SOYBEAN

Adjusting Management Practices Using Glyphosate-Resistant Soybean Cultivars

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ABSTRACT

Glyphosate [*N*-(phosphonomethyl)glycine]-resistant soybean [*Glycine max* (L.) Merr.] cultivars have increased drastically in usage and acceptance. Little information exists to see how glyphosate-resistant soybean cultivars should be managed. The objective of this study was to evaluate different row-spacing and plant population systems using three weed management systems. A field study was conducted from 1997 through 1999 at six locations in Wisconsin. Soybean was planted in 19-, 38-, and 76-cm rows at a recommended (optimum), low, and high plant population for each row-spacing system with three weed management systems [glyphosate-resistant soybean cultivars with glyphosate (GRS/G), glyphosate-resistant soybean cultivars with conventional herbicides (GRS/CN), and conventional soybean cultivars with conventional herbicides (CN/CN)]. In northern Wisconsin, soybean yield in a GRS/G system did not respond to plant population while GRS/CN and CN/CN systems yielded 6% more in high than in low plant population. Additionally, soybean yield responded positively to plant population in 76-cm row CN/CN and GRS/CN systems in northern Wisconsin. In southern Wisconsin, GRS/G and GRS/CN systems yielded 6% less than the CN/CN system. No differences were observed among weed management systems in central and northern Wisconsin. Averaged across weed management systems and plant population, 19- and 38-cm rows yielded 7, 9, and 10% more than 76-cm rows in southern, central, and northern Wisconsin, respectively. No yield differences were observed between optimum and high plant population across Wisconsin, averaging 4% greater yield than the low plant population. The results demonstrated that it might be beneficial to alter management practices when using glyphosate-resistant soybean in some production environments in Wisconsin.

GLYPHOSATE [*N*-(phosphonomethyl)glycine] is a nonselective herbicide that kills both annual and perennial grass and broadleaf weeds as well as woody species. The development of glyphosate-tolerant crops was pursued in the early 1980s, and glyphosate-resistant soybean was one of the first major applications of genetic engineering (Barry et al., 1992; Padgette et al., 1996). Glyphosate applied at labeled use rates does not affect glyphosate-resistant soybean adversely (Nelson and Renner, 1999). Holt et al. (1993) concluded that glyphosate-resistant soybean cultivars can improve current soybean management systems by (i) offering the farmer a new wide-spectrum weed control option, (ii) allowing the use of an environmentally sound herbicide system, (iii) providing a new herbicidal mode of action for in-season weed control with a product for which little weed resistance has developed, (iv) offering compatibility with minimum or no-tillage conservation systems, and (v) providing cost effective weed control. The advent of glyphosate-resistant cultivars presents a unique case since glyphosate-resistant cultivars can have both glyphosate and conventional herbicides applied to them, but conventional cultivars can only have conventional herbicides applied to them postemergence. Reddy and Whiting (2000) concluded that weed control cost is less using glyphosate-resistant soybean cultivars, even when the greater cost for seed of most glyphosate-resistant cultivars is considered. This translates to increased profits if yields from glyphosate-resistant cultivars are equal or nearly equal to those from conventional cultivars. However, if yields of glyphosate-resistant cultivars are greatly below those of conventional cultivars, the cost advantage for a weed management program with glyphosate will not result in greater net return (Webster et al., 1999).

Yield drag and/or lag have been demonstrated to affect the sustainability in a glyphosate-resistant soybean production system (Elmore et al., 2001). Previous comparisons suggested that glyphosate-resistant soybean cultivars yielded less than conventional soybean cultivars. Oplinger et al. (1999) analyzed performance trials from eight states and showed that yields of glyphosate-resistant soybean cultivars ranged from 86 to 113% of the yields of conventional soybean. Overall, glyphosate-resistant soybean cultivars yielded 4% less than conventional soybean, and it was anticipated that use of glyphosate-resistant soybean cultivars would continue to increase even though soybean growers may sacrifice maximum yield for ease of weed control. Elmore et al. (2001) compared five backcross-derived pairs of glyphosate-resistant soybean lines with conventional soybean sister lines and found that glyphosate-resistant cultivars yielded 5% less than the conventional sister lines, suggesting a yield drag.

Recent advances in tillage and planting equipment offer producers additional opportunities to maximize production and profitability. Commercially available 38-cm row planters allow soybean to be planted at a more uniform depth and distance between seeds than drills while perhaps realizing some of the benefits of drilled soybean. These benefits include a quicker canopy development and greater yields than when soybean is planted in 76-cm rows (Costa et al., 1980; Oplinger and Philbrook, 1992; Mickelson and Renner, 1997). Soybean

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Abbreviations: CN/CN, conventional soybean cultivars with conventional herbicides; GRS/CN, glyphosate-resistant soybean cultivars with conventional herbicides; GRS/G, glyphosate-resistant soybean cultivars with glyphosate.

canopy development, which is a function of row spacing, seeding rate, and environmental conditions, is an effective weed control tool (Peters et al., 1965; Duncan, 1986). Increased soybean densities promote a quicker canopy closure by increasing the leaf area index and light interception. The canopy will close in wide row spacings; however, Wilcott et al. (1984) found it to take about 15 d longer in 76- vs. 25-cm rows. Soybean planted in narrow rows (<76 cm) has been shown to intercept more sunlight than wide rows. This provides greater shading of weed seedlings and better crop competition, decreasing weed interference (Forcella et al., 1992). Yelverton and Coble (1991) found that as row spacing decreases, the number of weeds that emerge after herbicide application decreases linearly as a result of more light being intercepted by the soybean canopy.

Soybean has the ability to compensate for sparse plant populations resulting in similar yield per area compared with increased plant populations (Wells, 1991, 1993; Pedersen and Lauer, 2002). Increased seeding rates are required to maximize grain yields with narrow-row soybean (Devlin et al., 1995; Oplinger and Albaugh, 1996). However, drawbacks to increased soybean seeding rates include increased seed cost, increased plant mortality due to competition (Oplinger and Albaugh, 1996), and increased lodging (Costa et al., 1980; Oplinger and Philbrook, 1992; Oplinger and Albaugh, 1996).

Studies in recent years have examined the use of glyphosate-resistant soybean cultivars under various management practices. Young et al. (2001) concluded from their study in Illinois that increasing the glyphosate rate or delaying the glyphosate application did not consistently increase soybean yield regardless of row-spacing system. Levkulich et al. (1998) examined glyphosate-resistant soybean cultivars planted in 19- and 38-cm rows at two plant densities in Ohio. Soybean yield decreased in any treatment where glyphosate was applied once or following a pre-emergence herbicide compared with other treatments. Nelson and Renner (1999) examined wide- and narrow-row glyphosate-resistant soybean cultivars systems. They found that weed control was usually greater in 19- than 76-cm rows for treatments without glyphosate, and yield in 76-cm rows with nonglyphosate treatments was reduced compared with the weed-free control.

Use of glyphosate-resistant soybean cultivars has increased to a projected 84% in Wisconsin in 2002 (Natl. Agric. Stat. Serv., 2002). While much research has been conducted using conventional cultivars to measure the influence of row spacing and seeding rates (Costa et al., 1980; Oplinger and Philbrook, 1992; Oplinger and Albaugh, 1996; Pedersen and Lauer, 2002, 2003), little research has been conducted with glyphosate-resistant soybean cultivars. Our hypothesis is, that in parts of Wisconsin, it may be necessary and beneficial to alter management practices using glyphosate-resistant soybean cultivars compared with conventional cultivars to optimize yield. The objective of this research study was to evaluate different row-spacing and plant population systems using three weed management systems in Wisconsin.

MATERIALS AND METHODS

Field studies were conducted at six Wisconsin locations from 1997–1999 (Table 1). The locations were chosen to represent various Wisconsin environmental conditions and are divided into three production zones: southern, central, and northern. The treatments were arranged in a split-split plot randomized complete block design with weed management system (cultivar/herbicide systems) as whole-plot treatments. Weed management systems were conducted exclusively with herbicides and selected to compare yield potential in various management systems that are currently occurring in our pro-

Table 1. Field characteristics for six Wisconsin locations where the management of glyphosate-resistant soybean study was conducted during 1997-1999.

	Southern Wisconsin		Central Wisconsin		Northern Wisconsin	
	Janesville	Arlington	Fond du Lac	Galesville	Valders	Chippewa Falls
Latitude	42°6′ N	43°2′ N	43°6′ N	43°7′ N	44°1′ N	44°7′ N
Soil series	Plano silt loam	Plano silt loam	Pella silt loam	Downs silt loam	Kewaunee loam	Sattre loam
Soil family	fine-silty, mixed, mesic Typic Arguidolls	fine-silty, mixed, mesic Typic Arguidolls	fine-silty, mixed, mesic Typic Haplaquolls	fine-silty, mixed, mesic Mollic Hapludalfs	fine, mixed, mesic, Typic Hapludalfs	fine-loamy over sandy, mixed, mesic Mollic Hapludalfs
Soil fertility						
pH	6.6–6.7	6.1–6.8	6.5–6.7	5.9–6.1	7.2–7.4	5.9
P, g kg^{-1}	51–74	30–40	33–38	32–48	17–64	49–140
K, g kg^{-1}	195–240	120–210	100	150–170	125–250	150–155
OM, g kg^{-1}†	34–43	34–35	32–49	38–42	34–39	30–34
Previous crop						
1997	corn	not planted	corn	not planted	corn	corn
1998	corn	corn	corn	corn	corn	corn
1999	corn	corn	corn	corn	corn	corn
Planting date						
1997	10 May	not planted	12 May	not planted	22 May	6 May
1998	5 May	13 May	7 May	13 May	18 May	15 May
1999	4 May	5 May	28 May	25 May	30 May	10 May
Harvest date						
1997	1 October	not planted	6 October	not planted	10 October	10 October
1998	11 October	29 September	15 October	13 October	10 October	1 October
1999	24 September	5 October	11 October	12 October	7 October	1 October

† OM, organic matter.

Table 2. Weed management systems and herbicides applied in Wisconsin, 1997–1999. Herbicides were applied at no more than label use rate.

Treatment		Herbicides and years applied
		Southern Wisconsin
Conventional†	PRE‡	2,4-D (Arlington 1998, 1999); dimethenamid (Arlington 1999); glyphosate (Arlington 1998, 1999); imazethapyr (Arlington 1998, 1999); cloransulam-methyl (Janesville 1997, 1998); metolachlor (Arlington 1998; Janesville, 1997, 1998)
	POST§	Quizalofop (Arlington 1999; Janesville 1999); thifensulfuron (Arlington 1999); sethoxydim (Janesville 1997); bentazon (Janesville 1997); imazethapyr (Janesville 1999)
Glyphosate¶	PRE	2,4-D (Arlington 1998, 1999); glyphosate (Arlington 1998, 1999); cloransulam-methyl (Janesville 1997, 1998); metolachlor (Janesville, 1997, 1998)
	POST	Glyphosate (Arlington 1998, 1999; Janesville 1997, 1998, 1999)
		Central Wisconsin
Conventional	PRE	Metolachlor (Fond du Lac 1997, 1998, 1999; Galesville 1998, 1999); imazethapyr (Fond du Lac 1997, 1998); glyphosate (Galesville, 1999)
	POST	Sethoxydim (Fond du Lac 1997, 1998, 1999); imazethapyr (Fond du Lac 1999; Galesville 1998, 1999); bentazon (Fond du Lac 1997); quizalofop (Galesville 1998, 1999); thifensulfuron (Galesville 1998, 1999)
Glyphosate	PRE	Imazethapyr (Fond du Lac 1997); metolachlor (Fond du Lac 1997; Galesville 1998)
	POST	Glyphosate (Fond du Lac 1997, 1998, 1999; Galesville 1998, 1999)
		Northern Wisconsin
Conventional	PRE	Imazethapyr (Valders 1997, 1998; Chippewa Falls 1997, 1998); metolachlor (Chippewa Falls 1997; Valders, 1997); pendimethalin (Chippewa Falls 1998, Valders 1998)
	POST	Imazethapyr (Chippewa Falls 1999, Valders 1999); thifensulfuron (Chippewa Falls 1998, 1999; Valders 1999); quizalofop (Chippewa Falls 1999; Valders 1999)
Glyphosate	PRE	Pendimethalin (Valders 1998; Chippewa Falls 1998); imazethapyr (Valders 1998; Chippewa Falls 1997, 1998); metolachlor (Chippewa Falls 1997)
	POST	Glyphosate (Valders 1997, 1998, 1999; Chippewa Falls 1997, 1998, 1999)

† Conventional treatments were applied on both glyphosate-resistant and glyphosate-susceptible cultivars.
‡ PRE = applied preplanting or pre-emergence.
§ Post = applied postemergence.
¶ Glyphosate treatments were only applied on glyphosate-resistant cultivars.

duction fields. The three systems were conventional soybean cultivars with nonglyphosate herbicides applied postemergent (CN/CN), glyphosate-resistant soybean cultivars with nonglyphosate herbicides applied postemergent (GRS/CN), and glyphosate-resistant soybean cultivars with glyphosate applied postemergent (GRS/G). Herbicides were chosen based on weed spectrum at each site (Table 2) and were applied at appropriate rates and weed sizes based on label and university recommendations. All herbicides were applied in 187 L water ha^{-1} using a Hefty G experimental plot planter with a 2.5-m-wide boom (Oplinger et al., 1983). Pre-emergence herbicides were applied immediately after planting, and postemergence herbicides were applied at approximately growth stage V2 to V3 to control existing weeds (Fehr and Caviness, 1977).

The subplots consisted of three row spacings of 19-, 38-, and 76-cm row width, and the sub-subplots were three seeding rates for the three row spacings. The seeding rates included recommended (optimum) (Oplinger and Albaugh, 1996; Oplinger and Philbrook, 1992), low (optimum minus 124 000 plants ha^{-1}), and high (optimum plus 124 000 plants ha^{-1}; Table 3), thereby creating a set of row spacing/seeding rate systems for the three weed management systems. Cultivars were chosen to represent a maturity suitable to each zone. The cultivars used were Asgrow AG1900 and AG1901 (glyphosate resistant) in the southern zone, Novartis S19-90 and S20-B9 (glyphosate resistant) in the central zone, and Novartis S12-49 and S14-M7 (glyphosate resistant) in the northern zone. According to information provided by seed company agronomists, each pair of cultivars from the different zones were equivalent genotypes since they were either sister lines or parental.

Table 3. Row spacings and seeding rates used for management of glyphosate-resistant soybean study in Wisconsin during 1997–1999.

	Seeding rates		
Row spacing	Low	Optimum	High
cm		seeds ha^{-1}	
19	432 000	556 000	680 000
38	309 000	432 000	556 000
76	185 000	309 000	432 000

Soybean at the Arlington location was planted no-tillage using a John Deere 750 drill (John Deere, Moline, IL) and a KINZE 2000 Interplant row planter (KINZE Manufacturing, Williamsburg, IA). Plots measured 15.2 by 3.0 m. Soybean at all other locations was planted using conventional tillage at 4-cm depth in 7.6- by 2.5-m plots using the Hefty G experimental plot planter equipped with double-disk openers and a cone distributor to ensure accurate seeding rates. Further management practices for each location are presented in Table 1.

Data collected at harvest included grain yield, grain moisture, final plant population, plant height, lodging, and seed weight. Lodging was based on a 1 (no lodging) to 5 (completely lodged) scale. The center seven, four, and two rows of the 19-, 38-, and 76-cm plots were harvested with an Almaco Plot Combine (Allen Machine Co., Nevada, IA), with plot weight and moisture measurements collected using the HarvestData system (Harvestmaster, Logan, UT). Grain yields were adjusted to 130 g kg^{-1} grain moisture. Weed control after herbicide application was considered the same and excellent and was not measured.

All data were subjected to an analysis of variance using the PROC MIXED procedure (Littell et al., 1996) of SAS (SAS Inst., 1995) at $P \leq 0.05$. Data were first analyzed by years and locations. All effects except replicates were considered fixed in determining the expected mean squares. Data were then analyzed across locations and years within each production zone since different cultivars were used in each production zone. Replicate, location, and year were treated as random effects within each production zone in determining the expected mean square and appropriate F tests in the analysis of variance. Last, locations and years were considered an environment (Milliken and Johnson, 1994) after determining error variances were homogenous using the maximum likelihood estimation procedure in PROC MIXED. Replicate and environment were treated as random effects within each production zone in determining the expected mean square and appropriate *F* tests in the analysis of variance. When significant treatment effects ($P \leq 0.05$) were found, orthogonal contrasts were constructed to compare cultivars in the different production zones with all possible interactions of the experimental factors calculated. Mean comparisons were made using Fisher's protected LSD test ($P \leq 0.05$). Grain yield was regressed on final plant population using the maximum likelihood estimation procedure in PROC MIXED. Regression analysis was used to examine the relationship between grain yield and plant density for the different treatments. Regression coefficients were described when significant ($P \leq 0.05$).

RESULTS AND DISCUSSION

Growing conditions varied considerably over the 3 yr and influenced soybean yields and other agronomic traits at all locations. Average precipitation during the growing season (May to September) was greater than the 20-yr average in 1998 and similar to the 20-yr average for 1997 and 1999. Average temperatures during the growing season were below, above, and near normal for 1997, 1998, and 1999, respectively.

The three production zones are different from each other. The two southern locations at Arlington and Janesville represent ideal Wisconsin growing conditions for soybean with a silt loam soil type and long growing season compared with the northern part of Wisconsin. In the central zone, both locations have adequate growing seasons; however, Galesville has a high weed pressure. The Fond du Lac location has a heavy, poorly drained silt loam soil, which delays planting and early growth in a cool and wet spring. In the northern zone, Chippewa Falls is prone to dry conditions while the Valders site has a heavy clay soil that drains slowly and a cooler growing season due to its close proximity to Lake Michigan.

Grain Yield

No interactions were observed among treatment effects in the southern or the central zones (Table 4). However, a few interactions were observed among treatment effects in the northern zone. A weed management system × seeding rate interaction was observed, indicating that different plant populations responded differently to various weed management systems. No yield differences were found among the three plant populations in the GRS/G system. However, yield decreased on average 6% in the CN/CN and GRS/CN systems as plant population decreased from the optimum and high to the low plant population (data not shown). A weed management system × row spacing × seeding rate interaction was observed in the northern zone. In general, weed management systems and plant populations did not influence grain yield in 19- and 38-cm row spacing. However, in the CN/CN and GRS/CN systems planted in 76-cm rows, yield increased as plant population increased. No yield difference was found among plant populations in 76-cm rows the GRS/G system (data not shown). Soybean in the northern zone is normally under stress due to cool weather, and recovering from a conventional herbicide application may add more stress. It is speculated that at a cooler temperature, faster recovery to glyphosate as a result of less herbicide injury allows low plant populations to attain similar yields as high plant populations. Nelson and Renner (1999) found similar results and concluded that soybean injuries from nonglyphosate herbicides slowed canopy development. The lack of a yield response to population for the GRS/G system in northern Wisconsin warrants additional investigation to determine if a similar response is expressed by other genotypes.

No differences were found between weed management systems and yield in the central or in the northern zone (Table 4). In the southern zone, the GRS/CN and GRS/G systems averaged 6% less yield than the CN/CN system. No yield difference was observed between the two glyphosate systems, suggesting that there was not a yield difference associated with conventional herbicides. No yield difference was observed in the northern and central zones between glyphosate-resistant and conventional soybean cultivars. Southern Wisconsin is considered a high-yielding environment, and our data agree with other studies comparing glyphosate-resistant and conventional cultivars in high-yielding environments (Webster et al., 1999; Elmore et al., 2001; Heatherly et al., 2002).

In the southern zone, greatest (4.68 Mg ha^{-1}) and lowest (4.25 Mg ha^{-1}) yields were attained in the 38- and 76-cm rows, respectively. In the central and northern zones, no differences were found between 19- and 38-cm rows, averaging 9 and 10% more than the 76-cm rows, respectively. Soybean planted in 38-cm rows produced greater yields than soybean planted in 76-cm rows, regardless of weed management system and zone (Table 4). This supports the majority of research from Wisconsin that advocated planting in row spacing less than 76 cm (Costa et al., 1980; Oplinger and Philbrook, 1992). However, Pedersen and Lauer (2003) did not find any yield benefits in southern Wisconsin using row width less than 76 cm mainly because of various soil pathogens.

The effect of plant population on grain yield was consistent across the three production zones (Table 4). Grain yield increased as plant population increased, but no differences were found between optimum and high plant populations. This indicates the recommended optimum seeding rate in Wisconsin represents the maximum attainable grain yield in current production systems. Regression analysis of grain yield vs. final plant population was conducted for all treatment effects and their interactions in the different production zones with few relationships observed. With the exception of a positive linear relationship between grain yield and plant population for the GRS/CN system in the central zone, no relationships were observed among weed management systems and plant population (data not shown). Yield increased as plant population increased in a linear fashion for 19- and 38-cm row spacing in the northern zone (Table 5). The relationship between grain yield and plant density was best explained using a slower log-linear rate in the southern and central zones. However,

Table 4. Weed management system, row spacing, and seeding rate effect on soybean grain yield, grain moisture, height, lodging, seed weight, and final plant population in Wisconsin (1997–1999).

Treatment	Yield	Moisture	Height	Lodging†	Seed weight	Final plant population
	Mg ha^{-1}	g kg^{-1}	cm		g 100 seed^{-1}	plants ha^{-1}
			Southern Wisconsin‡			
Weed management system (S)§						
CN/CN	4.64	125	88.1	1.7	16.1	332 900
GRS/CN	4.37	123	104.0	2.5	16.2	328 700
GRS/G	4.39	125	106.7	2.5	16.6	331 200
LSD (0.05)	0.20	NS¶	7.7	0.3	NS	NS
Contrast: GRS vs. CN#	**	NS	***	***	NS	NS
Row spacing (R)						
19 cm	4.47	125	100.5	2.5	16.4	412 000
38 cm	4.68	124	98.9	2.2	16.2	325 500
76 cm	4.25	124	99.4	2.0	16.2	255 300
LSD (0.05)	0.18	NS	NS	0.2	NS	24 300
Seeding rate (SR)††						
Low	4.39	124	99.6	2.0	16.1	243 500
Optimum	4.48	124	99.2	2.3	16.2	335 400
High	4.53	124	100.0	2.4	16.5	413 900
LSD (0.05)	0.08	NS	NS	0.2	0.2	15 800
ANOVA						
S × R	NS	NS	NS	NS	NS	NS
S × SR	NS	NS	NS	NS	NS	NS
R × SR	NS	NS	NS	NS	NS	NS
S × R × SR	NS	NS	NS	NS	NS	NS
			Central Wisconsin			
Weed management system (S)						
CN/CN	3.99	129	85.1	1.5	20.9	319 600
GRS/CN	3.74	130	89.6	1.5	19.7	323 800
GRS/G	3.99	130	95.9	1.7	20.4	338 600
LSD (0.05)	NS	NS	3.9	NS	0.5	NS
Contrast: GRS vs. CN#	NS	NS	***	NS	***	NS
Row spacing (R)						
19 cm	4.01	131	92.1	1.7	20.2	419 500
38 cm	4.06	129	90.3	1.6	20.2	326 000
76 cm	3.66	129	88.3	1.4	20.6	236 500
LSD (0.05)	0.26	1	1.6	0.1	0.2	24 100
Seeding rate (SR)††						
Low	3.80	130	88.4	1.5	20.3	245 700
Optimum	3.94	130	90.8	1.5	20.2	325 200
High	3.99	130	91.4	1.7	20.4	411 200
LSD (0.05)	0.08	NS	1.4	0.1	NS	16 700
ANOVA						
S × R	NS	NS	NS	NS	NS	NS
S × SR	NS	NS	NS	NS	NS	NS
R × SR	NS	NS	NS	NS	NS	NS
S × R × SR	NS	NS	NS	NS	NS	NS
			Northern Wisconsin			
Weed management system (S)						
CN/CN	3.27	138	61.2	1.3	20.2	295 400
GRS/CN	3.09	139	65.0	1.5	19.4	303 000
GRS/G	3.34	137	70.3	1.6	19.9	308 900
LSD (0.05)	NS	NS	5.0	NS	0.6	NS
Contrast: GRS vs. CN	NS	NS	**	*	*	NS
Row spacing (R)						
19 cm	3.34	139	65.2	1.5	19.5	376 200
38 cm	3.35	138	65.6	1.4	19.8	303 100
76 cm	3.02	137	65.8	1.4	20.2	227 900
LSD (0.05)	0.12	NS	NS	0.1	0.2	18 000
Seeding rate (SR)††						
Low	3.14	138	64.6	1.4	19.8	228 000
Optimum	3.25	138	66.0	1.5	19.8	305 400
High	3.31	138	65.9	1.5	19.8	373 900
LSD (0.05)	0.07	NS	1.2	NS	NS	12 600
ANOVA						
S × R	NS	NS	NS	NS	NS	NS
S × SR	*	NS	NS	NS	NS	NS
R × SR	NS	NS	NS	NS	NS	NS
S × R × SR	*	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† Lodging score: the range extends from 1 = erect to 5 = flat.
‡ Southern Wisconsin: Janesville and Arlington; Central Wisconsin: Fond du Lac and Galesville; Northern Wisconsin: Valders and Chippewa Falls.
§ CN/CN, conventional cultivar with conventional herbicide; GRS/CN, glyphosate-resistant cultivar with conventional herbicide; GRS/G, glyphosate-resistant cultivar with glyphosate.
¶ NS, nonsignificant at the 0.05 level.
# Glyphosate-resistant cultivar (GRS) vs. conventional cultivar (CN).
†† See Table 3.

Table 5. Regression equations for soybean yield in three row-spacing systems in Wisconsin (1997–1999). Data were pooled across year, location within a production zone, weed management system, and replication and regressed against harvest plant population.

Row-spacing system	Regression equation†	R^2
	Southern Wisconsin	
19 cm	no significant coefficients	–
38 cm	$Y = 0.5563 + 0.3258 \ln(P)$	0.99
76 cm	$Y = 0.3328 + 0.3157 \ln(P)$	0.99
	Central Wisconsin	
19 cm	no significant coefficients	–
38 cm	no significant coefficients	–
76 cm	$Y = -0.0288 + 0.2991 \ln(P)$	0.99
	Northern Wisconsin	
19 cm	$Y = 3.1453 + 5.11 \times 10^{-7}(P)$	0.99
38 cm	$Y = 3.0044 + 1.13 \times 10^{-6}(P)$	0.99
76 cm	no significant coefficients	–

no relationships were observed between grain yield and plant population for 19-cm rows in the southern zone and 19- and 38-cm rows in the central zone. High R^2 values in all zones indicate a close relationship between yield and plant population, which may be related to the few plant densities per treatment in this study.

Grain Moisture

No differences in grain moisture were observed among treatments in the southern and northern zones (Table 4). However, in the central zone, grain moisture decreased as row spacing increased. Pedersen and Lauer (2003) found grain moisture content to decrease as row spacing increased. Grain moisture was greatest in northern Wisconsin and decreased moving southward. Grain moisture averaged 138, 130, and 124 g kg^{-1} for the northern, central, and the southern production zone.

Plant Height and Lodging

Plant height and lodging varied across the three zones. In the southern zone, the glyphosate-resistant cultivar resulted in 17% taller plants than the conventional cultivar, regardless of weed management system (Table 4). This resulted in a decreased lodging score (1.7) for the CN/CN system compared with the two glyphosate-resistant systems, which averaged a lodging score of 2.5. In the central zone, the glyphosate-resistant cultivar averaged 9% taller than the conventional cultivar. Overall, plants in the GRS/G system were the tallest, and plants in the CN/CN system were the shortest. Soybean in the GRS/CN system were 6 cm shorter than those in the GRS/G system, indicating that application of conventional herbicides on soybean in this zone resulted in shorter plants. Lodging was not influenced by weed management systems in the central zone. Similar results were observed in the northern zone. The glyphosate-resistant cultivar averaged 10% taller than the conventional cultivar. However, soybean height in weed management systems with a conventional herbicide applied did not differ, regardless of cultivar. This suggests that conventional herbicide application may have resulted in shorter plants regardless of cultivar and is in agreement with observations from Mississippi (Heatherly et al., 2002). Lodging was not influenced by weed management systems in the northern zone.

Plant height was not affected by row spacing in either the southern or in the northern zones (Table 4). Nevertheless, lodging was consistently influenced by row spacing in both zones with greatest and lowest lodging score observed in the 19- and 76-cm row spacing, respectively. In the central zone, however, row spacing influenced both plant height and lodging, with the tallest plants (92.1 cm) and greatest lodging score (1.7) observed in the 19-cm row spacing and the shortest plants (88.3 cm) and the smallest lodging score (1.4) observed in the 76-cm row spacing. Pedersen and Lauer (2003) observed a similar response from row spacing on plant height and lodging. However, Elmore (1998) did not find row spacing to affect plant height and lodging.

Pedersen and Lauer (2002) stated that lodging increased as plant population increased. In this study, however, plant population did not influence plant height in a consistent way. In the southern zone, plant population did not influence plant height; however, the smallest lodging score (2.0) was found in plots with low plant population, and greatest lodging score was found in plots with optimum and high plant population (2.3 to 2.4). Overall, plant height and lodging increased as plant population increased in the central and northern zones.

Seed Weight

No differences were found between weed management systems and seed weight in the southern zone (Table 4). In the central and northern zones, the GRS/CN and GRS/G systems averaged 3% less seed weight than the CN/CN system. A greater seed weight in non-glyphosate-resistant sister lines compared with glyphosate-resistant sister lines agrees with results of Elmore et al. (2001).

Row spacing influenced seed weight inconsistently in the three zones. In the central zone, lowest (20.2 g 100 seed^{-1}) and greatest (20.6 g 100 seed^{-1}) seed weight was found in 19- and 76-cm rows, respectively. No differences in seed weight were observed between 19- and 38-cm row spacing. In the northern zone, seed weight increased as row spacing increased. No differences in seed weight were found between the three row spacings in the southern zone. Pedersen and Lauer (2003) observed similar inconsistent relationship between seed weight and row spacing.

In the southern zone, seed weight was positively correlated with plant population. This result was unexpected and cannot be explained. No difference was found in seed weight among the different seeding rates in either the central or northern zones.

CONCLUSION

In general, our results indicate that management practices when using glyphosate-resistant cultivars should be similar to conventional cultivars. In southern Wisconsin, the GRS/G and GRS/CN systems yielded 6% less than the CN/CN system. No differences were observed among weed management systems in central or northern Wisconsin. Possible yield differences between glyphosate-resistant and conventional cultivars should be taken into account in high-yielding environments in Wisconsin when selecting soybean cultivars and weed management systems. However, since only a limited number of GRS/CN pairs were evaluated in this research, conclusions about their potential relative to non-GRS cultivars must be narrow. The focus of the study was on the response of this herbicide-resistant seed technology to row spacing and population instead of cultivar yield. Planting soybean in narrow rows (38 cm or less) resulted in the greatest yield in all zones and thereby gives another option to reduce production costs by using an interrow planter to share equipment costs between corn and soybean. Soybean yield increased as plant population increased in southern and central Wisconsin. However, in northern Wisconsin, no differences were observed among plant populations in 19- and 38-cm rows regardless of weed management systems, and no differences were observed among plant populations using 76-cm rows in a GRS/G system. Results from this study suggest that regardless of management practice, use of glyphosate-resistant soybean cultivars should be viewed as a weed management option rather than a selection criterion. However, when using a GRS/G system, it may be economically feasible to reduce seeding rates in parts of Wisconsin, as the results from northern Wisconsin demonstrated.

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