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Delayed Burndown in No-Tillage Glyphosate-Resistant Corn (*Zea mays*) Planted into Soybean (*Glycine max*) Residue and a Wheat (*Triticum aestivum*) Cover Crop[1]

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Abstract: Field trials were conducted in 1998 and 1999 to determine the effect of delayed burndown timings on weed control and yield of no-tillage glyphosate-resistant corn planted into soybean residue and into a wheat cover crop. Burndown treatments containing glyphosate were applied to both trials when the corn was planted (PRE), when the corn began to emerge (SPIKE), or when the corn had three visible leaves (3-LEAF). As burndown timing was delayed, velvetleaf control increased in corn planted into soybean residue. Glyphosate applied at 0.84 kg ae/ha at the SPIKE or 3-LEAF timing followed by a sequential application of glyphosate at 0.84 kg/ha controlled velvetleaf 91% and corn yields were similar to the weed-free plots. Corn yields among the burndown treatments were directly related to velvetleaf control. In the wheat cover crop trial, wheat treated at the PRE timing was completely controlled and corn yields were similar to the weed-free plots. As burndown timings were delayed, corn emergence and yields were severely reduced. Glyphosate applied at 0.84 kg/ha to 25-cm-wide strips over the corn row at planting and followed with delayed burndown timings increased corn emergence and yield.

Nomenclature: Glyphosate, *N*-(phosphonomethyl)glycine; corn, *Zea mays* L. DK 493RR; velvetleaf, *Abutilon theophrasti* Medicus #[3] ABUTH; winter wheat, *Triticum aestivum* L.

Additional index words: Herbicide-tolerant crops, living mulch, residual herbicides.

Abbreviations: PRE, preemergence; SPIKE, at corn emergence; 3-LEAF, corn with three visible leaves.

INTRODUCTION

Tillage has always been an integral part of corn production. However, advancements in farm machinery, adoption of herbicides, and concerns about soil erosion have reduced the reliance on tillage. Many factors associated with corn production are affected when tillage is reduced. Fortin (1993) reported that corn development was delayed and soil temperatures were reduced within the seed zone in no-tillage systems compared with conventional tillage systems. In Indiana, reduced tillage systems are adequately adapted to well-drained soils, but are not adapted to poorly drained, fine-textured soils (Griffith et al. 1973). No-tillage systems also affect weed control. Some weeds are more difficult to control in reduced tillage systems (Buhler 1992). Larger densities of green foxtail [*Setaria viridis* (L.) Beauv.] and redroot pigweed (*Amaranthus retroflexus* L.) were reported in no-tillage compared with conventional tillage systems, and horseweed [*Conyza canadensis* (L.) Cronq.] appeared only in no-tillage systems (Buhler 1992; Wrucke and Arnold 1985). The mean depth of weed emergence was found to be more shallow in no-tillage systems than in conventional (Buhler and Mester 1991). Mulugeta and Stoltenberg (1997) found that 74% of the total viable weed seeds in no-tillage systems were in the top 10 cm of the soil profile compared with 43% in conventional tillage. Differences in weed control have caused farmers to develop weed management strategies that are unique to no-tillage systems.

Cover cropping systems can be easily integrated into no-tillage corn production. Proper management of the cover crop is needed to obtain the beneficial aspects of a cover cropping system. When managed appropriately, cover crops can reduce water and wind erosion (Frye et al. 1983; Smith et al. 1987), sequester excess nitrates (Jackson et al. 1993; Shipley et al. 1992), provide nitrogen to succeeding crops (Mitchell and Teel 1977; Wagger 1989), provide a favorable environment for predatory insects (Bugg 1991; Clark et al. 1993; Kaakeh and Dutcher 1993), and suppress weeds (Lal et al. 1991; Weston 1996).

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

Cover crops are often desiccated before corn planting to provide nonliving surface residues, but can be managed to provide living surface residues, as in living mulch systems (Eberlein et al. 1992; Echtenkamp and Moomaw 1989). Delaying the timing of cover crop desiccation will increase the biomass of the cover crop and ultimately result in higher surface residues and accumulated nitrogen (Clark et al. 1997a; Smith et al. 1992). Wagger (1989) cautioned that managing a cover crop for additional growth and nitrogen accumulation should not delay corn planting.

Reports on the influence of cover crop desiccation timing on corn growth and yield are mixed. Munawar et al. (1990) and Raimbault et al. (1991) reported yield reductions from cover crops desiccated later in the season, whereas others reported yield reductions from early timings of desiccation (Clark et al. 1995; Clark et al. 1997b). These differences were attributed to differences in soil moisture and potential allelopathic effects. Munawar et al. (1990) stated that early-season cover crop growth depleted soil moisture, but that during years of high spring rainfall the removal of soil moisture might be advantageous. Clark et al. (1997b) concluded that soil moisture conservation by cover crop residues was more important than spring water depletion in determining corn yield. Rainfall patterns are important factors to consider in cover crop management. Weston (1996) reported allelopathic effects of many plant species used as cover crops. Tollenaar et al. (1993) and Raimbault et al. (1991) suggested that reductions in corn development and yield could be caused by allelopathic interactions.

In no-tillage corn production, nonselective herbicides with no soil residual activity, such as glyphosate or paraquat, are often applied before planting to remove existing vegetation that would have been removed by tillage in conventional systems. These applications are commonly referred to as burndown applications. Herbicides with residual herbicidal activity in the soil are often combined with the nonselective herbicides to provide seasonlong weed control (Blackshaw 1989; Wilson et al. 1985). The availability of glyphosate-resistant corn hybrids provides the opportunity to remove vegetation effectively after corn emergence. The objective of this research was to determine if glyphosate applied alone and in tank mixtures with residual herbicides could be delayed to increase weed control and crop yield in no-tillage corn planted into soybean residue. Delayed glyphosate burndown applications were also examined in no-tillage corn planted into a wheat cover crop to determine the effect of the cover crop on corn yield.

MATERIALS AND METHODS

No-Tillage Corn into Soybean Residue. Field trials were conducted in 1998 and 1999 on the Crop and Soil Sciences Research Farm at Michigan State University in East Lansing, MI. The soil was a Capac sandy loam (fine-loamy, mixed mesic Aeric Ochraqualf) with a pH of 6.2 and 3.1% organic matter in 1998 and a Capac sandy clay loam with a pH of 6.9 and 2.9% organic matter in 1999. A 34–0–0 (N-P-K) fertilizer was broadcast before corn planting and a 6–24–24 fertilizer was banded 5 cm below and 5 cm to the side of the corn seed during the planting operation. Fertilizer rates were determined from the results of a soil analysis with a corn yield goal of 9.42 Mg/ha. DK 493RR hybrid corn was no-till planted into soybean residue on May 14, 1998 at a population of 70,400 seeds/ha and on May 10, 1999 at a population of 71,600 seeds/ha. Plots consisted of four rows spaced 76 cm apart with lengths of 10.7 m. The trials were not irrigated or cultivated.

Four burndown herbicide treatments were applied at three timings. The burndown herbicide treatments were glyphosate at 0.84 kg ae/ha applied alone, glyphosate at 0.84 kg/ha tank-mixed with atrazine [6-chloro-*N*-ethyl-*N*'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] at 1.12 kg ai/ha, glyphosate at 0.84 kg/ha tank-mixed with a premixture[4] of acetochlor [2-chloro-*N*-(ethoxymethyl)-*N*-(2-ethyl-6-methylphenyl)acetamide] at 0.88 kg ai/ha with MON 4660 (safener) (N-dichloroacetyl-1-oxa-4-aza-spiro-4,5-decane) plus atrazine at 0.7 kg/ha, and an initial application of 0.84 kg/ha glyphosate applied alone followed by a sequential application of glyphosate at 0.84 kg/ha. Each of the burndown herbicide treatments were applied before corn emergence (PRE), when corn in the weed-free plots was beginning to emerge (SPIKE), and when corn in the weed-free plots had three visible leaves (3-LEAF). The average height of velvetleaf was 1.3 cm at the PRE timing in both years, 3.8 cm in 1998 and 2.5 cm in 1999 at the SPIKE timing, and 3.8 cm at the 3-LEAF timing in both years. Velvetleaf in plots receiving sequential treatments averaged 5 cm in height. Sequential treatments were applied 25 and 24 d after the PRE application, 28 and 27 d after the SPIKE application, and 27 and 19 d after the 3-LEAF application in 1998 and 1999, respectively. Ammonium sulfate at 2% (w/w) was included with all glyphosate applications. Weed-free plots were treated with a PRE application of a premixture[5] of *S*-metolachlor [2-chloro-*N*-(2-ethyl-6-

[4] Harness Xtra 5.6L, Monsanto, St. Louis, MO 63167.

[5] Bicep Lite II Magnum, Novartis, Crop Protection Division, P.O. Box 18300, Greensboro, NC 27419.

methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide, *S*-enantiomer] at 2.24 kg/ha with CGA-154281 (safener) [4-(dichloroacetyl)-3,4-dihydro-3-methyl-2*H*-1,4-benzoxazine] plus atrazine at 1.12 kg/ha followed by hand-weeding as needed. Herbicides were applied with a tractor-mounted compressed-air sprayer equipped with flat-fan nozzles[6] and calibrated to deliver 187 L/ha at a pressure of 207 kPa.

Velvetleaf was the dominant weed species present in both years. Visual estimates of velvetleaf control were compared against untreated velvetleaf that were located in bordering areas. Visual estimates were based on a scale of 0 (no control) to 100 (all plants dead) 28 d after the final postemergence sequential application. Aboveground shoots of velvetleaf within a 930-cm^2 quadrant in 1998 and a 1900-cm^2 quadrant in 1999 were harvested from each plot 80 d after corn planting. The harvested shoots were oven-dried for at least 5 d and dry weights were determined. Corn grain yield was determined by harvesting the center two rows of each plot with a mechanical plot harvester. Corn grain yield was corrected to 15.5% moisture.

The trial was a two-factor factorial designed as a randomized complete block with three replications. The factors were burndown herbicide treatments and burndown application timings. Weed-free plots were included but were not part of the factorial treatment arrangement. Visual estimates of weed control were subjected to ANOVA procedures for a two-factor factorial. Data from the weed-free plots were not included in the statistical analysis of weed control since the values contained no variance. Corn yields from plots, excluding the weed-free plots, were subjected to ANOVA procedures for a two-factor factorial. Corn yields from plots including the weed-free plots were analyzed using ANOVA procedures as a single-factor trial. Means of the weed control data and corn yield were separated using Fisher's protected LSD at the $P = 0.05$ level of probability. Visual estimates of weed control and corn yields were subjected to *F*-Max tests to test for homogeneity of variance among years (Kuehl 1994). Data found to be homogenous were pooled over years.

No-Tillage Corn into a Wheat Cover Crop. Experimental techniques and environments were identical to the previously described no-tillage corn-into-soybean residue trials, except that DK 493RR was no-till planted into an actively growing winter wheat cover crop on May 13, 1998 at a population of 70,400 seeds/ha and on May 10, 1999 at a population of 71,600 seeds/ha. The wheat cover crop was drilled the previous fall of each year. Wheat and corn growth stages are listed in Table 1. Permethrin [(3-phenoxyphenyl)methyl(±)cis-trans 3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate] at 0.11 kg ai/ha was broadcast over the entire study on June 27, 1998 and June 15, 1999 to minimize corn damage from armyworms (*Pseudaletia unipuncta*).

The four burndown herbicide treatments and three application timings used in the previously described no-tillage corn-into-soybean residue trials were also used in these trials. However, an additional treatment of glyphosate at 0.84 kg/ha applied in 25-cm-wide bands directly over the corn row were included in these trials. The banded glyphosate was applied immediately after corn planting with a tractor-mounted compressed-air sprayer equipped with even flat-fan nozzles[7] and calibrated to deliver 187 L/ha at a pressure of 207 kPa. Plots previously treated with the PRE banded glyphosate applications were treated with the four burndown herbicide treatments broadcast at the SPIKE timing and at the 3-LEAF timing.

Weed populations were negligible both years. Therefore, no visual estimates of weed control were recorded. Visual estimates of wheat control were compared against untreated wheat plants in bordering areas using a scale of 0 (no control) to 100 (all plants dead) 28 d after the 3-LEAF burndown timing. The emergence and height of corn plants were recorded 45 d after planting from the center two rows of each plot in both years. Corn grain yield was determined by harvesting the center two rows of each plot with a mechanical plot harvester. Corn grain yield was corrected to 15.5% moisture.

The design and analysis of these trials were identical to the no-tillage corn-into-soybean residue trials except that an additional factorial arrangement of burndown herbicide treatments at the SPIKE and 3-LEAF burn-

Table 1. Growth stages of corn and wheat cover crop at each burndown herbicide application, 1998 and 1999.

Burndown timing[a]	Corn growth stage	Wheat: Growth stage	Wheat: Height 1998	Wheat: Height 1999
			cm	
PRE	At planting	Jointing	38	33
SPIKE	Emergence	Boot	53	36
3-LEAF	One visible collar	Flowering	61	46

[a] PRE, preemergence; SPIKE, at corn emergence; and 3-LEAF, corn with three visible leaves.

[6] TeeJet XR 8003VS. Spraying Systems Co., North Avenue, Wheaton, IL 60188.

[7] TeeJet 80015EVS. Spraying Systems Co., North Avenue, Wheaton, IL 60188.

Table 2. Effect of delayed glyphosate burndown applications on velvetleaf control, velvetleaf biomass, and corn yield in no-tillage corn planted into soybean residue, 1998 and 1999.[a]

Variable		Velvetleaf control[b]	Velvetleaf biomass[c] 1998	Velvetleaf biomass[c] 1999
			g/m²	g/m²
Burndown herbicide treatment (main effect)[d]				
Glyphosate alone		14 c	816 a	112 a
Glyphosate plus atrazine		39 b	167 c	42 bc
Glyphosate plus acetoclor/atrazine		34 b	395 b	71 ab
Glyphosate sequential		76 a	63 c	7 c
Burndown timing (main effect)[e]				
PRE		21 c	817 a	94 a
SPIKE		45 b	127 b	50 ab
3-LEAF		56 a	144 b	30 b
Burndown herbicide treatment by burndown timing[f]				
Glyphosate alone	PRE	0 g	1850 a	162 a
	SPIKE	15 fg	210 cd	116 abc
	3-LEAF	28 ef	390 c	58 bcd
Glyphosate plus atrazine	PRE	27 ef	300 cd	47 ce
	SPIKE	40 cde	169 cd	33 cd
	3-LEAF	50 bc	32 d	47 cd
Glyphosate plus acetochlor/atrazine	PRE	12 fg	977 b	153 ab
	SPIKE	33 de	115 cd	50 cd
	3-LEAF	58 b	94 d	10 d
Glyphosate sequential	PRE	48 bcd	143 cd	14 d
	SPIKE	91 a	13 d	1 d
	3-LEAF	90 a	17 d	6 d
Weed free		100	0	0

[a] All treatments included ammonium sulfate at 2% (w/w).

[b] Visual ratings recorded 28 d after the final postemergence sequential application.

[c] Velvetleaf was harvested 80 d after corn planting.

[d] Means are pooled over burndown timings and represent a main effect. Means that are followed by the same letter are not significantly different according to Fisher's Protected LSD ($P = 0.05$).

[e] Means are pooled over burndown herbicide treatment and represented a main effect. Means that are followed by the same letter are not significantly different according to Fisher's Protected LSD ($P = 0.05$). Pre, preemergence, SPIKE, at corn emergence; and 3-LEAF, corn with three visible leaves.

[f] Data analyzed as single factor experiment using ANOVA procedure. Means that are followed by the same letter are not significantly different according to Fisher's Protected LSD ($P = 0.05$).

down timings were applied where glyphosate had been applied PRE in bands. Statistical analysis of corn yields was previously described. Since most of the wheat control data was between 80 and 100%, the data were arcsine transformed before statistical analysis and subjected to ANOVA procedures. Means of the transformed wheat control data, corn emergence, height, and yield data were separated using Fisher's protected LSD at the $P = 0.05$ level of probability. Nontransformed means are presented for clarity. All data were subjected to *F*-Max tests to test for homogeneity of variance among years (Kuehl 1994). Data found to be homogenous were pooled over years.

RESULTS AND DISCUSSION

No-Tillage Corn into Soybean Residue. Glyphosate has negligible herbicidal activity in most soils. Therefore, weeds that emerge after a glyphosate application will not be controlled unless a residual herbicide is also applied. Glyphosate applied once did not provide seasonlong control of velvetleaf (Table 2). Visual control ratings reflect more on the number of weeds that emerged after application rather than the herbicide effectiveness on weeds that were emerged at application. Sequential applications of glyphosate provided the greatest control of velvetleaf, and dramatically increased velvetleaf control at each timing compared with a single application of glyphosate. Gonzini et al. (1999) also reported increased weed control in soybeans from sequential applications of glyphosate compared with glyphosate applied once. When the initial applications of glyphosate were delayed, the sequential applications were subsequently delayed, resulting in increased velvetleaf control.

Velvetleaf control was increased and velvetleaf biomass was reduced as burndown application timings were delayed (Table 2). The 3-LEAF timing resulted in greater control of velvetleaf by glyphosate than the PRE timing

Table 3. Effect of delayed glyphosate burndown applications on wheat cover crop control and corn emergence, height, and yield in no-tillage corn planted into a wheat cover crop, 198 and 1999.[a]

Variable		Wheat cover crop control[b]	Corn	
			Population[c]	Height[c]
		%	plants/m row	cm
Burndown herbicide treatment (main effect)[d]				
Glyphosate alone		93 a	3.7 a	48 a
Glyphosate plus atrazine		81 b	3.7 a	45 a
Glyphosate plus acetoclor/atrazine		81 b	3.6 a	45 a
Glyphosate sequential		94 a	3.7 a	45 a
Burndown timing (main effect)[e]				
PRE		100 a	4.4 a	60 a
SPIKE		90 b	3.6 b	43 b
3-LEAF		72 c	3.1 c	35 c
Burndown herbicide treatment by burndown timing[f]				
Glyphosate alone	PRE	100 a	4.4 a	65 a
	SPIKE	96 b	3.7 bc	43 c
	3-LEAF	83 c	3.2 cde	37 d
Glyphosate plus atrazine	PRE	100 a	4.3 a	57 b
	SPIKE	87 c	3.5 cd	43 c
	3-LEAF	58 d	3.3 cde	37 d
Glyphosate plus acetochlor/atrazine	PRE	100 a	4.5 a	61 ab
	SPIKE	83 c	3.4 cd	43 c
	3-LEAF	61 d	2.8 e	33 d
Glyphosate sequential	PRE	100 a	4.4 a	59 b
	SPIKE	96 b	3.6 bcd	43 c
	3-LEAF	85 c	3.1 de	34 d
Weed free		100 a	4.1 ab	58 b

[a] All treatments included ammonium sulfate at 2% (w/w).

[b] Visual ratings recorded 28 d after the burndown timing when corn had three developed leaves.

[c] Measurements recorded 45 d after corn planting.

[d] Means are pooled over burndown timings and represent a main effect. Means that are followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

[e] Means are pooled over burndown herbicide treatment and represent a main effect. Means that are followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05). PRE, preemergence; SPIKE, at corn emergence; and 3-LEAF, corn with three visible leaves.

[f] Data analyzed as a single factor experiment using ANOVA procedure. Means that are followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

because less velvetleaf emerged after the 3-LEAF application compared with the PRE timing. Glyphosate plus atrazine applied at the 3-LEAF timing controlled velvetleaf greater than when applied at the PRE timing. In addition, velvetleaf control increased and velvetleaf biomass decreased as applications of glyphosate plus acetochlor/atrazine were delayed. A tank-mixed residual herbicide or a sequential application of glyphosate generally increased velvetleaf control compared with glyphosate applied once. Control of broadleaf weed species is often increased when herbicides are tank-mixed with atrazine (Culpepper and York 1999; Wilson et al. 1985).

Carey and Kells (1995) showed that weeds emerging with corn could potentially reduce yield if the weeds are not removed before they reach 10 cm in height. In our trials, velvetleaf height never exceeded 10 cm when burndown applications were applied, and yields were increased as burndown timings were delayed (Table 2). Therefore, yield reductions in our trials were likely caused by competition from weeds that emerged after application. Sequential applications of glyphosate and delayed applications of burndown treatments that included residual herbicides resulted in corn yields that were similar to the weed-free plots (Table 2). Corn yields in plots treated with glyphosate applied once at all burndown timings were lower than yields of weed-free plots. Sequential glyphosate applications and residual herbicide treatments controlled velvetleaf sufficiently to prevent corn yield loss from velvetleaf competition.

No-Tillage Corn into a Wheat Cover Crop. All of the burndown herbicide treatments applied at the PRE timing completely controlled the wheat cover crop (Table 3). Control was reduced as the application timings were delayed. The reduced control ratings reflect the size and growth stage of the wheat at the SPIKE and 3-LEAF burndown timing (Table 1). Wheat was beginning to flower and was near physiological maturity at these de-

Table 4. 1998 and 1999 precipitation amounts compared to the 30-yr average (1951–1980).

	1998	1999	30-yr average
	cm		
May	6.9	4.8	6.9
June	6.4	5.1	9.0
July	7.2	12.1	7.7
August	10.0	5.3	7.3

Table 5. Effect of banded applications of glyphosate on corn emergence, height, and yield at delayed burndown timings, 1998 and 1999.

Variable	Banded glyphosate[a]	Corn Population[b]	Corn height[b]	Corn Yield
		plants/m row	cm	Mg/ha
Banded glyphosate (main effect)[c]				
	Yes	4.0 a	50 a	8.27 a
	No	3.3 b	39 b	6.69 b
Burndown timing by banded glyphosate (interaction)[d]				
SPIKE	Yes	4.0 a	51 a	8.70 a
	No	3.6 b	43 c	7.44 b
3-LEAF	Yes	4.0 a	48 b	7.83 b
	No	3.1 c	35 d	5.94 c

[a] Glyphosate plus ammonium sulfate applied in 25-cm bands directly over corn row at planting.

[b] Measurements recorded 35 d after corn planting.

[c] Means are pooled over burndown timings and burndown herbicide treatments and represent a main effect. Means that are followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

[d] Means are pooled over burndown herbicide treatments and represent the interaction of burndown timing and banded glyphosate. Means that are followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05). Abbreviations: SPIKE, burndown treatments broadcast at corn emergence; 3-LEAF, burndown treatments broadcast when corn had three visible leaves.

layed timings. Tank mixtures of glyphosate with atrazine reduced cover crop control, compared with glyphosate applied alone, when applications were delayed. Antagonism of the herbicidal activity of glyphosate plus atrazine tank mixtures has been reported on other plant species (Selleck and Baird 1981). Sequential applications of glyphosate did not increase control of the wheat cover crop compared with a single application of glyphosate.

Residual herbicides or sequential applications of glyphosate did not affect the emergence and height of corn compared with glyphosate applied alone (Table 3). The emergence and height of corn were significantly reduced as burndown timings were delayed. Within each herbicide treatment, corn emergence and height at the PRE timing were similar to corn in the weed-free plots. However, corn emergence and height were reduced in treatments where herbicide application was delayed beyond the PRE timing. Teasdale and Shirley (1998) showed that delaying the kill date of a hairy vetch (*Vicia villosa* Roth) cover crop reduced corn emergence in three of four trials. As herbicide applications were delayed beyond corn planting, the wheat cover crop was undergoing rapid stem elongation, developing an extensive root system, and flowering, which provided it with a competitive advantage over the emerging corn crop (Table 1). These competitive differences contributed to reduced corn populations and heights. These effects were probably exacerbated by below-average precipitation in June of both years (Table 4).

Corn yields were similar among burndown herbicide treatments within each burndown timing (Table 3). Within each burndown herbicide treatment, corn yields in plots where the wheat cover crop was controlled at planting were similar to the yields in weed-free plots. Delayed applications resulted in reduced yields compared with the PRE timing and compared with the yields of the weed-free plots. Differences in the competitive ability of the wheat cover crop compared with corn likely contributed to differences in corn yields among the treatments. Teasdale and Shirley (1998) similarly reported that delaying control of a hairy vetch cover crop reduced the yield of corn planted into the cover crop. They attributed corn yield reductions to soil moisture depletion by the hairy vetch cover crop.

Plots previously treated with banded applications of glyphosate contained a larger number of corn plants that grew taller and yielded more than corn in plots that were not treated with banded applications of glyphosate (Table 5). Eberlein et al. (1992) reported reduced soil moisture availability and reduced yields of corn planted into a partially suppressed alfalfa sod (*Medicogi sativa* L.). Corn yields were not reduced by the presence of a living crimson clover mulch (*Trifolium incarnatum*), as long as the clover was desiccated in strips greater than 60% of the total area (Kumwenda et al. 1993). When burndown treatments were applied at the SPIKE and 3-LEAF timing, the glyphosate-treated strips of wheat provided an environment that was conducive to corn germination, but the plants that emerged in the 3-LEAF timing plots were stunted from competition with wheat that remained in the interrow (Table 5). Corn yields were also reduced when burndown treatments were delayed to 3-LEAF compared with SPIKE timings.

Results of this research suggest that performance of delayed applications of burndown herbicides are influenced by the amount of vegetation that is present before corn planting. Minimal vegetation was present in the trials that were no-till planted into soybean residue. In these trials, velvetleaf control and corn yields increased as burndown timings were delayed compared with when the burndown treatments were applied at planting. Sequential applications of glyphosate provided the greatest weed control and corn yields. Results of delayed applications of burndown herbicides differed when an actively growing cover crop was present at the time of corn planting. The population and yield of corn planted into a wheat cover crop were reduced as applications of burndown herbicides were delayed. The wheat competed with the corn for moisture and other growth requirements. The data from these trials suggest that burndown of a wheat cover crop should occur no later than the time nonirrigated corn is planted to avoid yield loss from competition.

LITERATURE CITED

Blackshaw, R. E. 1989. HOE-39866 use in chemical fallow systems. Weed Technol. 3:420–428.

Bugg, R. L. 1991. Cover crops and control of arthropod pests of agriculture. *In* W. L. Hargrove, ed. Cover Crops for Clean Water. Ankeney, IA: Soil and Water Conserv. Soc. pp. 157–163.

Buhler, D. D. 1992. Population dynamics and control of annual weeds in corn (*Zea mays*) as influenced by tillage systems. Weed Sci. 40:241–248.

Buhler, D. D. and T. C. Mester. 1991. Effect of tillage systems on the emergence depth of giant foxtail (*Setaria faberi*) and green foxtail (*Setaria viridis*). Weed Sci. 39:200–203.

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.

Clark, A. J., A. M. Decker, J. L. Meisinger, F. R. Mulford, and M. S. McIntosh. 1995. Hairy vetch kill date effects on soil water and corn productivity. Agron. J. 87:579–585.

Clark, A. J., A. M. Decker, J. J. Meisinger, and M. S. McIntosh. 1997a. Kill date of vetch, rye, and a vetch-rye mixture. I. Cover crop and corn nitrogen. Agron. J. 89:427–434.

Clark, A. J., A. M. Decker, J. J. Meisinger, and M. S. McIntosh. 1997b. Kill date of vetch, rye, and a vetch-rye mixture. II. Soil moisture and corn yield. Agron. J. 89:427–434.

Clark, M. S., J. M. Luna, N. D. Stone, and R. R. Youngman. 1993. Habitat preferences of generalist predators in reduced-tillage corn. J. Entomol. Sci. 28:404–416.

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

Eberlein, C. V., C. C. Sheaffer, and V. F. Oliveira. 1992. Corn growth and yield in an alfalfa living mulch system. J. Prod. Agric. 5:332–339.

Echtenkamp, G. W. and R. S. Moomaw. 1989. No-till corn production in a living mulch system. Weed Technol. 3:261–266.

Fortin, M. C. 1993. Soil temperature, soil water, and no-till corn development following in-row residue removal. Agron. J. 85:571–576.

Frye, W. W., J. H. Herbek, and R. L. Blevins. 1983. Legume cover crops in production of no-tillage corn. *In* W. Lockeretz, ed. Environmentally Sound Agriculture. New York: Praeger Publishers. pp. 179–191.

Gonzini, L. C., S. E. Hart, and L. M. Wax. 1999. Herbicide combinations for weed management in glyphosate-resistant soybean (*Glycine max*). Weed Technol. 13:354–360.

Griffith, D. R., J. V. Mannering, H. M. Galloway, S. D. Parsons, and C. B. Richey. 1973. Effect of eight tillage-planting systems on soil temperature, percent stand, plant growth, and yield of corn on five Indiana soils. Agron. J. 65:321–326.

Jackson, L. E., L. J. Wugland, and L. J. Strivers. 1993. Winter cover crops to minimize nitrate losses in intensive lettuce production. J. Agric. Sci. 121:55–62.

Kaakeh, W. and J. D. Dutcher. 1993. Rates of increase and probing behavior of *Acythosiphonpisum* (Homoptera: Aphidiae) on preferred and nonpreferred host cover crops. Environ. Entomol. 22:1016–1021.

Kuehl, R. O. 1994. Statistical Principles of Research Design and Analysis. Belmont, CA: Wadsworth. 686 p.

Kumwenda, J.D.T., D. E. Radcliffe, W. L. Hargrove, and D. C. Bridges. 1993. Reseeding of crimson clover and corn grain yield in a living mulch system. Soil Sci. Soc. Am. J. 57:517–523.

Lal, R., E. Regnier, D. S. Eckert, W. M. Edwards, and R. Hammond. 1991. Expectations of cover crops for sustainable agriculture. *In* W. L. Hargrove, ed. Cover Crops for Clean Water. Ankeny, IA: Soil and Water Conserv. Soc. pp. 1–11.

Mitchell, W. H. and M. R. Teel. 1977. Winter-annual cover crops for no-tillage corn production. Agron. J. 69: 569–572.

Mulugeta, D. and D. E. Stoltenberg. 1997. Weed and seedbank management with integrated methods as influenced by tillage. Weed Sci. 45:706–715.

Munawar, A., R. L. Blevins, W. W. Frye, and M. R. Saul. 1990. Tillage and cover crop management for soil water conservation. Agron. J. 82:773–777.

Raimbault, B. A., T. J. Vyn, and M. Tollenaar. 1991. Corn response to rye cover crop, tillage methods, and planter options. Agron J. 83: 287–290.

Selleck, G. W. and D. D. Baird. 1981. Antagonism with glyphosate and residual herbicide combinations. Weed Sci. 29:185–190.

Shipley, P. R., J. J. Meisinger, and A. M. Decker. 1992. Conserving residual corn fertilizer nitrogen with winter cover crops. Agron J. 84:869–876.

Smith, M. A., P. R. Carter, and A. A. Imholte. 1992. Conventional vs. no-till corn following alfalfa/grass: timing of vegetation kill. Agron. J. 84:780–786.

Smith, M. S., W. W. Frye, and J. J. Varco. 1987. Legume winter cover crops. Adv. Soil Sci. 7:96–139.

Teasdale, J. R. and D. W. Shirley. 1998. Influence of herbicide application timing on corn production in a hairy vetch cover crop. J. Prod. Agric. 11:121–125.

Tollenaar, M., M. Mihajlovic, and T. J. Vyn. 1993. Corn growth following cover crops: influence of cereal cultivar, cereal removal, and nitrogen rate. Agron J. 85:251–255.

Wagger, M. G. 1989. Time of desiccation effects on plant composition and subsequent nitrogen release from several winter annual cover crops. Agron. J. 81:236–241.

Weston, L. A. 1996. Utilization of allelopathy for weed management in agroecosystems. Agron. J. 88:860–866.

Wilson, H. P., T. E. Hines, R. R. Bellinder, and J. A Grande. 1985. Comparisons of HOE-39866, SC-0224, paraquat, and glyphosate in no-till corn (*Zea mays*). Weed Sci. 33:531–536.

Wrucke, M. A. and W. E. Arnold. 1983. Weed species distribution as influenced by tillage and herbicides. Weed Sci. 33:853–856.