WEED CHANGES AFTER EIGHT YEARS OF CONTINUOUS GLYPHOSATE USE

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Introduction

Glyphosate-resistant soybeans have been widely adopted by growers due to the benefits of broad-spectrum efficacy, reduced crop injury, and simplification of weed management. Glyphosate-resistant corn has expanded in use in recent growing seasons and as a result, glyphosate is increasingly being depended upon as the primary means of weed management in corn and soybean production.

The widespread use of this technology has produced concerns about the effect of continuous use of glyphosate on weed community composition and the development of new weed problems. The goal of this research was to determine the long-term weed management and agronomic risks in glyphosate-resistant corn and soybean as influenced by intensity of tillage and glyphosate use. Research was conducted at the University of Wisconsin from 1998 to 2006 to determine the long-term effects of primary tillage system and glyphosate use intensity on weed population dynamics in a glyphosate-resistant corn and soybean annual rotation.

Methods

Research was conducted at the University of Wisconsin Arlington Agricultural Research Station from 1998 through 2006. Six weed management treatments were compared in a corn-soybean annual rotation across three primary tillage systems: moldboard plow, chisel plow, and no-tillage (Table 1).

Table 1. Weed management treatments in a corn-soybean annual rotation from 1998-2006.

Treatment †	Soy: 1998, 2000, 2002, 2004, 2006	Corn: 1999, 2001, 2003, 2005
1	Glyphosate POST	Glyphosate POST
2	Glyphosate POST	Glyphosate POST + LPOST
3	Glyphosate POST	Glyphosate POST + Cultivation
4	Glyphosate POST	Non-Glyphosate
5	Non-Glyphosate	Non-Glyphosate
6	Residual grass herbicide PRE + Glyphosate POST	Residual grass herbicide PRE + Glyphosate POST

† PRE = preemergence, POST = postemergence, LPOST = late postemergence

Non-glyphosate treatments consisted of herbicide combinations for broad-spectrum weed control. Weed management treatments in no-tillage included glyphosate applied as a burn-down. The experimental design was a randomized complete block in a split-split-block arrangement with three replications. The main plots were factorial combinations of tillage and cropping sequence treatments (corn-soybean annual rotation shown only), and the subplot factors were weed management treatments.

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Soil type was Plano silt loam with pH 5.8 and 4.1% organic matter. Primary tillage was conducted during the fall of each year. The seedbed was prepared shortly before planting with a field cultivator/straight-tooth harrow in moldboard plow and chisel plow systems. Soybean was planted in 1998, 2000, 2002, 2004, and 2006, and corn was planted in 1999, 2001, 2003, and 2005. Glyphosate-resistant soybean was drilled in early May at 250,000 seeds/acre in rows spaced 7.5 inches apart. Glyphosate-resistant corn was planted in late April or early May at 32,000 seeds/acre in rows spaced 30 inches apart. For corn, 150 lb/acre N were applied pre-plant and 150 lb/acre 6-24-24 N-P_2O_5-K_2O was applied as starter fertilizer at planting. Corn and soybean were harvested by machine for grain yield.

Plots were maintained in the same location and received consistent treatments over the duration of the experiment. Plot size was 20-ft wide by 40-ft long. The soil weed seedbank was sampled each spring. Weed seeds were quantified from 30 soil cores taken from the upper 4 inches of the soil profile in each plot. Sixteen micro-plots (each 10 inches by 10 inches) were established within each plot for measuring weed plant density. Plant densities of each weed species were measured immediately prior to POST herbicide treatments, 4 weeks after POST treatment (WAT), 8 WAT, and prior to crop harvest. Plots were sub-sampled for weed shoot biomass prior to crop harvest.

Results

Thirty-three weed species were identified in this experiment from 1998 to 2006 (data not shown). Averaged over tillage systems, common lambsquarters, redroot pigweed, and giant foxtail were the most abundant species in the weed seedbank community from 1999 to 2005 (Table 2). Other species, particularly giant ragweed, shattercane, and large crabgrass increased in abundance in the seedbank over time. Common lambsquarters and giant foxtail were also the most abundant species over time in the plant community, based on weed density measurements at the time of POST treatments. In contrast, redroot pigweed abundance in the weed plant community decreased over time, whereas the abundance of giant ragweed, shattercane, and large crabgrass increased between 1999 and 2005. The most notable increase in the plant community was for giant ragweed.

Table 2. Weed species composition of the soil seedbank and plant community in 1999 and 2005.†

	Seedbank		Plant community	
Weed species	1999	2005	1999	2005
	% of total			
Common lambsquarters	70	65	33	34
Redroot pigweed	12	11	20	6
Giant foxtail	16	11	33	29
Velvetleaf	2	2	8	2
Shattercane	0	3	1	2
Giant ragweed	0	3	0	23
Large crabgrass	0	1	0	1
Other species	0	3	5	4

† The total number of viable weed seeds in the upper 4 inches of the soil profile was measured in April or May each year. Plant densities were measured prior to POST herbicide treatments. Data were averaged across tillage systems.

The total viable weed seedbank density was significantly affected by tillage system, weed management treatment, and year (Table 3). However, the total viable seedbank density decreased between 1998 and 2006 for most weed management treatments in each tillage system (Figure 1). Common lambsquarters seedbank density was similar across tillage systems and weed management treatments (Table 3), and either changed little or decreased between 1998 and 2006 (Fig. 1).

Table 3. Tillage, weed management, and year effects on the viable weed seedbank (1999-2006) and weed plant community (1998-2005) composition in an annual corn-soybean rotation. †

Weed community	Factor	Total weed species	Common lambsquarters	Redroot pigweed	Giant foxtail	Other broadleaves	Other grasses
		p-value					
Seedbank	Tillage	0.0382	NS ‡	NS	NS	0.0135	NS
	Weed mgmt	0.0015	NS	NS	<0.0001	0.0271	<0.0001
	Year	<0.0001	<0.0001	<0.0001	<0.0001	0.0409	<0.0001
Plant	Tillage	0.0024	0.0171	0.0428	NS	0.0097	NS
	Weed mgmt	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	Year	NS	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

† The total number of viable weed seeds in the upper 4 inches of the soil profile was measured in April or May each year. Plant densities were measured prior to POST herbicide treatments.
‡ NS indicates not significant at $\alpha = 0.05$.

Total weed plant density at the time of POST treatments was significantly affected by tillage system (Table 3) and was typically less in moldboard plow than chisel plow or no-tillage systems (Figure 2). Weed management treatment also significantly affected total weed plant density at the time of POST treatments, with the greatest densities typically associated with the glyphosate POST treatment in corn and soybean (Treatment 1 in Table 1). However, most glyphosate-based weed management treatments were associated with a reduction in total weed density of 85% or more by late-season (Fig. 2).

Common lambsquarters plant density at the time of POST treatments was significantly affected by tillage system (Table 3) and was typically greater in moldboard plow and chisel plow systems than the no-tillage system in most years (Fig. 3). Common lambsquarters plant density at the time of POST treatment was also significantly affected by weed management treatment over time, but the relationship between density and weed management treatment was inconsistent. In contrast, weed management treatments were associated with a high level of efficacy on common lambsquarters, based on late-season plant densities. Across weed management treatments, reduction in common lambsquarters density between early and late season was 98, 88, and 82% or greater in moldboard plow, chisel plow, and no-tillage systems, respectively.

Although changes in weed density are commonly used to assess efficacy of weed management treatments, such measures may not reflect the impact of a few highly competitive weeds. In an effort to assess this aspect of weed community composition, we measured late-season shoot biomass of weeds before crop harvest. These late-season measurements showed that total weed shoot biomass per unit area was inversely related to the intensity of tillage, i.e. late-season weed shoot biomass was typically lowest in the moldboard plow system and greatest in the no-tillage system (Fig. 4). Total weed shoot biomass averaged 12 g m^{-2} in the moldboard plow system compared to 99 and 113 g m^{-2} in the chisel plow and no-tillage systems, respectively. Consistent with late-season common lambsquarters densities (Fig. 3), common lambsquarters contributed very little to late-season shoot dry biomass of the weed community, averaging less than 1 g m^{-2} across treatments (Fig. 4).

In contrast to common lambsquarters, giant ragweed and shattercane accounted for most of the late-season shoot biomass of the weed community (Fig. 5). Giant ragweed was not observed during the first 2 years of the experiment; however, populations quickly established beginning in year three (data not shown). Giant ragweed shoot biomass was the greatest in the chisel plow system and least in the moldboard plow system. The apparent greater affinity of giant ragweed for the chisel plow system relative to moldboard plow and no-tillage systems may be attributable to a greater proportion of giant ragweed seeds at optimal soil depths for germination, emergence, and early growth. Giant ragweed emergence rates have been found to be greatest at a seed burial depth of about 1 inch, although emergence can occur from as deep as 6 inches. Emergence rates are typically very low within the upper 0.5 inch of the soil profile, where a large proportion of the weed seedbank is found in no-tillage systems. Additionally, high rates of giant ragweed seed predation have been observed in no-tillage systems, making no-tillage a less favorable environment for giant ragweed proliferation.

In the chisel-plow system, late-season giant ragweed biomass was typically greatest in treatments that included a non-glyphosate component (Treatments 4 and 5 in Table 1) in years five to seven of the experiment (Fig. 5). Modifications in non-glyphosate treatment chemistries during this time were successful to some extent in reducing giant ragweed biomass in these treatments. In addition, giant ragweed shoot biomass increased during years six to eight for treatments that included glyphosate POST only for post-emergence weed management in corn and soybean (Table 1, Treatments 1 and 6) in both chisel plow and no-tillage systems. In contrast, extended periods of efficacy associated with treatments that included glyphosate LPOST or cultivation (Treatments 2 and 3 in Table 1, respectively) were associated with low levels of giant ragweed shoot biomass over time.

Late-season shoot biomass levels of shattercane were the greatest of any weed species in the experiment; shattercane was a particularly difficult management problem in the no-tillage system (Fig. 5). Shattercane shoot biomass averaged 1, 10, and 61 g m^{-2} in the moldboard plow, chisel plow, and no-tillage systems, respectively. Among weed management treatments, the patterns of shattercane biomass were similar to those for giant ragweed. Shattercane biomass levels increased most notably in the chisel plow and no-tillage systems where glyphosate POST in soybean was rotated annually with a non-glyphosate herbicide program in corn (Treatment 4 in Table 1) and where non-glyphosate herbicides only were used (Treatment 5 in Table 1). Also in the no-tillage system, shattercane was a management problem during years six to eight for treatments that included glyphosate POST only for postemergence weed management in corn and soybean (Treatments 1 and 6 in Table 1).

Conclusions

Changes in the species composition of weed communities were relatively minor over 8 years in glyphosate-based treatments, with common lambsquarters and giant foxtail persisting as the most abundant weed species. However, management efficacy of common lambsquarters remained at a high level over time. The most rapid changes in the weed community were associated with the non-glyphosate herbicide treatments, and were largely due to increases in giant ragweed and shattercane populations. Although only minor changes in weed species abundance occurred in glyphosate-based treatments, an extended emergence period may be a key mechanism by which weed populations persisted or increased over time.

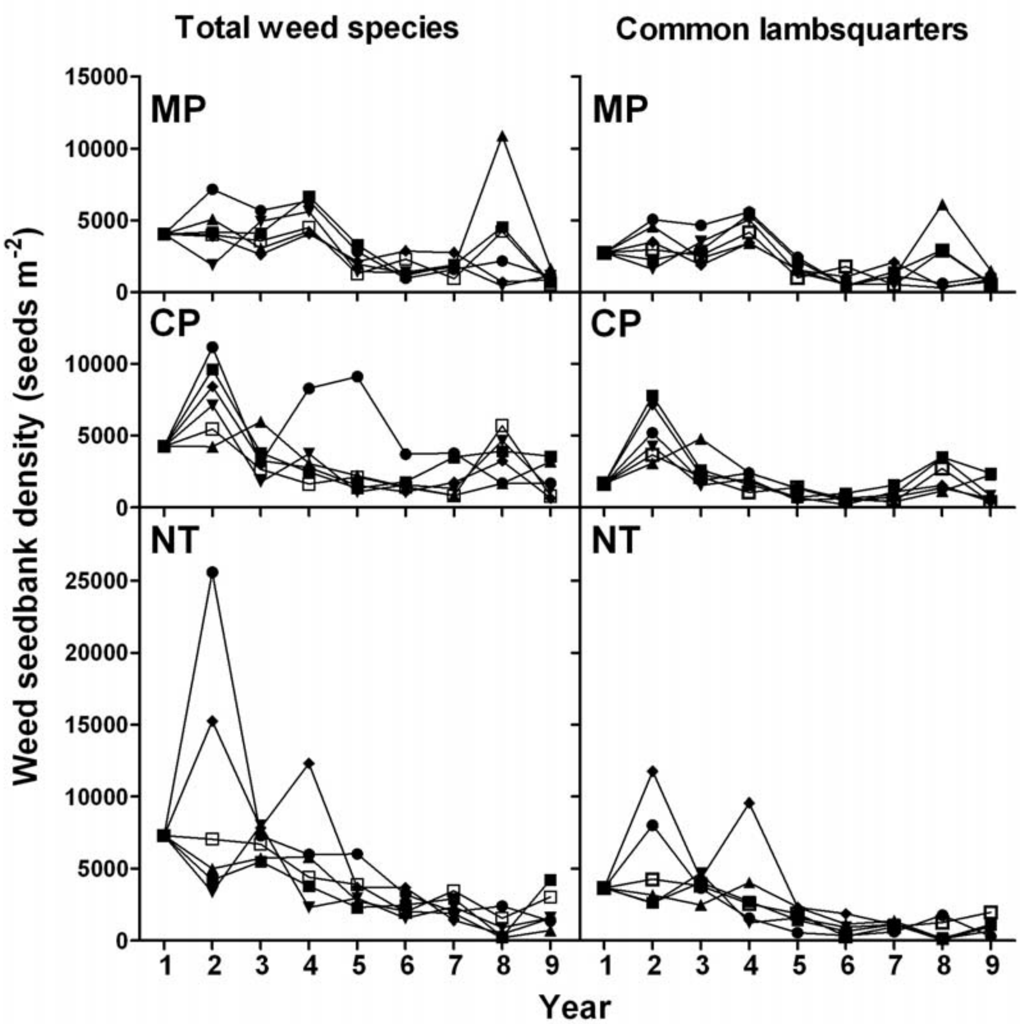

Figure 1. Viable seedbank density for total weed species and common lambsquarters from 1998-2006 as affected by moldboard plow (MP), chisel plow (CP), and no-tillage (NT) systems and weed management treatment in an annual corn-soybean rotation. Soybean was planted in 1998, 2000, 2002, 2004, and 2006; corn was planted in 1999, 2001, 2003, and 2005. Weed management treatments were 1) glyphosate POST in corn and soybean (■), 2) glyphosate POST and LPOST in corn and glyphosate POST in soybean (▲), 3) glyphosate POST plus inter-row cultivation in corn, and glyphosate POST in soybean (▼), 4) glyphosate POST in soybean rotated annually with a non-glyphosate herbicide program in corn (◆), 5) a non-glyphosate herbicide program in both corn and soybean (●), and 6) a PRE grass herbicide followed by glyphosate POST in both corn and soybean (□). Weed management treatments in NT included glyphosate applied as a burn-down.

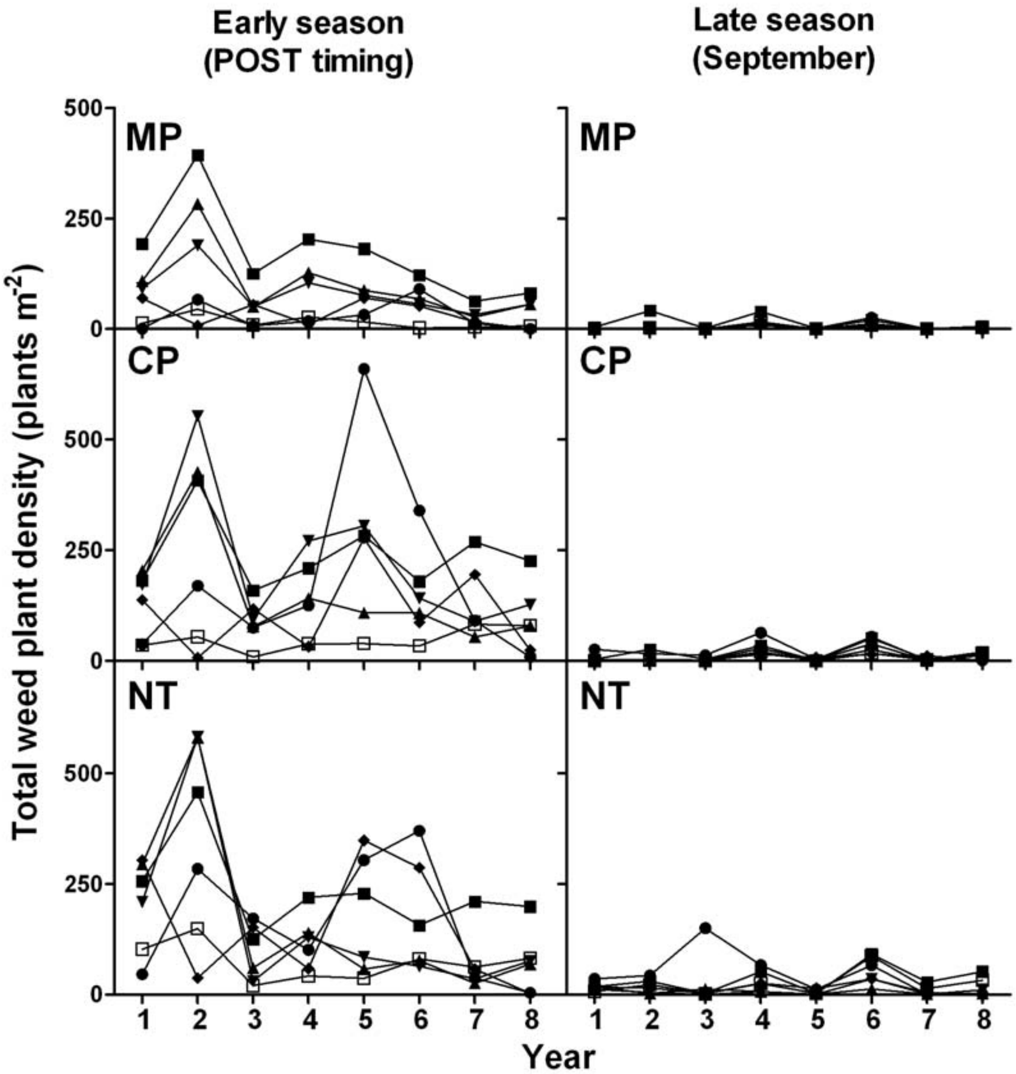

Figure 2. Total weed plant density early season (at the time of POST herbicide treatments) and late season from 1998-2005 as affected by moldboard plow (MP), chisel plow (CP), and no-tillage (NT) systems and weed management treatment in an annual corn-soybean rotation. Soybean was planted in 1998, 2000, 2002, and 2004; corn was planted in 1999, 2001, 2003, and 2005. Weed management treatments were 1) glyphosate POST in corn and soybean (■), 2) glyphosate POST and LPOST in corn and glyphosate POST in soybean (▲), 3) glyphosate POST plus inter-row cultivation in corn, and glyphosate POST in soybean (▼), 4) glyphosate POST in soybean rotated annually with a non-glyphosate herbicide program in corn (◆), 5) a non-glyphosate herbicide program in both corn and soybean (●), and 6) a PRE grass herbicide followed by glyphosate POST in both corn and soybean (□). Weed management treatments in NT included glyphosate applied as a burn-down.

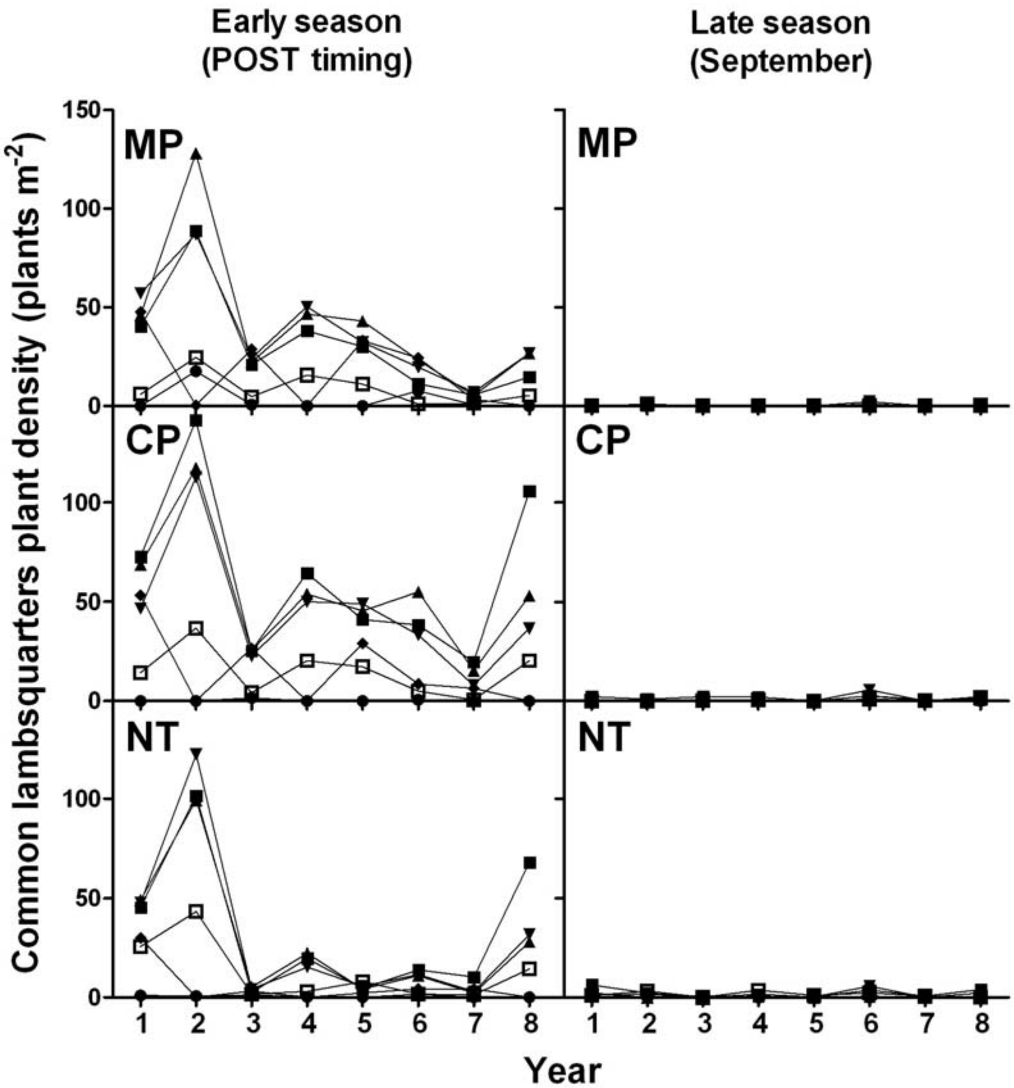

Figure 3. Common lambsquarters plant density early season (at the time of POST herbicide treatments) and late season from 1998-2005 as affected by moldboard plow (MP), chisel plow (CP), and no-tillage (NT) systems and weed management treatment in an annual corn-soybean rotation. Soybean was planted in 1998, 2000, 2002, and 2004; corn was planted in 1999, 2001, 2003, and 2005. Weed management treatments were 1) glyphosate POST in corn and soybean (■), 2) glyphosate POST and LPOST in corn and glyphosate POST in soybean (▲), 3) glyphosate POST plus inter-row cultivation in corn, and glyphosate POST in soybean (▼), 4) glyphosate POST in soybean rotated annually with a non-glyphosate herbicide program in corn (◆), 5) a non-glyphosate herbicide program in both corn and soybean (●), and 6) a PRE grass herbicide followed by glyphosate POST in both corn and soybean (□). Weed management treatments in NT included glyphosate applied as a burn-down.

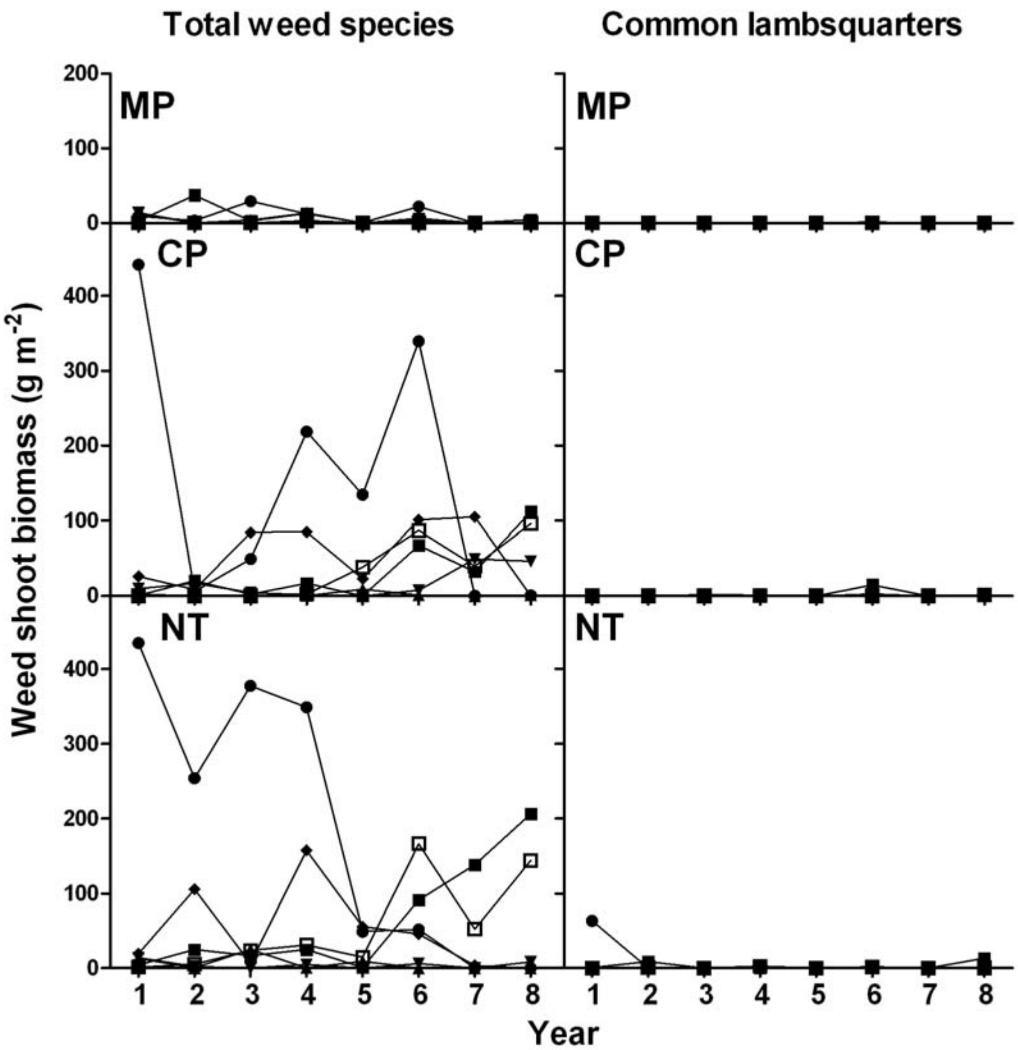

Figure 4. Late-season weed shoot biomass for total weed species and common lambsquarters from 1998-2005 as affected by moldboard plow (MP), chisel plow (CP), and no-tillage (NT) systems and weed management treatment in an annual corn-soybean rotation. Soybean was planted in 1998, 2000, 2002, and 2004; corn was planted in 1999, 2001, 2003, and 2005. Weed management treatments were 1) glyphosate POST in corn and soybean (■), 2) glyphosate POST and LPOST in corn and glyphosate POST in soybean (▲), 3) glyphosate POST plus inter-row cultivation in corn, and glyphosate POST in soybean (▼), 4) glyphosate POST in soybean rotated annually with a non-glyphosate herbicide program in corn (◆), 5) a non-glyphosate herbicide program in both corn and soybean (●), and 6) a PRE grass herbicide followed by glyphosate POST in both corn and soybean (□). Weed management treatments in NT included glyphosate applied as a burn-down.

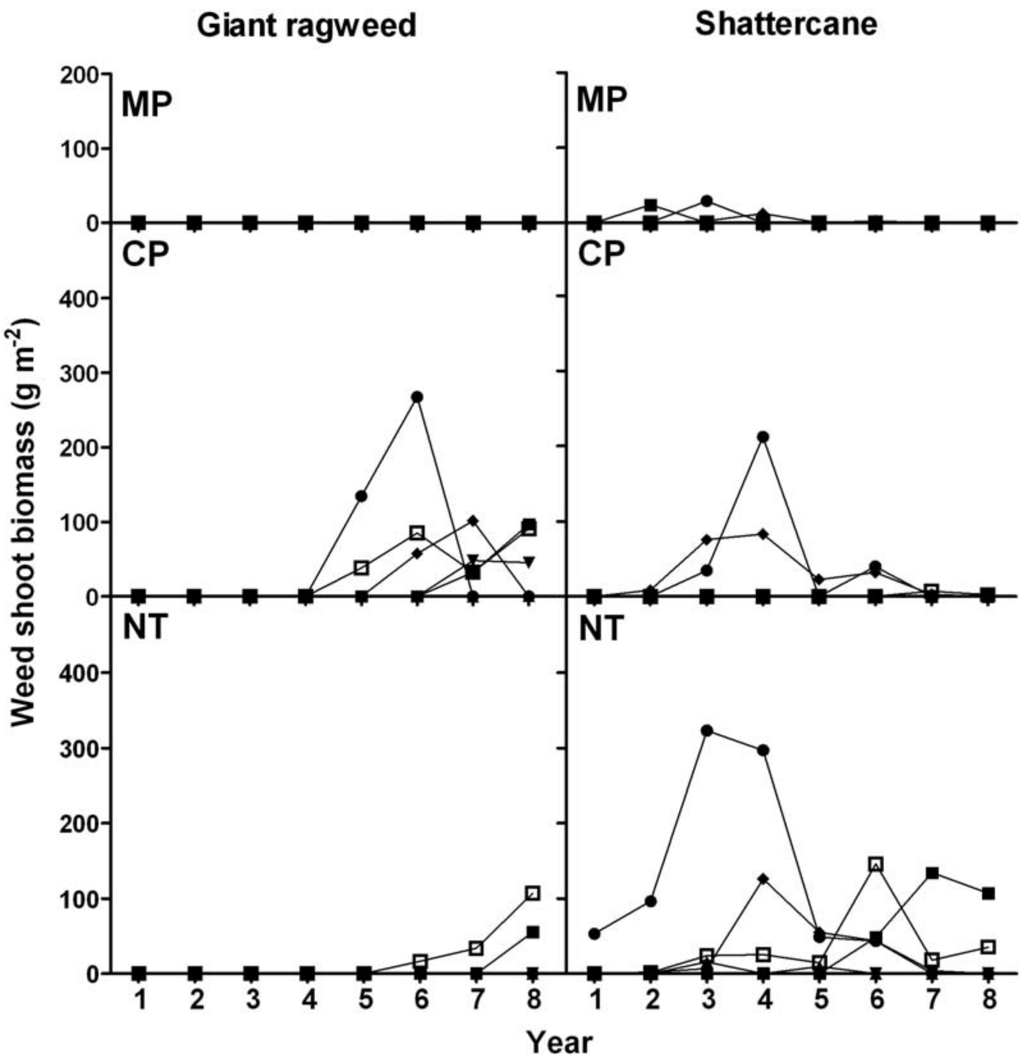

Figure 5. Late-season weed shoot biomass for giant ragweed and shattercane from 1998-2005 as affected by moldboard plow (MP), chisel plow (CP), and no-tillage (NT) systems and weed management treatment in an annual corn-soybean rotation. Soybean was planted in 1998, 2000, 2002, and 2004; corn was planted in 1999, 2001, 2003, and 2005. Weed management treatments were 1) glyphosate POST in corn and soybean (■), 2) glyphosate POST and LPOST in corn and glyphosate POST in soybean (▲), 3) glyphosate POST plus inter-row cultivation in corn, and glyphosate POST in soybean (▼), 4) glyphosate POST in soybean rotated annually with a non-glyphosate herbicide program in corn (◆), 5) a non-glyphosate herbicide program in both corn and soybean (●), and 6) a PRE grass herbicide followed by glyphosate POST in both corn and soybean (□). Weed management treatments in NT included glyphosate applied as a burn-down.