WEED MANAGEMENT AND AGRONOMIC RISKS ASSOCIATED WITH GLYPHOSATE-RESISTANT CORN AND SOYBEAN CROPPING SYSTEMS

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ABSTRACT

Cropping systems are changing rapidly in the upper Midwest. Growers are increasingly adopting herbicide-resistant crop cultivars, particularly transgenic crops with resistance to glyphosate. Grower interest in glyphosate-resistant corn and soybean has rapidly and dramatically changed weed management practices. The potential exists on many acres where glyphosate is the primary, if not only, herbicide used for weed management in both corn-soybean rotation and in continuous-corn cropping systems Although growers are implementing these new technologies, many questions remain about the long-term impact of glyphosate-resistant cropping systems on weed management. Limited research information has been available to growers about the potential for new weed problems, weed resistance to glyphosate, or the integration of glyphosate use with other cultural, mechanical, and chemical practices. Therefore, research was initiated in 1998 and conducted through 2001 at the University of Wisconsin Arlington Agricultural Research Station to determine the long-term weed management and agronomic risks in glyphosate-resistant corn and soybean cropping systems as influenced by primary tillage, crop rotation, and intensity of glyphosate use. Specific objectives were to determine changes over time in the number and type of weed species, weed plant density and biomass, soil seed bank density, and crop yield. Tillage treatments included moldboard plow, chisel plow, and no-tillage systems. Cropping system treatments included continuous corn and corn-soybean rotation. Weed management treatments included glyphosate only, glyphosate use integrated with other chemical and mechanical practices, and conventional herbicide programs. Among weed management treatments, glyphosate applied sequentially or glyphosate plus inter-row cultivation were among the most consistent and effective treatments in continuous corn. Results for these particular treatments since 1998 indicate that weed population densities have decreased over time. In corn-soybean rotation, most treatments that included glyphosate were effective for weed management, particularly in moldboard plow and chisel plow systems. Common lambsquarters, giant foxtail, and velvetleaf were the dominant weed species in most glyphosate-based treatments in each cropping system, but these occurred at low to very low densities. In contrast, giant ragweed and/or shattercane populations increased over time to become the dominant weed species and serious weed management problems in treatments that included broad-spectrum preemergence soil-residual herbicides. Results suggest that the weed management and agronomic risks associated with glyphosate use in glyphosate-resistant corn and soybean were no greater than those associated with conventional preemergence soil-residual herbicide programs.

BACKGROUND

Weed management in corn and soybean cropping systems is changing rapidly in the upper Midwest. Herbicide-resistant crop cultivars, especially those resistant to non-selective, post-emergence herbicides, are a major factor contributing to this change (Duke 1996). Such crop cultivars lend themselves to increased spectrum of efficacy, reduced or eliminated potential for crop injury, reduced soil erosion, and greatly reduced impact on water resources. In addition, if appropriately used, herbicide-resistant crops could be an important tool for the management of weed resistance to herbicides.

Farmers typically consider several factors before selecting a herbicide for weed management: spectrum of herbicide efficacy, potential for crop injury, cost, environmental impact, and fit with soil conservation practices (Padgette et al. 1996). Genetically-modified crop cultivars with the resistance to non-selective herbicides, e.g. glyphosate-resistant soybean, have become attractive weed management alternatives to many growers. Glyphosate is highly effective on a broad spectrum of annual and perennial weed species common to many cropping systems. Positive environmental characteristics of glyphosate include strong sorption to soil, rapid biodegradation, and extremely low toxicity to mammals, birds, and fish (Padgette et al. 1996). However, one of the most critical factors for the rapid and widespread adoption of glyphosate-resistant cultivars appears to be the simplification of weed management decision making and practices.

Although growers are implementing these new technologies, many questions remain concerning the long-term impact of continuous glyphosate-resistant cropping systems on weed management. Limited research information has been available to growers about the potential for new weed problems, weed resistance to glyphosate, and the integration of glyphosate use with other cultural, mechanical, and chemical practices.

New weed problems over time (i.e. weed species shifts) in cropping systems can be due to several factors including tillage, herbicide use, crop rotation, and other agronomic factors (Froud-Williams 1988; Haas and Streibig 1982; Swanton et al. 1993). Crop rotation can disrupt the continuous dominance of specific weed species in a field, decrease the buildup of weed populations, and prevent major shifts in weed species composition (Ball 1992; Blackshaw et al. 1994; Schreiber 1992; Schweizer and Zimdahl 1984). Tillage systems can exert strong selection on weed species (Lowery and Stoltenberg 1998). Consequently, the affinity of many weed species varies among tillage systems (Forcella and Burnside 1994). Tillage impacts the vertical distribution of weed seeds within the soil profile and thus, it impacts weed seed fate, including weed seed germination and weed emergence. Unlike moldboard plowing which buries surface-deposited weed seeds, many conservation-tillage systems result in only partial inversion of the soil and weed seed burial (Mulugeta and Stoltenberg 1997; Pareja et al. 1985).

Herbicide use is another important factor that influences weed species shifts. Changes in weed species composition within a field are relatively common following repeated annual herbicide application (Radosevich et al. 1997). Because of herbicide selectivity, the repeated use of a particular herbicide often causes a shift within a weed community from susceptible to more resistant species (Radosevich et al. 1997). Over-reliance on a single herbicide chemistry has been associated with the development of resistance of many weed species in Wisconsin (Stoltenberg and Wiederholt 1995; Volenberg et al. 2000; Volenberg et al. 2001; Wiederholt and Stoltenberg 1995). Because of the apparent widespread adaptability of weed species to herbicides, more than a single chemical tool for each cropping system is likely needed. Weed species shifts and the development of weed resistance to herbicides strongly suggests the need for integrating chemical and mechanical weed management methods within a cropping system, and for using cultural methods such as crop rotation. The impact of the high level of glyphosate use on weed management and corn and soybean production over time has not been characterized in cropping systems of the upper Midwest.

The primary research objective was to determine the long-term weed management and agronomic risks in glyphosate-resistant corn and soybean cropping systems as influenced by primary tillage, crop rotation, and intensity of glyphosate use. Specific objectives were to determine long-term changes in the number and type of weed species, weed plant density and biomass, soil seed bank density, and crop yield.

METHODS

Site description and experimental design

Field research was initiated in 1998 and conducted through 2001 at the University of Wisconsin Arlington Agricultural Research Station on Plano silt loam soil with pH 5.8 and 4.1% organic matter. The experimental design was a randomized complete block design in a split-split-block arrangement with three replications. The main plots were factorial combinations of primary tillage treatments and crop rotation treatments. The subplot factors were six weed management treatments based on glyphosate use intensity. Each tillage strip within a replication was 260-ft long and 90-ft wide; a 50-ft wide grass strip was maintained between each tillage strip. This layout minimized weed seed dispersal among main plot treatments and permitted the use of standard equipment for field operations. Each subplot is 20 by 40 feet (108 subplots total). Sixteen micro-plots (each 10 by 10 inches) were established within each subplot (1,728 micro-plots total) for data collection. Since 1998, main plots and subplots have been maintained in the same location and have received the same combination of tillage, crop rotation, and weed management treatments.

Tillage system treatments

Moldboard plow, chisel plow, and no-tillage systems were established at the site in 1984. Since 1998, moldboard plowing and chisel plowing have been conducted in the fall. In the moldboard plow system, soil was plowed to a depth of 8 to 10 inches; the seedbed was prepared for planting with one pass each of a field cultivator and a soil finishing unit (straight coulters, sweeps, harrow teeth, and roller basket). The chisel plow system consisted of one pass with a twisted-shank chisel plow followed by one pass with a soil finishing unit. In the no-tillage system, crop seed was planted directly into the crop residue from the previous year. The same planter was used in each tillage system, but adjustments were made to obtain proper planting depth in each tillage system. Soil surface residue was measured after planting by the intercept method; measurements were made perpendicular to the crop rows.

Cropping system treatments

Treatments include glyphosate-resistant continuous corn and a glyphosate-resistant corn-soybean rotation. In the corn-soybean rotation, soybean was planted in 1998 and 2000, and corn was planted in 1999 and 2001. Asgrow 2101 RR soybean was drilled at 250,000 seeds/acre in rows spaced 7.5-inches apart. DeKalb 493 RR corn was planted in each cropping system at 32,000 seeds/acre in rows spaced 30-inches apart. For corn, urea (46-0-0) was applied preplant at 325 lb/A and starter fertilizer (6-24-24) was applied at planting at 150 lb/A. Chlorpyrifos was applied in furrow at planting at 8 oz/1000 ft row.

Weed management treatments

Weed management treatments were based on strategies that provided a wide range of glyphosate use intensity for weed management:

- glyphosate applied postemergence (POST)
- glyphosate applied POST and late postemergence (LPOST)
- glyphosate applied POST followed by inter-row cultivation
- glyphosate applied POST and rotated annually with a broad-spectrum soil-residual herbicide program applied preemergence (PRE)
- a soil-residual grass herbicide applied PRE and glyphosate applied POST

C a broad-spectrum soil-residual herbicide program applied PRE

Specific treatments in continuous corn are shown in Table 1. In the corn-soybean rotation (Table 2), weed management treatments were also based on a wide range of glyphosate use intensity, but treatments in soybean reflected the high competitive ability of drilled soybean with weeds. However, treatments in corn were identical between the corn-soybean rotation and the continuous corn systems. In each cropping system, weed management treatments in the no-tillage system also included glyphosate applied as a burn-down treatment prior to crop planting.

Data collection

The soil weed seed bank was sampled in each subplot in the spring. Weed plant density was determined by species before POST weed management treatments and monthly thereafter. Plant number was counted in each of the 16 micro-plots in each subplot. Weed plant height was determined after treatment application. Late-season (e.g. September) weed density and biomass were determined by species before crop harvest. Crop stand and height were measured between 4 and 6 weeks after planting. Corn and soybean grain yield were determined by machine harvest in each subplot. Final grain yield was adjusted to 15.5 and 13.0% moisture for corn and soybean, respectively.

RESULTS

Research has been conducted for 4 years, from 1998 to 2001. Since treatments in 2000 included both corn and soybean, data from 2000 are presented below, with emphasis on total weed density, weed biomass, and crop yield. These data are an indication, at least in part, of the cumulative effect of treatments over 3 years.

Tillage systems have strongly affected weed management efficacy (i.e. reduction in total weed density and biomass), with greater efficacy associated with greater tillage intensity (i.e. less crop residue) in continuous corn (Table 1) and in corn-soybean rotation (Table 2). This association was strongest for the broad-spectrum soil-residual herbicide program compared to other weed management treatments. Weed management efficacy in the corn-soybean rotation was similar to or greater than that in continuous corn for most treatments, but differences were specific to tillage and weed management treatment.

Among weed management treatments, glyphosate applied sequentially (POST/LPOST) or glyphosate plus inter-row cultivation were among the most consistent and effective treatments in continuous corn (Table 1). Results for these particular treatments since 1998 suggest that weed populations have decreased over time (data not shown). In corn-soybean rotation, most treatments that included glyphosate were effective, particularly in moldboard plow and chisel plow systems (Table 2). In treatments that included glyphosate, common lambsquarters, giant foxtail, velvetleaf, and/or pigweed species were the dominant weed species in each cropping system, but these occurred at low to very low densities (data not shown). In contrast, giant ragweed and/or shattercane densities (and biomass) increased dramatically over 3 years to become the dominant weed species in treatments that included the broad-spectrum soil-residual herbicide program (data not shown).

Corn grain yields in the moldboard plow system (162 to 188 bu/acre) and chisel plow system (122 to 171 bu/acre) were equal to or greater than that in the no-tillage system (88 to 156 bu/acre) in 2000 (Table 3). Relatively low yields occurred for the broad-spectrum soil-residual herbicide program, particularly in chisel plow and no-tillage systems. For this particular treatment, corn-yield loss was attributed largely to competition with giant ragweed and/or shattercane, depending on the tillage system. In the moldboard plow system, the highest corn yield occurred in the glyphosate POST/LPOST treatment, whereas in the chisel plow and no-tillage systems, yields were similar among treatments that included glyphosate.

Soybean grain yields in 2000 were similar among tillage systems and weed management treatments, however yields were the most variable in the broad-spectrum soil-residual herbicide program, particularly in chisel plow and no-tillage systems (Table 4). Yields ranged from 52 to 60 bu/acre in the moldboard plow system, from 45 to 58 bu/acre in the chisel plow system, and from 34 to 56 bu/acre in the no-tillage system.

In summary, weed density, biomass, and species number tended to be greater in no-tillage than in chisel plow or moldboard plow systems for most weed management treatments. Glyphosate applied sequentially or glyphosate plus inter-row cultivation were among the most consistent and effective treatments across tillage systems. Results for these particular treatments since 1998 suggest that weed population densities have decreased over time, but more importantly, that weed biomass was very low in these treatments. Common lambsquarters, giant foxtail, pigweed species, and velvetleaf were the dominant weed species in most glyphosate-based treatments in each cropping system. However, in treatments that included broad-spectrum preemergence herbicides, giant ragweed and/or shattercane populations increased dramatically. These results suggest that weed management and agronomic risks associated with glyphosate-based treatments were no greater than those associated with soil-residual herbicide treatments.

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TABLE 1. Weed species, total weed density, and total weed biomass as influenced by weed management and tillage in a glyphosate-resistant continuous-corn cropping system in 2000 (Year 3).

	Weed species[a]			Total weed density						Total weed biomass		
	June 6, 2000			June 6, 2000			September 26, 2000			September 26, 2000		
	Tillage system[b]			Tillage system			Tillage system			Tillage system		
Weed management treatment[c]	MP	CP	NT	MP	CP	NT	MP	CP	NT	MP	CP	NT
	no./m²			plants/m²			plants/m²			g/m²		
Glyphosate 0.75 lb/A POST	6 ± 1[d]	7 ± 1	6 ± 1	76±15	280±110	270±60	4 ± 4 (95)[e]	6 ± 1 (98)	16 ± 17 (94)	2 ± 2	5 ± 1	92 ± 95
Glyphosate 0.56 lb/A POST/ Glyphosate 0.56 lb/A POST	7 ± 1	8 ± 3	6 ± 2	150±64	140±34	24±8	2 ± 4 (99)	5 ± 4 (97)	4 ± 5 (85)	1 ± 1	2 ± 2	1 ± 2
Glyphosate 0.75 lb/A POST/ Inter-row cultivation	6 ± 2	8 ± 1	6 ± 1	79±5	150±23	90±34	7 ± 3 (91)	15 ± 6 (90)	28 ± 9 (68)	5 ± 4	6 ± 4	36 ± 29
Year 1 and 3: Glyphosate 0.75 lb/A POST Year 2 and 4: Atrazine 1.0 lb/A + Metolachlor 1.25 lb/A + Flumetsulam 0.025 lb/A PRE	6 ± 2	8 ± 1	7 ± 2	130±83	160±50	150±100	6 ± 7 (95)	9 ± 7 (94)	66 ± 62 (55)	2 ± 2	3 ± 1	70 ± 82
Atrazine 1.0 lb/A + Metolachlor 1.25 lb/A + Flumetsulam 0.025 lb/A PRE	2 ± 1	4 ± 2	4 ± 1	5±2	46±37	140±230	3 ± 3 (40)	13 ± 8 (71)	110 ±160 (24)	250±440	320±400	450±420
Metolachlor 1.27 lb/A PRE/ Glyphosate 0.75 lb/A POST	5 ± 1	4 ± 1	3 ± 2	73±52	57±26	36±40	2 ± 2 (98)	10 ± 9 (83)	27 ± 26 (27)	1± 1	6 ± 5	170±260

[a] Principal weed species included common lambsquarters, pigweed species (redroot pigweed, smooth pigweed, and Powell amaranth), velvetleaf, giant foxtail, giant ragweed, shattercane, horseweed, and dandelion.

[b] MP= moldboard plow, CP = chisel plow, NT = no-tillage.

[c] PRE = preemergence, POST = postemergence, LPOST = late postemergence; PRE treatments were applied April 27; POST and LPOST treatments were applied on June 8 and June 23, respectively. NT treatments included glyphosate applied PRE as a burndown treatment. Interrow cultivation was conducted on June 23.

[d] Mean value ± standard deviation.

[e] Values in parentheses are percent reduction in total weed density on September 26 compared to density on June 6.

TABLE 2. Weed species, total weed density, and total weed biomass as influenced by weed management and tillage in soybean in a glyphosate-resistant corn-soybean rotation in 2000 (Year 3).

	Weed species[a]			Total weed density						Total weed biomass		
	June 6, 2000			June 6, 2000			September 26, 2000			September 26, 2000		
	Tillage system[b]			Tillage system			Tillage system			Tillage system		
Weed management treatment[c]	MP	CP	NT	MP	CP	NT	MP	CP	NT	MP	CP	NT
	no./m²			plants/m²			plants/m²			g/m²		
Year 1 and 3 (soybean): Glyphosate 0.56 lb/A POST Year 2 and 4 (corn): Glyphosate 0.75 lb/A POST	5 ± 1[d]	7 ± 1	7 ± 2	130±55	160±92	130±34	1 ± 2 (99)[e]	3 ± 6 (98)	2 ± 1 (98)	2 ± 4	2 ± 4	17 ± 29
Year 1 and 3 (soybean): Glyphosate 0.56 lb/A POST Year 2 and 4 (corn): Glyphosate 0.56 lb/A POST/ Glyphosate 0.56 lb/A POST	6 ± 1	7 ± 3	6 ± 1	50±13	78±36	60±2	0 (100)	1 ± 2 (99)	13 ± 19 (79)	0	0	25 ± 45
Year 1 and 3 (soybean): Glyphosate 0.56 lb/A POST Year 2 and 4 (corn): Glyphosate 0.75 lb/A POST/ Inter-row cultivation	5 ± 1	7 ± 1	6 ± 2	51±3	95±46	31±4	0 (100)	2 ± 2 (98)	0 (100)	0	4 ± 7	0
Year 1 and 3 (soybean): Glyphosate 0.56 lb/A POST Year 2 and 4 (corn): Atrazine 1.0 lb/A + Metolachlor 1.25 lb/A + Flumetsulam 0.025 lb/A PRE	5 ± 2	7 ± 1	5 ± 2	55±31	120±41	150±64	1 ± 2 (98)	1± 2 (99)	2 ± 2 (98)	4 ± 7	84±124	7 ± 11
Year 1 and 3 (soybean): Metolachlor 1.27 lb/A + Flumetsulam 0.06 lb/A PRE Year 2 and 4 (corn): Atrazine 1.0 lb/A + Metolachlor 1.25 lb/A + Flumetsulam 0.025 lb/A PRE	2 ± 1	4 ± 1	5 ± 1	7±3	75±68	170±190	1 ± 1 (90)	12 ± 10 (84)	150±240 (14)	29 ± 50	49 ± 36	380 ± 520
Year 1 and 3 (soybean): Metolachlor 1.27 lb/A PRE/ Glyphosate 0.56 lb/A POST Year 2 and 4 (corn): Metolachlor 1.25 lb/A PRE/ Glyphosate 0.75 lb/A POST	3 ± 1	3 ± 2	5 ± 3	9±3	9±8	21±13	0 (100)	1 ± 1 (93)	2 ± 2 (92)	0	0	24 ± 24

[a] Principal weed species included common lambsquarters, pigweed species (redroot pigweed, smooth pigweed, and Powell amaranth), velvetleaf, giant foxtail, giant ragweed, shattercane,

horseweed, and dandelion.
[b] MP= moldboard plow, CP = chisel plow, NT = no-tillage.
[c] PRE = preemergence, POST = postemergence, LPOST = late postemergence; PRE treatments were applied May 5; POST treatments were applied on June 8. NT treatments included glyphosate applied PRE as a burndown treatment.
[d] Mean value ± standard deviation.
[e] Values in parentheses are percent reduction in total weed density on September 26 compared to density on June 6.

TABLE 3. Field corn density, height, and grain yield as influenced by weed management and tillage in a glyphosate-resistant continuous-corn cropping system in 2000 (Year 3).

Weed management treatment[c]	Corn density July 6, 2000 Tillage system[b]			Corn height July 14, 2000 Tillage system			Corn grain yield[a] October 30, 2000 Tillage system		
	MP	CP	NT	MP	CP	NT	MP	CP	NT
	1000 plants/A			inches			bu/A		
Glyphosate 0.75 lb/A POST	28.7 ± 0.2[d]	28.8 ± 0.6	24.8 ± 1.6	75 ± 4	76 ± 4	58 ± 6	168 ± 7	171 ± 14	144 ± 7
Glyphosate 0.56 lb/A POST/ Glyphosate 0.56 lb/A POST	29.5 ± 0.1	29.2 ± 0.3	23.9 ± 0.9	74 ± 5	70 ± 6	63 ± 1	188 ± 2	169 ± 9	156 ± 19
Glyphosate 0.75 lb/A POST/ Inter-row cultivation	28.6 ± 0.2	28.9 ± 0.2	23.0 ± 0.2	77 ± 2	72 ± 3	52 ± 14	173 ± 8	151 ± 13	140 ± 4
Year 1 and 3: Glyphosate 0.75 lb/A POST Year 2 and 4: Atrazine 1.0 lb/A + Metolachlor 1.25 lb/A + Flumetsulam 0.025 lb/A PRE	29.5 ± 0.9	29.4 ± 0.3	25.6 ± 1.2	67 ± 11	74 ± 5	56 ± 4	163 ± 15	165 ± 3	131 ± 14
Atrazine 1.0 lb/A + Metolachlor 1.25 lb/A + Flumetsulam 0.025 lb/A PRE	29.4 ± 0.2	28.1 ± 1.3	22.2 ± 1.5	77 ± 8	71 ± 10	52 ± 7	162 ± 15	122 ± 43	88 ± 71
Metolachlor 1.27 lb/A PRE/ Glyphosate 0.75 lb/A POST	29.2 ± 0.6	28.9 ± 0.5	24.9 ± 3.6	77 ± 2	73 ± 3	56 ± 5	177 ± 8	170 ± 4	124 ± 38

[a] Corn grain yield adjusted to 15.5% moisture.
[b] MP= moldboard plow, CP = chisel plow, NT = no-tillage.
[c] PRE = preemergence, POST = postemergence, LPOST = late postemergence; PRE treatments were applied April 27; POST and LPOST treatments were applied on June 8 and June 23, respectively. NT treatments included glyphosate applied PRE as a burndown treatment. Interrow cultivation was conducted on June 23.
[d] Mean value ± standard deviation.

TABLE 4. Soybean density, height, and grain yield as influenced by weed management and tillage in a glyphosate-resistant corn-soybean rotation in 2000 (Year 3).

	Soybean density			Soybean height			Soybean grain yield[a]		
	July 11, 2000			July 14, 2000			October 4, 2000		
	Tillage system[b]			Tillage system			Tillage system		
Weed management treatment[c]	MP	CP	NT	MP	CP	NT	MP	CP	NT
	1000 plants/A			inches			bu/A		
Year 1 and 3 (soybean): Glyphosate 0.56 lb/A POST; Year 2 and 4 (corn): Glyphosate 0.75 lb/A POST	181 ± 3[d]	180 ± 2	127 ± 5	23 ± 2	23 ± 3	15 ± 1	54 ± 2	54 ± 6	50 ± 5
Year 1 and 3 (soybean): Glyphosate 0.56 lb/A POST; Year 2 and 4 (corn): Glyphosate 0.56 lb/A POST/ Glyphosate 0.56 lb/A POST	182 ± 2	181 ± 2	124 ± 17	23 ± 1	24 ± 1	16 ± 2	60 ± 6	58 ± 3	52 ± 4
Year 1 and 3 (soybean): Glyphosate 0.56 lb/A POST; Year 2 and 4 (corn): Glyphosate 0.75 lb/A POST/ Inter-row cultivation	179 ± 3	181 ± 5	130 ± 6	23 ± 2	24 ± 1	17 ± 1	55 ± 4	57 ± 4	56 ± 2
Year 1 and 3 (soybean): Glyphosate 0.56 lb/A POST; Year 2 and 4 (corn): Atrazine 1.0 lb/A + Metolachlor 1.25 lb/A + Flumetsulam 0.025 lb/A PRE	180 ± 3	182 ± 5	115 ± 10	23 ± 1	22 ± 2	16 ± 1	54 ± 2	54 ± 5	51 ± 1
Year 1 and 3 (soybean): Metolachlor 1.27 lb/A + Flumetsulam 0.06 lb/A PRE; Year 2 and 4 (corn): Atrazine 1.0 lb/A + Metolachlor 1.25 lb/A + Flumetsulam 0.025 lb/A PRE	180 ± 4	183 ± 5	117 ± 12	22 ± 1	22 ± 3	18 ± 3	53 ± 3	45 ± 8	34 ± 29
Year 1 and 3 (soybean): Metolachlor 1.27 lb/A PRE/ Glyphosate 0.56 lb/A POST; Year 2 and 4 (corn): Metolachlor 1.25 lb/A PRE/ Glyphosate 0.75 lb/A POST	178 ± 7	184 ± 5	125 ± 5	21 ± 1	21 ± 2	14 ± 1	52 ± 4	55 ± 3	51 ± 2

[a] Soybean grain yield adjusted to 13% moisture.
[b] MP= moldboard plow, CP = chisel plow, NT = no-tillage.
[c] PRE = preemergence, POST = postemergence, LPOST = late postemergence; PRE treatments were applied May 5; POST treatments were applied on June 8. NT treatments included glyphosate applied PRE as a burndown treatment.
[d] Mean value ± standard deviation.