Weed Technology 2012 26:617–621

Evaluation of Application Program and Timing in Herbicide-Resistant Corn

Laura E. Lindsey, Wesley J. Everman, Andrew J. Chomas, and James J. Kells*

Field studies were conducted from 2007 to 2009 in East Lansing, MI to evaluate three residual herbicide programs, three POST herbicide application timings, and two POST herbicides in glyphosate- and glufosinate-resistant corn. Herbicide programs included a residual PRE-applied herbicide followed by (fb) POST application (residual fb POST), a residual herbicide tank-mixed with a POST herbicide (residual + POST), and a nonresidual POST. Three POST herbicide application timings included early POST (EP), mid-POST (MP), and late POST (LP) at an average corn growth stage of V3/V4, V4/V5, and V5/V6, respectively. The two POST herbicides evaluated were glyphosate and glufosinate. Control of common lambsquarters and giant foxtail was evaluated 28 d after the LP application. Glyphosate often provided greater weed control than glufosinate. The LP application resulted in greater giant foxtail control compared with the EP application timing, which may be attributed to control of late-emerging weeds. The EP application timing improved common lambsquarters control compared with the LP application timing. The residual + POST program resulted in greater weed control compared with the residual fb POST program in all years. The effect of residual herbicide program, POST herbicide, and POST application timing on corn grain yield varied by year. In 2007, the use of glyphosate resulted in higher grain yield compared with glufosinate. In 2008, corn grain yield was the highest in the PRE fb POST program and with POST applications at EP and MP. To provide the most consistent weed control and minimize the likelihood of grain yield reductions, a PRE fb POST program applied at EP or MP is recommended.
Nomenclature: Acetochlor; atrazine; glufosinate; glyphosate; common lambsquarters, *Chenopodium album* L.; giant foxtail, *Setaria faberi* Herrm.; corn, *Zea mays* L.
Key words: Grain yield, postemergence, preemergence, residual herbicide.

En East Lansing, MI, se realizaron estudios de campo desde 2007 a 2009 para evaluar tres programas de herbicidas residuales, tres momentos de aplicación de herbicidas POST y dos herbicidas POST en maíz resistente a glyphosate y a glufosinate. Los programas de herbicidas incluyeron un herbicida residual aplicado PRE seguido de (fb) una aplicación POST (residual fb POST), y una aplicación no residual POST. Los tres momentos de aplicación POST incluyeron POST temprano (EP), POST medio (MP) y POST tardío (LP) a un estado de desarrollo promedio del maíz de V3/V4, V4/V5 y V5/V6, respectivamente. Los dos herbicidas POST evaluados fueron glyphosate y glufosinate. El control de *Chenopodium album* y *Setaria faberi* fue evaluado 28 d después de la aplicación LP. Glyphosate frecuentemente brindó mayor control de malezas que glufosinate. La aplicación LP resultó en mayor control de *S. faberi* comparada a la aplicación EP, lo cual podría ser atribuido al control de malezas de emergencia tardía. La aplicación EP mejoró el control de *C. album* comparada con la aplicación LP. El programa residual + POST resultó en mayor control de malezas comparado con el programa residual fb POST en todos los años. El efecto del programa residual de herbicidas, de herbicidas POST y del momento de aplicación en el rendimiento de grano del maíz varió según el año. En 2007, el uso de glyphosate resultó en un mayor rendimiento de grano comparado con glufosinate. En 2008, el mayor rendimiento de grano del maíz se obtuvo en el programa PRE fb POST y con aplicaciones POST EP y MP. Para brindar un control de malezas más consistente y minimizar la probabilidad de reducciones en rendimiento de grano, se recomienda el programa PRE fb POST aplicado a EP o MP.

Early-season weed interference reduces light, nutrients, and moisture available to the crop (Dalley et al. 2006; DiTomaso 1995; Lindquist et al. 2010; Moechnig et al. 2003; Vengris et al. 1955; Young et al. 1984). Corn growing with weeds exhibits shade-avoidance characteristics including fewer kernels per plant and reduced biomass partitioning to the developing ear (Page et al. 2010). Both resource-dependent (i.e., light, nutrients, and moisture) and resource-independent (light interference) weed competition may reduce corn grain yield (Hall et al. 1992; Knake and Slife 1969; Knezevic et al. 1994; Young et al. 1984). There are many combinations of herbicide programs and application timings that utilize herbicide-resistance technology to minimize weed interference; however, previous studies have not evaluated all of these factors in a comprehensive study.

Several studies have investigated the critical time of weed removal, which is defined as the point in time when weeds need to be controlled to avoid yield reduction (Zimdahl 2004). Current recommendations are based on controlling weeds by a certain corn growth stage or weed height (Gower et al. 2002; Knezevic et al. 1994). Knezevic et al. (1994) reported a 5% reduction in corn grain yield when redroot pigweed (*Amaranthus retroflexus* L.), at a density as low as 0.33 plants m^{-2}, was not controlled until the V4 growth stage of corn. In contrast, Myers et al. (2005) reported that weed control at the V4 to V8 stage with a single POST application of glyphosate was adequate to avoid grain yield reductions at weed densities less than 14 plants m^{-2}. When glufosinate is

DOI: 10.1614/WT-D-12-00012.1
* First, third, and fourth authors: Graduate Assistant, Research Technician, and Professor, Department of Crop and Soil Sciences, Michigan State University, East Lansing, MI 48824; second author: Assistant Professor, Department of Crop Science, North Carolina State University, Box 7620, Raleigh, NC 27695. Corresponding author's E-mail: kells@msu.edu

https://doi.org/10.1614/WT-D-12-00012.1 Published online by Cambridge University Press

applied in combination with a residual herbicide, weed control is optimized at the V3 to V5 growth stage (Hamill et al. 2000). With respect to weed height, control of weeds between 10- and 15-cm tall is ideal to minimize grain yield losses in the Midwest (Carey and Kells 1995; Dalley et al. 2004; Gower et al. 2002; Tapia et al. 1997). However, under less competitive conditions (i.e., adequate rainfall and low weed density), grain yield losses may not occur until weeds are taller than 30 cm (Dalley et al. 2006). After weeds were removed, many of these studies maintained weed-free plots for the remainder of the season, failing to take into account the effects of late-emerging weeds. Therefore, it is important to also consider studies that have allowed new weeds to emerge after POST application.

POST herbicide strategies that include a residual herbicide provide equally consistent or more consistent weed control than a PRE herbicide treatment alone (Gower et al. 2002; Zuver et al. 2006). When glyphosate or glufosinate was tank-mixed with a residual herbicide, an increase in corn grain yield has been reported when compared with POST herbicide application alone (Hamill et al. 2000; Tharp and Kells 2002). However, in another study, the inclusion of a residual herbicide PRE followed by (fb) glyphosate POST did not improve grain yield when applied to 10- to 15-cm weeds (Gower et al. 2002). Variable results may be partially attributed to the herbicide program (i.e., PRE residual herbicide or POST + residual herbicide) and warrant further research.

Single-pass POST herbicide application when weeds are 5- to 10-cm tall may result in corn grain yield reductions due to weed reinfestations (Gower et al. 2002), and consequently increase the weed seed bank (Myers et al. 2005). Herbicide application to weeds 10- to 15-cm tall can result in corn grain yields equal to those in weed-free plots (Dalley et al. 2006), but POST applications when weeds are $\geq$ 15-cm tall provide the most consistent season-long weed control when compared with applications when weeds are $<$ 15 cm (Gower et al. 2003). Additionally, two-pass herbicide programs have been investigated to reduce yield losses that may occur due to early-season weed competition and late-emerging weeds (Bradley et al. 2000; Gower et al. 2002). Studies examining PRE fb POST programs found that weed control occasionally improved in comparison with a total POST program (Gower et al. 2002; Shrestha et al. 2001; Tharp and Kells 2002).

The development of herbicide-resistant crops allows weed control by nonselective POST herbicides such as glyphosate and glufosinate, widening the array of weed-management programs available to producers (Culpepper and York 1999; Johnson et al. 2000). Both glyphosate and glufosinate control a wide range of weeds in herbicide-resistant crops (Corbett et al. 2004) with little, if any, crop injury (Bradley et al. 2000; Ritter and Menbere 2001). POST applications of glyphosate or glufosinate in corn provide consistent and greater control of large-seeded broadleaf weed species including velvetleaf (*Abutilon theophrasti* Medik.), giant ragweed (*Ambrosia trifida* L.), common cocklebur (*Xanthium strumarium* L.), and morningglory (*Ipomoea* spp.) compared with PRE herbicides (Zuver et al. 2006). Even though glyphosate and glufosinate performance is similar, glufosinate is less likely to succeed in a single POST application program (Bradley et al. 2000).

Several studies have compared timing of herbicide applications, the effect of including a residual herbicide, or POST herbicide applications of glyphosate vs. glufosinate; however, there has been no single, comprehensive study that has evaluated all of these factors. Therefore, the objectives of our research were to determine the effect of POST herbicide application timing, the use of a residual herbicide, and the POST herbicides glyphosate and glufosinate on weed control and corn grain yield.

Materials and Methods

Field studies were conducted in 2007, 2008, and 2009 at the Michigan State University Crop and Soil Sciences Research Farm in East Lansing. Soil texture was a sandy loam (3.3% organic matter), clay loam (3.4% organic matter), and loam (3.4% organic matter) in 2007, 2008, and 2009, respectively. Soil pH ranged from 6.4 to 6.6 for each year of the study. Hybrids, consisting of 'Pioneer 38B86' in 2007 and 'Pioneer 37Y14' in 2008 and 2009, were resistant to both glyphosate and glufosinate. Plots (3.0 by 10.7 m) consisted of four rows 76 cm apart. Tillage included chisel plowing the previous fall and field cultivation twice before planting. Fertilizer was applied according to Michigan State University recommendations with urea broadcast at 142 to 155 kg N ha^{-1} and incorporated before planting. Starter fertilizer consisting of 27, 12, and 22 kg ha^{-1} of N, P, and K, respectively, was banded 5 cm below and 5 cm to the side of the corn seeds at planting. Corn was planted at rate of 72,900, 74,000, and 72,000 seeds ha^{-1} on May 7, 2007, May 5, 2008, and May 7, 2009, respectively.

An augmented factorial arranged in a randomized complete block with three replications was used in all experiments. Factors consisted of three residual herbicide programs, two POST nonresidual herbicides, three POST application timings, a weed-free control, and nontreated (full-season weedy) control. Residual herbicide programs included a residual herbicide PRE application fb a nonresidual POST application (residual fb POST), a residual herbicide tank-mixed with a nonresidual POST application (residual + POST), and a nonresidual POST (POST) application. POST application timings consisted of early POST (EP), mid-POST (MP), and late POST (LP) applications. The two nonresidual POST herbicides evaluated were glyphosate and glufosinate. Average common lambsquarters height, giant foxtail height, and corn growth stage at each application timing for each year of the study are given in Table 1. With the exception of the LP timing in 2007, all herbicide applications in the study received at least 5 mm of rainfall with 7 d of treatment.

The residual herbicide was a premix of acetochlor applied at 0.87 kg ai ha^{-1} and atrazine applied at 0.70 kg ai ha^{-1} (Harness Xtra 5.6L®, Monsanto Company, St. Louis, MO 63167). Glyphosate (Touchdown Total®, Syngenta Crop Protection, Inc., Box 183000, Greensboro, NC 27709) or glufosinate (Liberty®, Bayer CropScience LP, Box 12014, Research Triangle Park, NC 27709) was applied POST at 0.84 kg ae ha^{-1} and 0.47 kg ai ha^{-1}, respectively. Ammonium

https://doi.org/10.1614/WT-D-12-00012.1 Published online by Cambridge University Press

Table 1. Average common lambsquarters height, giant foxtail height, and corn growth stage at each application timing and year of the study.[a]

	CHEAL height			SETFA height			Corn growth stage[b]		
Application timing	2007	2008	2009	2007	2008	2009	2007	2008	2009
	%								
EP	2.5	12.5	7.5	8.8	15.0	7.5	V3	V4/V5	V3/V4
MP	3.8	25.0	12.5	15.0	30.0	20.0	V4	V5	V5
LP	10.0	32.5	12.5	25.0	35.0	47.5	V4/V5	V5	V5/V6

[a] Abbreviations: CHEAL, common lambsquarters; SETFA, giant foxtail; EP, early POST; MP, mid-POST; LP, late POST.

[b] Corn growth stage based on number of fully emerged leaves with visible collar.

sulfate at 2% (w/v) was added to all treatments containing glyphosate or glufosinate. All herbicides were applied with a tractor-mounted compressed-air sprayer equipped with flat-fan nozzles (TeeJet XR 8003, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60187) and calibrated to deliver 187 L ha^{-1} at a pressure of 207 kPa.

Common lambsquarters and giant foxtail control was visually estimated 28 d after the LP (DALP) application. Weed densities from the nontreated controls are given in Table 2. Weed control was compared with the nontreated control using a scale of 0 (no control) to 100% (all plants dead). Corn grain yield was determined by harvesting the center two rows of each plot with a mechanical plot harvester (Massey-Ferguson 8XP Harvest Master, AGCO, Duluth, GA 30096) and correcting grain yield to 15% moisture content.

All statistical procedures were conducted using SAS 9.1 (SAS Institute 2003). An initial ANOVA revealed a significant treatment-by-year interaction for visual estimates of weed control and grain yield; therefore, each year was analyzed separately. Visual ratings of weed control were arcsine-transformed. Nontransformed means are reported for readability, whereas the statistical interpretation is based on the transformed data. Single degree-of-freedom contrasts were used to compare the effect of nonresidual POST herbicide, residual herbicide programs, and POST application timing on common lambsquarters and giant foxtail control at 28 DALP. A mixed model (Proc Mixed) was used to evaluate grain yield. Replication was considered a random factor in the model. Normality of the residuals was assessed by normal probability plot. Homogeneity of residual variances was examined and similar treatment variances were grouped when appropriate as indicated by Levene's test (Schultz 1985). Least significant difference ($\alpha = 0.05$) was used to detect differences among treatment means.

Table 2. Mean common lambsquarters, giant foxtail, common ragweed, redroot pigweed, and velvetleaf densities in untreated plots.[a]

	Weed densities					
Year	CHEAL	SETFA	AMBEL	AMARE	ABUTH	Total
	Weeds m^{-2}					
2007	720	130	0	10	10	870
2008	280	150	110	10	10	560
2009	410	500	0	40	10	960

[a] Abbreviations: CHEAL, common lambsquarters; SETFA, giant foxtail; AMBEL, common ragweed; AMARE, redroot pigweed; ABUTH, velvetleaf.

Results and Discussion

Weed Control. Common lambsquarters, giant foxtail, redroot pigweed, and velvetleaf were present for each year of the study (Table 2). Common ragweed (*Ambrosia artemisiifolia* L.) was present only in 2008. Because of low redroot pigweed and velvetleaf densities and the presence of common ragweed in 1 of 3 yr of the study, control of these weed species is not reported.

POST Herbicide Comparison. Common lambsquarters control was similar for glyphosate and glufosinate in 2007 and 2009 (Table 3). In 2008, common lambsquarters control was 98% when glyphosate was applied and 88% when glufosinate was applied. Common lambsquarters control can be close to 100% with glufosinate, but glyphosate tends to control common lambsquarters more consistently than glufosinate (Culpepper et al. 2000; Wilson et al. 2002). Control of common lambsquarters ranged from 45 to 92% with a single application of glufosinate, whereas control ranged from 93 to 96% with a single glyphosate application (Wiesbrook et al. 2001). Inconsistent common lambsquarters control using glufosinate compared with glyphosate may be attributed to common lambsquarters tolerance of glufosinate (Steckel et al. 1997a). Glufosinate exhibits minimal translocation in common lambsquarters (Steckel et al. 1997b), making control more difficult compared with glyphosate (Culpepper et al. 2000).

Giant foxtail control was similar for glyphosate and glufosinate applications in 2007 and 2009 (Table 3). In

Table 3. Single degree-of-freedom contrasts comparing the effect of nonresidual POST herbicide, residual herbicide programs, and application timing on CHEAL and SETFA control for each year of the study.[a]

	CHEAL control[b]			SETFA control		
Contrast	2007	2008	2009	2007	2008	2009
	%					
Glyphosate	94 a[c]	98 a	87 a	95 a	98 a	86 a
Glufosinate	93 a	88 b	85 a	94 a	96 b	84 a
Residual fb POST	98 b	97 b	78 b	96 b	98 a	77 b
Residual + POST	99 a	99 a	99 a	98 a	98 a	97 a
EP	90 a	95 a	84 a	93 b	98 a	80 b
LP	94 a	92 a	79 b	97 a	97 a	91 a

[a] Abbreviations: CHEAL, common lambsquarters; SETFA, giant foxtail; fb, followed by; EP, early POST; LP, late POST.

[b] Visual determination of CHEAL and SETFA control in the treated plot compared with the nontreated (full-season weedy) plot.

[c] Same letters indicate no significant differences in grain yield for the contrast within an individual year at $\alpha = 0.05$.

https://doi.org/10.1614/WT-D-12-00012.1 Published online by Cambridge University Press

Table 4. Main effect of nonresidual POST herbicide, residual herbicide program, and POST application timing on corn grain yield for each year of the study.[a]

Factor	Corn grain yield		
	2007	2008	2009
	Mg ha^{-1}		
Nonresidual POST			
Glyphosate	12.60 a[b]	12.72 a	13.61 a
Glufosinate	12.19 b	12.55 a	13.97 a
Residual program			
Residual fb POST	12.29 a	13.57 a	14.32 a
Residual + POST	12.35 a	12.27 b	13.80 a
Nonresidual POST	12.53 a	12.08 b	13.78 a
POST timing			
EP	12.33 a	12.91 aa	13.95 a
MP	12.38 a	12.68 ab	13.98 a
LP	12.46 a	12.33 bb	13.97 a

[a] Abbreviations: fb, followed by; EP, early POST; MP, mid-POST; LP, late POST.

[b] Same letters indicate no significant differences in grain yield for study factor within an individual year at $\alpha = 0.05$.

2008, giant foxtail control was statistically greater when glyphosate was used compared with glufosinate, but control was > 95% for both herbicides. Glyphosate and glufosinate have been found to be effective at controlling giant foxtail (Corbett et al. 2004; Steckel et al. 1997a; Tharp et al. 1999).

Residual Herbicide Programs. In 2007 and 2008, control of common lambsquarters and giant foxtail was > 95% for the residual fb POST and residual + POST programs (Table 3). In 2009, common lambsquarters and giant foxtail control was at least 20% greater for the residual + POST program compared with the residual fb POST program. When glyphosate was used as the POST herbicide, previous studies found little difference in common lambsquarters and giant foxtail control between a residual fb POST program and a residual + POST program (Johnson et al. 2000; Tharp and Kells 2002). However, when glufosinate was used as the POST herbicide, common lambsquarters and giant foxtail control was greater in four of eight instances in a residual fb POST program compared with a residual + POST program (Tharp and Kells 2002).

POST Application Timing. In 2007 and 2008, there were no significant differences in common lambsquarters control between EP and LP applications (Table 3). In 2009, common lambsquarters control was 5% greater for the EP application timing compared with the LP application timing. Conversely, giant foxtail control was 6 and 13% greater when herbicide was applied LP compared with EP in 2007 and 2009, respectively. No differences in giant foxtail control were observed between EP and LP applications in 2008.

Common lambsquarters and giant foxtail control is often greater when weeds are controlled at 5-cm height compared with 10-cm height (Gower et al. 2002). However, at the 10- to 15-cm height, common lambsquarters and giant foxtail control occasionally improves (Gower et al. 2002). Common lambsquarters control using glyphosate has also been found to be greater with an EP herbicide application compared with a LP herbicide application (Krausz et al. 1996). Glufosinate applied at 0.42 kg ai ha^{-1} may control 10-cm common lambsquarters better than 5-cm common lambsquarters (Steckel et al. 1997a).

Corn Grain Yield. Main effects are presented for corn grain yield because of no significant interactions among the study factors at $\alpha = 0.05$ (data not shown).

POST Herbicide Comparison. Corn grain yield was affected by the type of POST herbicide used (glyphosate or glufosinate) in 2007 but not in 2008 and 2009 (Table 4). In 2007, grain yield was 12.60 Mg ha^{-1} when glyphosate was used as the POST herbicide and 12.19 Mg ha^{-1} when glufosinate was used. Glufosinate can perform similarly to glyphosate; however, glufosinate is less likely to succeed in a single POST application program (Bradley et al. 2000). In 2007, common lambsquarters control was 81, 87, and 96% when glyphosate was applied without a residual herbicide at EP, MP, and LP, respectively (data not shown). When glufosinate was applied without a residual herbicide common lambsquarters control was 74, 84, and 91% at EP, MP, and LP, respectively (data not shown). In 2007, there were 720 common lambsquarters m^{-2}, whereas there were only 280 and 410 common lambsquarters m^{-2} in 2008 and 2009, respectively (Table 2). Grain yield may have been less when glufosinate was applied compared with glyphosate due to high density of common lambsquarters and reduced control with glufosinate compared with glyphosate when applied without a residual herbicide.

Residual Herbicide Programs. Residual herbicide programs significantly influenced corn grain yield in 2008; however, there were no significant differences in 2007 and 2009 (Table 4). In 2008, mean corn grain yield was 13.57 Mg ha^{-1} in the residual fb POST program, which was significantly greater than the residual + POST and nonresidual POST programs, with yields of 12.24 and 12.08 Mg ha^{-1}, respectively. Grain yield followed a similar pattern in 2009, but yield differences were not significant at $\alpha = 0.05$.

In 2008, the first POST application occurred 37 d after the residual fb POST application, whereas the first POST treatment was applied 23 and 29 d after the residual fb POST application in 2007 and 2009, respectively. In 2008, the delayed POST application increased the duration of weed interference and as a result may have increased competition between weeds and corn, reducing yields compared with the residual fb POST program.

POST Application Timing. Corn grain yield was significantly different because of POST application timing in 2008, but not in 2007 and 2009 (Table 4). Results from a 2-yr study conducted in several locations throughout the north-central United States suggest that weeds should be controlled in corn before 10-cm weed height, which corresponds to the EP application timing in this study, to avoid grain yield loss (Gower et al. 2003). However, the onset of the critical time of weed removal may be variable, ranging from three- to nine-corn leaf stages depending on weed density and environmental factors (Hall et al. 1992). In Michigan, when soil moisture was not limiting, grain yield losses did not occur until weeds were 30-cm tall (Dalley et al. 2006). In 2008, grain yield was

https://doi.org/10.1614/WT-D-12-00012.1 Published online by Cambridge University Press

12.91, 12.68, and 12.33 Mg ha^{-1} when the average weed canopy height at the time of herbicide application was approximately 7, 14, and 21 cm, respectively.

Management Implications. Common lambsquarters and giant foxtail control was greater in 1 of 3 yr when glyphosate was used compared with glufosinate (Table 3). In all years, common lambsquarters and giant foxtail control was greater when a residual herbicide was tank-mixed with the POST herbicide (residual + POST) compared with the residual herbicide applied as a PRE fb a POST herbicide application (residual fb POST). One year out of three, common lambsquarters control improved with an EP application compared with a LP application. Giant foxtail control was greater 2 yr of 3 for a LP application compared with an EP application. The effect of residual herbicide program, POST herbicide, and POST application timing on corn grain yield varied by year. In 2007, the use of glyphosate resulted in higher grain yield compared with glufosinate. In 2008, corn grain yield was the greatest in the PRE fb POST program and with POST applications at EP and MP. To minimize the likelihood of grain yield reductions, a PRE fb POST program applied from EP to MP is recommended.

Literature Cited

Bradley, P. R., W. G. Johnson, S. E. Hart, M. L. Buesinger, and R. E. Massey. 2000. Economics of weed management in glufosinate-resistant corn (*Zea mays* L.). Weed Technol. 14:495–501.

Carey, J. B. and J. J. Kells. 1995. Timing of total postemergence herbicide applications to maximize weed control and corn (*Zea mays*) yield. Weed Technol. 9:356–361.

Corbett, J. L., S. D. Askew, W. E. Thomas, and J. W. Wilcut. 2004. Weed efficacy evaluations for bromoxynil, glufosinate, glyphosate, pyrithiobac, and sulfosate. Weed Technol. 18:443–453.

Culpepper, A. S. and A. C. York. 1999. Weed management in glufosinate-resistant corn (*Zea mays*). Weed Technol. 13:324–333.

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.

Dalley, C. D., M. L. Bernards, and J. J. Kells. 2006. Effect of weed removal and row spacing on soil moisture in corn (*Zea mays*). Weed Technol. 20:399–409.

Dalley, C. D., J. J. Kells, and K. A. Renner. 2004. Effect of glyphosate application timing and row spacing on corn (*Zea mays*) and soybean (*Glycine max*). Weed Technol. 18:165–176.

DiTomaso, J. M. 1995. Approaches for improving corn competitiveness through the manipulation of fertilization strategies. Weed Sci. 43:491–497.

Gower, S. A., M. M. Loux, J. Cardina, and S. K. Harrison. 2002. Effect of planting date, residual herbicide, and postemergence application timing on weed control and grain yield in glyphosate-tolerant corn (*Zea mays*). Weed Technol. 16:488–494.

Gower, S. A., M. M. Loux, J. Cardina, S. K. Harrison, P. L. Sprankle, N. J. Probst, T. T. Bauman, W. Bugg, W. S. Curran, R. S. Currie, R. G. Harvey, W. G. Johnson, J. J. Kells, M. D. K. Owen, D. L. Regehr, C. H. Slack, M. Spaur, C. L. Sprague, M. VanGessel, and B. G. Young. 2003. Effect of postemergence glyphosate application timing on weed control and grain yield in glyphosate-resistant corn: results of a 2-yr multistate study. Weed Technol. 17:821–828.

Hall, M. R., C. J. Swanton, and G. W. Anderson. 1992. The critical period of weed control in grain corn (*Zea mays*). Weed Sci. 40:441–447.

Hamill, A. S., S. Z. Knezevic, K. Chandler, P. H. Sikkema, F. J. Tardif, A. Shrestha, and C. J. Swanton. 2000. Weed control in glufosinate-resistant corn (*Zea mays*). Weed Technol. 14:578–585.

Johnson, W. G., P. R. Bradley, S. E. Hart, M. L. Buesinger, and R. E. Massey. 2000. Efficacy and economics of weed management in glyphosate-resistant corn (*Zea mays*). Weed Technol. 14:57–65.

Knake, E. L. and F. W. Slife. 1969. Effect of time of giant foxtail removal from corn and soybeans. Weed Sci. 17:281–283.

Knezevic, S. Z., S. F. Weise, and C. J. Swanton. 1994. Interference of redroot pigweed (*Amaranthus retroflexus*) in corn (*Zea mays*). Weed Sci. 42:568–573.

Krausz, R. F., G. Kapusta, and J. L. Matthews. 1996. Control of annual weeds with glyphosate. Weed Technol. 10:957–962.

Lindquist, J. L., S. P. Evans, C. A. Shapiro, and S. Z. Knezevic. 2010. Effect of nitrogen addition and weed interference on soil nitrogen and corn nitrogen nutrition. Weed Technol. 24:50–58.

Moechnig, M. J., C. M. Boerboom, D. E. Stoltenberg, and L. K. Binning. 2003. Growth interactions in communities of common lambsquarters (*Chenopodium album*), giant foxtail (*Setaria faberi*), and corn. Weed Sci. 51:363–370.

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.

Page, E. R., M. Tollenaar, E. A. Lee, L. Lukens, and C. J. Swanton. 2010. Shade avoidance: an integral component of crop-weed competition. Weed Res. 50:218–288.

Ritter, R. L. and H. Menbere. 2001. Weed management systems utilizing glufosinate-resistant corn (*Zea mays*) and soybean (*Glycine max*). Weed Technol. 15:89–94.

SAS Institute. 2003. SAS/STAT User's Guide. Version 9.1. Cary, NC: SAS Institute.

Schultz, B. B. 1985. Levene's test for relative variation. Syst. Zool. 34:449–456.

Shrestha, A., I. Rajcan, K. Chandler, and C. J. Swanton. 2001. An integrated weed management strategy for glufosinate-resistant corn (*Zea mays*). Weed Technol. 15:517–522.

Steckel, G. J., S. E. Hart, and L. M. Wax. 1997b. Absorption and translocation of glufosinate on four weed species. Weed Sci. 45:378–381.

Steckel, G. J., L. M. Wax, F. W. Simmons, and W. H. Phillips II. 1997a. Glufosinate efficacy on annual weeds is influenced by rate and growth stage. Weed Technol. 11:484–488.

Tapia, L. S., T. T. Bauman, R. G. Harvey, J. J. Kells, G. Kapusta, M. M. Loux, W. E. Lueschen, M. D. K. Owen, L. H. Hageman, and S. D. Strachan. 1997. Postemergence herbicide application timing effects on annual grass control and corn (*Zea mays*) grain yield. Weed Sci. 45:138–143.

Tharp, B. E. and J. J. Kells. 2002. Residual herbicides used in combination with glyphosate and glufosinate in corn (*Zea mays*). Weed Technol. 16:274–281.

Tharp, B. E., O. Schabenberger, and J. J. Kells. 1999. Response of annual weed species to glufosinate and glyphosate. Weed Technol. 13:542–547.

Vengris, J., W. G. Colby, and M. Drake. 1955. Plant nutrient competition between weeds and corn. Agron. J. 47:213–216.

Wiesbrook, M. L., W. G. Johnson, S. E. Hart, P. R. Bradley, and L. M. Wax. 2001. Comparison of weed management systems in narrow-row, glyphosate- and glufosinate-resistant soybean (*Glycine max*). 15:122–128.

Wilson, R. G., C. D. Yonts, and J. A. Smith. 2002. Influence of glyphosate and glufosinate on weed control and sugarbeet (*Beta vulgaris*) yield in herbicide-tolerant sugarbeet. Weed Technol. 16:66–73.

Young, F. L., D. L. Wyse, and R. J. Jones. 1984. Quackgrass (*Agropyron repens*) interference in corn (*Zea mays*). Weed Sci. 32:226–234.

Zimdahl, R. L. 2004. The effect of competition duration. Pages 109–130 *in* Weed–Crop Competition. Ames, IA: Blackwell Publishing.

Zuver, K. A., M. L. Bernards, J. J. Kells, C. L. Sprague, C. R. Medlin, and M. M. Loux. 2006. Evaluation of postemergence weed control strategies in herbicide-resistant isolines of corn (*Zea mays*). Weed Technol. 20:172–178.

Received February 1, 2012, and approved May 22, 2012.

https://doi.org/10.1614/WT-D-12-00012.1 Published online by Cambridge University Press