Crop Sci. 40:757−764.

Bassett, I.J. and C.W. Crompton. 1978. The biology of Canadian weeds. 32. *Chenopodium album* L. Can. J. Plant Sci. 58:1061−1072.

Bhowmik, P.C. and K.N. Reddy. 1988. Interference of common lambsquarters (*Chenopodium album*) in transplanted tomato (*Lycopersicon esculentum*). Weed Technol. 2: 505−508.

Blackshaw, R.E., J.T. O'Donovan, K.N. Harker, G.W. Clayton, and R.N. Stougaard. 2006. Reduced herbicide doses in field crops: A review. Weed Biol. Management 6:10−17.

Boströn, U. and H. Fogelfors. 2002. Long-term effects of herbicide-application strategies on weeds and yield in spring-sown cereal. Weed Sci. 50:196−203.

Colquhoun, J., D.E. Stoltenberg, L.K. Binning, and C.M. Boerboom. 2001. Phenology of common lambsquarters growth parameters. Weed Sci. 49:177−183.

Corrigan, K.A. and R.G. Harvey. 2000. Glyphosate with ant without herbicides in no-till glyphosate-resistant soybean (*Glycine max*). Weed Technol. 14:569−577.

Crook, T.M. and K.A. Renner. 1990. Common lambsquarters (*Chenopodium album*) competition and time removal in soybeans (*Glycine max*). Weed Sci. 38:358−364.

Culpepper, A.S., A.C. York, R.B. Batts, and K.M. Jennings. 2000. Weed management in glufosinate and glyphosate-resistant soybean (*Glycine max*). Weed Technol. 14:77−88.

DeFelice, M.S., W.B. Brown, R.J. Aldrich, B.D. Sims, D.T. Judy, and D.R. Guethle. 1989. Weed control in soybean (*Glycine max*) with reduced rates of postemergence herbicides. Weed Sci. 37:365−374.

Fehr, W.R. and C.E. Caviness. 1977. Stages of soybean development. Spec. Rep. 80. Iowa Agric. Home Econ. Exp. Stn., Iowa State Univ., Ames.

Grichar, W.J., B.A. Bessler, and K. D. Brewer. 2004. Effect of row spacing and herbicide dose on weed control and grain sorghum yield. Crop Protection 23:263−267.

Harrison, S.K. 1990. Interference and seed production by common lambsquarters (*Chenopodium album*) in soybean (*Glycine max*). Weed Sci. 38:113-118.

Holshouser, D.L. and J.P. Whittaker. 2002. Plant population and row-spacing effects on early soybean production systems in the Middle-Atlantic USA. Agron. J. 94:603−611.

Howe, O.W. and L.R. Oliver. 1987. Influence of soybean (*Glycine max*) row spacing on pitted morningglory (*Ipomoea lacunose*) interference. Weed Sci. 35:185−193.

Kratochvil, R.J., J.T. Pearce, and M.R. Harrison Jr. 2004. Row spacing and seeding rate effects on glyphosate-resistant soybean for Mid-Atlantic production systems. Agron. J. 96:1029−1038.

Knoche, M. 1994. Effect of droplet size and carrier volume on performance of foliage-applied herbicides. Crop Prot. 13:163−178.

Koger, C.H. 2004. Effect of glyphosate spray coverage on control of pitted morningglory (*Ipomoea lacunosa*). Weed Technol. 18:124−130.

Loux, M.M., J.F. Stachler, and B.A. Miller. 2005. Response of common lambsquarters to glyphosate in the greenhouse and growth chamber. Proc. North Cent. Weed Cont. Conf. 60:202−203.

Mulugeta, D. and C.M. Boerboom. 2000. Critical time of weed removal in glyphosate-resistant *Glycine max.* Weed Sci. 48:35−42.

Mulugeta, D. and C.M. Boerboom. 1996. Critical period of weed management in glyphosate-resistant soybean systems. Proc. North Cent. Weed Cont. Conf. 51:130−131.

Myers, M.W., W.S. Curran, M.J. VanGessel, B.A. Majek, B.A. Scott, D.A. Mortensen, D.D. Calvin, H.D. Karsten, and G.W. Roth. 2005. The effect of weed density and application timing on weed control and corn grain yield. Weed Technol. 19:102−107.

Nice, G.R., N.W. Buehring, and D.R. Shaw. 2001. Sicklepod (*Senna obtusifolia*) response to shading, soybean (*Glycine max*) row spacing, and population in three management systems. Weed Technol. 15:155−162.

Norsworthy, J.K. 2005. Optimizing glyphosate timing in a mixed stand of glyphosate-resistant/conventional, drill-seeded soybean. Weed Technol. 19:942−946.

Norsworthy, J.K. 2003. Use of soybean production surveys to determine weed management needs of South Carolina farmers. Weed Technol. 17:195-201.

Norsworthy, J.K. and J.R. Frederick. 2002. Reduced seeding rate for glyphosate resistant, drilled soybean on the Southeastern coast plain. Agron. J. 94:1282−1288.

Norsworthy, J.K. and L.R. Oliver. 2001. Effect of seeding rate of drilled glyphosate resistant soybean (*Glycine max*) on seed yield and gross profit margin. Weed Technol. 15:284−292.

O'Donovan, J.T., K.N. Harker, G.W. Clayton, J.C. Newman, D. Robinson, and L.M. Hall. 2001. Barley seeding rate influence the effects of variable herbicide rates on wild oat. Weed. Sci. 49:746−754.

Ogg, A.G. and J.H. Dawson. 1984. Time of emergence of eight weed species. Weed Sci. 32:327−335.

Payne, S.A. and L.R. Oliver 2000. Weed control programs in drilled glyphosate-resistant soybean. Weed Technol. 14:413−422.

Prostko, E.P. and J.A. Meade. 1993. Reduced rates of postemergence herbicides in conventional soybeans (*Glycine max*). Weed Technol. 7:365−369.

Reddy, K.N. and K. Whiting. 2000. Weed control and economic comparisons of glyphosate-resistant, sulfonylurea-tolerant, and conventional soybean (*Glycine max*) systems. Weed Technol. 14:204−211.

Renner, K.A. and J.A.Mickelson. 1997. Weed control using reduced rates of post-emergence herbicides in narrow and wide row soybean. J. Prod. Agric. 10:431−437.

Renner, K.A. and K.A. Nelson. 1999. Weed management in wide and narrow row glyphosate resistant soybean. J. Prod. Agric. 12:460−465.

Santos, B.M., J.A. Dusky, W.M. Stall, and J.P. Gilreath. 2004. Effects of phosporus fertilization on common lambsquarters (*Chenopodium album*) duration of interference in lettuce (*Lactuca sativa*). Weed Technol. 18:152−156.

Shropshire, C., P.H. Sikkema, A.S. Hamill, S.E. Weaver, and P.B. Cavers. 2004. Response of common lambsquarter (*Chenopodium album*) to glyphosate application timing and rate in glyphosate-resistant corn. Weed Technol. 18:908−916.

Taylor, F.E., L.E. Davies, and A.H. Cobb. 1981. An analysis of the epicuticular was of *Chenopodium album* leaves in relation to environmental change, leaf wettability and the penetration of the herbicide bentazon. Ann. Appli. Biol. 98:471−478.

Taylorson, R.B. and H.A. Borthwick. 1969. Light infiltration by foliar canopies; significance for light-controlled weed seed germination. Weed Sci. 17:48-51.

VanGessel M.J., C.M. Whaley, and Q.R. Jhonson. 2003. Impact of soybean leaf area interference and row spacing on preharvest glyphosate application. Weed Technol. 17:491−495.

Young, B.G., J.M. Young, L.C. Gonzini, S.E. Hart, L.M. Wax, and G. Kapusta. 2001. Weed management in narrow and wide row glyphosate-resistant soybean (*Glycine max*) Weed Technol. 15:112−121.

Table 1. Date of soybean and common lambsquarters planting, lambsquarters emergence and herbicide application to evaluate the effect of soybean plant density on common lambsquarters.

Procedure	Date
Soybean planting	May 05
Common lambsquarters planting	
• First planting date	May 19
• Second planting date	Jun 02
Common lambsquarters emergence	
• First planting date	May 22
• Second planting date	Jun 07
Glyphosate application	Jun 22
Water-sensitive card trial	Jun 23
Grain harvest	Sep 21

Table 2. Herbicide efficacy for controlling common lambsquarters influenced by soybean density and glyphosate rate at 14 and 21 DAA. First planting date.

Soybean density (seed ha^{-1})	Common lambsquarters control (%)			
	Glyphosate rate (kg ha^{-1})			
	0.5		1.0	
	14DAA[a]	21DAA	14DAA	21DAA
240,000	87	100	100	100
300,000	80	100	100	100
360,000	76	100	96	100
420,000	71	100	100	100
$LSD_{0.05}$	15	NS	NS	NS

[a] Days after application.

NS, nonsignificant at the 0.05 level.

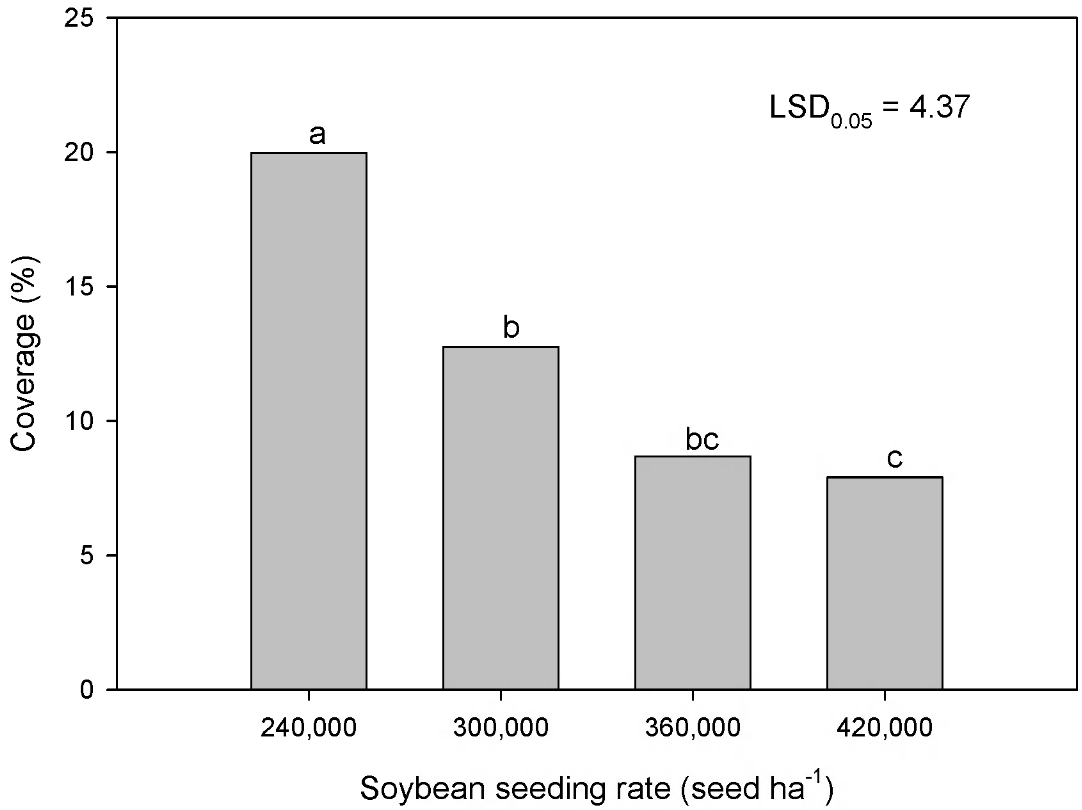

Figure 1. Spray coverage of water sensitive cards as influenced by the canopy of four soybean densities at V6 soybean stage.

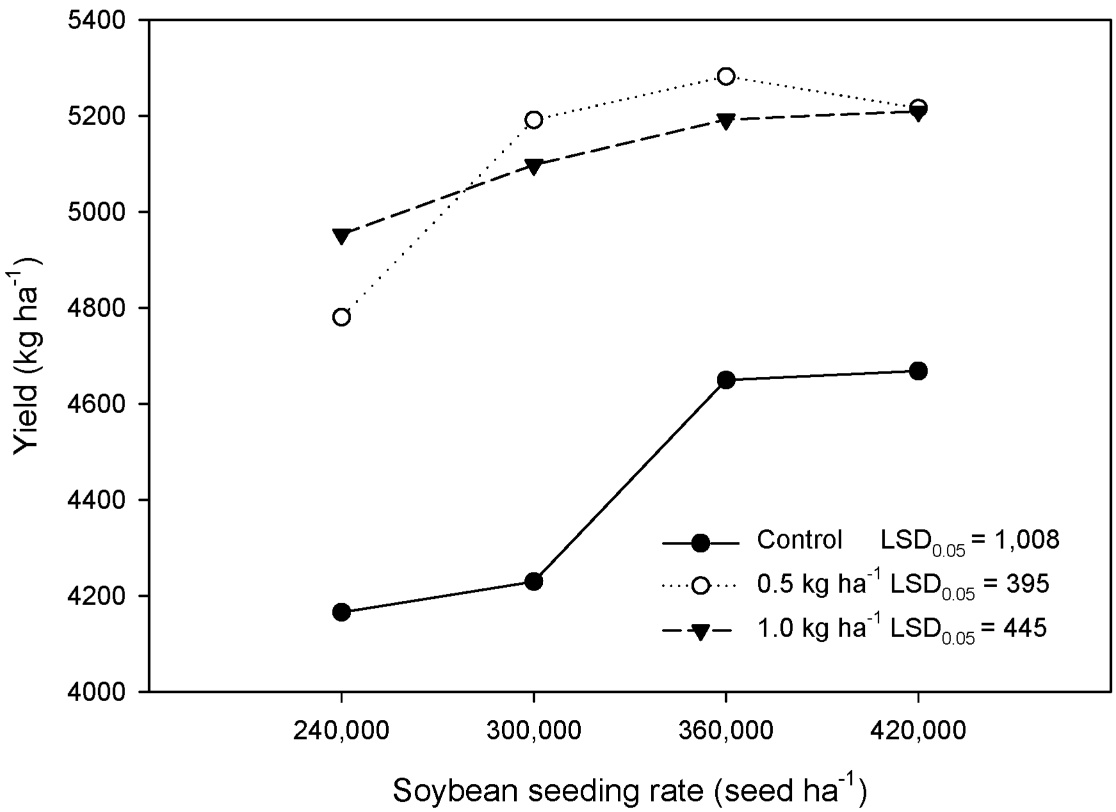

Figure 2. Effect of common lambsquarters on soybean yield as influenced by glyphosate rates and soybean densities.

CHAPTER IV

General Conclusions

Soybean yield at the lowest seeding rate (240,000 seed ha^{-1}) was reduced compared to higher densities at all three locations. Yield losses at the low seeding rate varied among locations and may depend on density and type of weeds (e.g. broadleaves and grasses) competing with soybean. Additionally, orthogonal contrasts showed that places with high weed densities such as Hancock no single application was enough to guarantee high grain yields for the other three seeding rates (300,000, 360,000, or 420 seed ha^{-1}).

Seeding rate did not affect the efficacy of glyphosate, however, at one of three locations end-of-season weed densities were higher in the low seeding rate compared to higher seeding rates. This response is probably due to the effect of seeding rate on canopy development and ability to suppress late-emerging weeds.

In the absence of weed control, soybean seeding rate did not influence yield losses associated with weed competition. However, at all locations the amount of weed biomass produced was indirectly related to soybean population. This suggest that higher seeding rates enhance inter specific competition, but the benefits may not always result in reduction in yield losses.

Timing of weed control only influenced soybean yield at the location with the highest weed densities. At this site, no single application provided yield equivalent to the weed-free treatment. Therefore a second glyphosate application may be needed to protect yields from weed competition.

Iowa recommendations for soybean seeding rates are close to the highest seeding rate used in this experiment (420,000 seed ha^{-1}). Results showed that soybean seeding rate can be lowered to 360,000 seed ha^{-1} without compromising grain yield.