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Source: *Weed Science*, Vol. 58, No. 3 (July-September 2010), pp. 234-243

Published by: Cambridge University Press on behalf of the Weed Science Society of America

Stable URL: <https://www.jstor.org/stable/40891092>

Accessed: 04-07-2023 06:10 +00:00

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Weed Populations as Affected by Residue Management Practices in a Wheat–Soybean Double-Crop Production System

Nyambilila Amuri, Kristofor R. Brye, Edward E. Gbur, Dick Oliver, and Jason Kelley*

Management practices and cropping systems that serve as integrated weed management practices, and at the same time can contribute to improved soil quality, will be important for the sustainability of agricultural production systems. The objective of this study was to assess weed species population density under contrasting tillage (conventional tillage [CT] and no tillage [NT]), residue burning (burn and no burn), and residue level (low and high) treatments after 5 and 6 yr of consistent management in a wheat–soybean double-crop production system. A field experiment was conducted from fall 2001 to fall 2007 in the Mississippi River Delta region of eastern Arkansas on a Calloway silt–loam. Weed assessments were conducted twice during the soybean growing season, before (early season) and after herbicide application (late season) in 2006 and 2007. Total weed density was greater under CT (513 plants m⁻²) than under NT (340 plants m⁻²) early in the growing season in 2006, but was greater under NT than CT late in the season in 2007, suggesting that the effectiveness of glyphosate on total weeds differs between CT and NT. Averaged across residue levels, grass species density was greatest in the NT–burn (68 to 167 plants m⁻²) combination and lowest in the NT–no-burn (41 to 63 plants m⁻²) early in the growing season in both years. Broadleaf density was greater early (200 to 349 plants m⁻²) than late (18 to 20 plants m⁻²) in the growing season under both CT and NT in 2006, but in 2007 broadleaf density did not differ by tillage treatment between seasons. Perennial weed density was greater in the burn (99 plants m⁻²) than in the no-burn (59 plants m⁻²) treatment in 2006. No tillage, no burning, and a high residue level appeared to contribute to the suppression of most weed species without reducing herbicide efficiency.

Nomenclature: Soybean, *Glycine max* Merr.; wheat, *Triticum aestivum* L.

Key words: Burning, conventional tillage, no tillage, residue, weed species composition.

Adoption of the double-crop production system with appropriate residue management techniques, such as NT and retaining crop residues on the soil without burning, have potential to increase crop productivity and soil quality by minimizing potential negative effects of weeds. Crop rotation and conservation tillage are among the important components of integrated weed management systems that modify soil and crop microenvironments to reduce germination, growth, and dissemination of weeds, hence minimizing the need for and use of herbicides (Liebman and Davis 2000; Locke et al. 2002a; Swanton and Murphy 1996). However, there is concern about shifting of weed species with the adoption of the double-crop system and conservation tillage that is associated with crop yield losses (Locke et al. 2002a; Shrestha et al. 2002) and increased demand for pest control inputs, particularly in the long term. Therefore, periodic weed assessments conducted in conjunction with changes in agronomic management practices are essential to ensure long-term agricultural productivity.

Multiple abiotic, biotic, agronomic (i.e., tillage and cover crop), environmental (i.e., moisture and temperature), herbicide use, and soil fertility factors influence the weed community in agricultural systems (Davis 2007; Derksen et al. 1993). Increased weed density under CT has been shown to be related to increased aeration and exposure of weed seeds to light, thus promoting germination and rapid weed growth (Shrestha et al. 2002; Teasdale 1993). In contrast, other studies have reported greater weed density under NT than CT

due to the reduction of annual weeds under CT and/or increases in perennial weeds and grasses under NT in the central United States (Buhler 1992). Weed composition is also affected by changes in tillage management practices (Barberi and Cascio 2000; Buhler et al. 1994; Fischer et al. 2002; Norsworthy 2008; Puricelli and Tuesca 2005; Wruckle and Arnold 1985), but few consistent tillage effects have been reported.

Crop rotation alone can improve weed management regardless of tillage, because of rotations affecting weed populations and composition through altering the weed seedbank and subsequent weed growth (Bellinder et al. 2004). Multicrop rotations with different growing seasons and varied herbicide usage may have the advantage of counteracting herbicide resistance by reducing the number of troublesome weeds in any particular growing season (Fischer et al. 2002). However, the soil seedbank will subsequently likely contain seeds from the diverse and abundant weed species associated with each crop in the rotation (Smith and Gross 2006). Thus, inconsistencies in the effect of crop rotation, management practices, including tillage and burning as a common residue management practice, and weed species affected further necessitate weed assessments beginning shortly after changes in management practice are implemented, particularly in the increasingly more common wheat–soybean double-crop production system popular in the Mississippi River Delta region.

Crop residues left on the soil surface under conservation tillage also contribute to weed management through allelopathic inhibitory effects and by acting as a physical barrier for light penetration (Bellinder et al. 2004; Fischer et al. 2002; Liebman and Davis 2000; Shrestha et al. 2002). However, crop residues left on the soil surface in NT can also interfere with herbicide activity to reduce herbicide efficiency (Locke et al. 2002a,b). Reduced herbicide efficiency due to crop residue cover is caused by preventing the herbicide from reaching the soil and herbicide sorption due to increased soil organic matter (SOM) after residue decomposition, which often

DOI: 10.1614/WS-09-088.1

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results in the need for greater rates and increased frequencies of spraying, adding to the costs of production (Locke et al. 2002a; Reddy et al. 1995). The contrasting residue-level effect on weed species populations suggests the need to assess weed populations in cropping systems with alternative residue management practices and differential N fertilization schemes to generate information necessary for achieving and maintaining sustainable crop production, particularly in the wheat–soybean double-crop production system.

The use of broad-spectrum herbicides, such as glyphosate, along with adoption of glyphosate-resistant soybean, have also improved weed control, particularly under conservation tillage. However, continuous use of glyphosate has caused changes in weed species composition in agricultural systems (Norsworthy 2008; Puricelli and Tuesca 2005; Rankins et al. 2005). It is evident that investigation of alternative management practices as an integrated weed management tool is important to determine if such practices will ameliorate some of the limitations associated with the continuous use of herbicides with a single mode of action. In addition, weed assessment is necessary to determine the effect of alternative residue management practices in continuous double-crop production beyond 5 yr without a fallow period and whether those practices are ecologically and economically sustainable.

The objective of this study was to assess weed species populations and composition early and late in the soybean growing season under contrasting tillage (CT and NT), burning (burn and no burn), and residue level (low and high) treatments after 5 and 6 yr of consistent management in a wheat–soybean double-crop production system in the Mississippi River Delta region of eastern Arkansas. It was hypothesized that CT, residue burning, and a low residue level will lead to greater weed density and composition than in NT, no residue burning, and a high residue level. It was also hypothesized that weed density may differ between tillage treatments and between burn treatments because of differences in how surface residue is managed.

Materials and Methods

Site Description and Experimental Design. A wheat–soybean double-crop rotation was initiated in fall 2001 at the University of Arkansas Lon Mann Cotton Research Station, Marianna (34°44′2.26″N; 90°45′51.56″W; Cordell 2004) in the Mississippi River Delta region of eastern Arkansas. The soil is a Calloway silt–loam (fine silty, mixed, active, thermic Glossaquic Fraglossudalf; U.S. Department of Agriculture, Natural Resource Conservation Services [USDA-NRCS] 2008). The study area was under continuous soybean production with CT prior to initiation of this field experiment (Brye et al. 2006; Cordell et al. 2006).

This study consisted of three factors: tillage, burning, and residue-level factors (Brye et al. 2006). Tillage treatments (CT and NT) represented the main plot and were arranged as a randomized complete block with three replications. Burn treatments (burn and no burn) formed a strip plot and were arranged across tillage treatments with two replications. Residue level [high (H) and low (L)] represented the strip-split plot within tillage–burning treatment combinations. There were six replications of the eight treatment combinations for a total of 48 field plots throughout the duration of this study (Cordell 2004).

Field Management. In fall 2001, the study area was prepared by disking twice, followed by a broadcast application of 20 kg N ha⁻¹, 22.5 kg P ha⁻¹, 56 kg K ha⁻¹, and 1,120 kg ha⁻¹ of pelletized limestone prior to wheat planting. Wheat ('Coker 9663') was a winter crop and was drill seeded in fall each year. Plots, 3 m wide by 6 m long, were established in early spring 2002 and were maintained throughout the study period. In early March 2002 through 2004, all plots were broadcast fertilized with 101 kg N ha⁻¹ as urea. To obtain different levels of wheat residue, the high-residue plots ($n = 24$) were broadcast fertilized with an additional 101 kg N ha⁻¹ as urea at about the late-jointing stage in approximately late March. In spring 2005, no N fertilizer was applied because a wheat stand was not established because of excessive moisture in fall 2004. In 2006 and 2007, only the high-residue plots were broadcast fertilized with only 56 kg N ha⁻¹ as urea in early March, followed by an additional 56 kg N ha⁻¹ in late March to reduce or eliminate the potential for carryover N to affect the subsequent soybean crop and any weeds that may grow differentially. Low-residue treatments did not receive any N fertilizer to ensure a residue-level difference was achieved. Brye et al. (2007) demonstrated that, at greater N fertilization rates and in the same plots as used in this study, neither nitrate-N, ammonium-N, nor total inorganic N (i.e., nitrate- plus ammonium-N) differed among residue levels in 2002 or 2003 when sampled following wheat, but prior to soybean. Thus, it was reasonably assumed that, at the lower N fertilization rates used in this study, there was no difference in carryover N from the wheat to affect early season soybean or weed growth and establishment differentially. Soil pH averaged 7.3, and SOM averaged 2.85 kg m⁻² in the top 10 cm in 2006 and 2007 (Amuri et al. 2008).

Standing wheat stubble was mowed each year to about 3 cm from the soil surface to create a uniform, residue-covered soil surface after wheat grain harvest in early June. Residue amounts from a single, representative location in each plot were quantified at this time by collecting the residue from a 0.25-m² metal frame followed by oven drying at ~ 55 C for 5 d and weighing. The burn treatment was then imposed, followed by tillage. Fire was controlled by 12-m–wide alleys between burn treatments that were disked multiple times to create a bare soil surface prior to actual burning. In 2005 and 2007, residue burning was not possible because of the absence of a wheat stand in spring 2005 because of wet conditions at planting and prolonged wet conditions in spring 2007. However, the weeds that were present comprised the residue treatment in 2005 and 2007. Tillage treatments consisted of either CT as disking twice to a depth of about 10 cm and seedbed smoothing or NT.

Glyphosate-resistant soybean ('Armor'—maturity group 5.3 for 2002 through 2005 and maturity group 5.4 for 2006 and 2007) were drill seeded in early to mid-June each year. Irrigation was performed as needed during the soybean growing season. In 2002 through 2004, all plots were furrow irrigated. In 2005, an irrigation treatment was added to the study so that thereafter, from 2005 through 2007, only one half of the plots were irrigated four to six times throughout the soybean growing season. The other half of the plots were left as dry land.

Pest management was performed uniformly in all plots on an as-needed basis. During the wheat growing season, thifensulfuron plus tribenuron-methyl was sprayed uniformly on all plots as per University of Arkansas Cooperative

Table 1. Summary of the combined weed species present during the 2006 and 2007 soybean growing seasons before (i.e., early season) and after (i.e., late season) herbicide application and their mean ($n = 96$) density throughout the whole study area in a wheat–soybean double-crop production system in the Mississippi River Delta region of eastern Arkansas. Standard errors are shown in parentheses.

Scientific name	Common name	Weed density	
		Early	Late
		Plants m ⁻²	
<i>Aeschynomene virginica</i> (L.) B.S.P.	Northern jointvetch	0	0.3 (0.1)
<i>Allium canadense</i> L.	Wild onion	0	0.8 (0.4)
<i>Amaranthus hybridus</i> L.	Smooth pigweed	76 (10)	0.7 (0.3)
<i>Amaranthus palmeri</i> S. Wats.	Palmer amaranth	4.6 (0.7)	0.2 (0.1)
<i>Bromus secalinus</i> L.	Cheat	30 (5)	0
<i>Campsis radicans</i> (L.) Seem. ex Bureau	Trumpet creeper	0.1 (0.1)	0.3 (0.1)
<i>Conyza Canadensis</i> (L.) Cronq.	Horseweed	0	0.2 (0.1)
<i>Cynodon dactylon</i> (L.) Pers.	Bermudagrass	0	0.02 (< 0.1)
<i>Cyperus esculentus</i> L.	Yellow nutsedge	0.8 (0.6)	0.9 (0.6)
<i>Cyperus iria</i> L.	Rice flatsedge	39 (6)	0
<i>Digitaria sanguinalis</i> (L.) Scop.	Large crabgrass	2.1 (0.5)	0
<i>Echinochloa crus-galli</i> (L.) Beauv.	Barnyardgrass	0.1 (0.1)	0
<i>Eclipta prostrata</i> (L.) L.	Eclipta	1.7 (0.5)	0
<i>Eleusine indica</i> (L.) Gaertn.	Goosegrass	8.6 (1)	0.1 (0)
<i>Euphorbia maculata</i> (L.)	Spotted spurge	9.3 (4.0)	0.4 (0.2)
<i>Ipomoea hederacea</i> var. <i>integriuscula</i> Gray	Entireleaf morningglory	1.3 (0.3)	0.9 (0.3)
<i>Ipomoea lacunosa</i> L.	Pitted morningglory	5.0 (1)	5.4 (1)
<i>Lamium amplexicaule</i> L.	Henbit	0	17 (4)
<i>Lepidium virginicum</i> L.	Virginia pepperweed	0.4 (0.1)	0
<i>Leptochloa filiformis</i> (Lam.) Beauv.	Red sprangletop	37 (4)	1.8 (0.5)
<i>Mollugo verticillata</i> L.	Carpetweed	60 (8)	0.3 (0.1)
<i>Oenothera laciniata</i> Hill	Cutleaf eveningprimrose	0.3 (0.1)	0
<i>Oxalis stricta</i> L.	Yellow woodsorrel	6.8 (2)	0.1 (0.1)
<i>Panicum dichotomiflorum</i> Michx.	Fall panicum	3.3 (0.8)	13 (3)
<i>Physalis angulata</i> L.	Cutleaf groundcherry	0.8 (0.3)	0
<i>Portulaca oleracea</i> L.	Common purslane	0.5 (0.3)	0.3 (0.1)
<i>Sida spinosa</i> L.	Prickly sida	7.8 (1)	4.8 (0.9)
<i>Trifolium pratense</i> L.	Red clover	0	0.04 (< 0.1)
<i>Trifolium repens</i> L.	White clover	2.0 (2)	0

Extension Service (UACES) recommendations (Cordell et al. 2006; UACES 2003a,b) in March each year, except in 2005, when there was no wheat stand, and in 2007, when herbicide application was not needed. Glyphosate was sprayed once approximately 10 to 20 d after planting (DAP) soybean at a rate of 0.75 kg ae ha⁻¹ as per recommendations by the University of Arkansas Cooperative Extension Service (UACES 2003a,b).

Weed Population Assessment. Weed species and population density assessments were conducted in two randomly located 0.25-m² sections in each plot by visual observation and identification. Weed population assessments were conducted twice during the 2006 and 2007 soybean growing seasons, once within 1 wk before herbicide application (early season) and again late in the growing season approximately 97 DAP. Weed species populations from the two locations per plot were averaged to obtain one weed density value per species per plot and converted to plants m⁻² before being subjected to statistical analysis.

Data Analysis

Weed density data were analyzed by analysis of variance (ANOVA) as per the split-strip plot design to determine the effects of tillage, burning, and residue level on weed population density. Because the blocking structure for the irrigation treatment coincided exactly with the blocking structure for the burn treatment, the irrigation treatment was not considered in the analysis of these data. Year (i.e.,

2006 and 2007) and season (i.e., early and late season) as a split-plot factor were included in the statistical model as fixed effects to determine treatment effects before and after herbicide application. Means were separated with the use of Fisher's protected LSD at $\alpha = 0.05$. All statistical analyses were performed with the use of the PROC MIXED procedure of SAS (SAS 9.1 2002).¹ Because irrigation was standardized until 2005, no irrigation difference existed throughout the entire 6-yr field study; thus potential irrigation treatment effects were not considered in this analysis.

Results and Discussion

Surface Residue Differences. In 2006, soil surface coverage by residue in the NT–no-burn treatment combinations was nearly 100%, and the mean residue level was greater ($P < 0.05$) in the high- (11,036 kg ha⁻¹) than in the low-residue treatment (6,455 kg ha⁻¹) (Amuri et al. 2008), whereas surface residue coverage after imposing the burn and CT treatment combinations was < 10%. In 2007, soil surface coverage by residue in all NT treatment combinations was also nearly 100%, and the mean residue level was also greater ($P < 0.05$) in the high- (9,381 kg ha⁻¹) than in the low-residue treatment (5,806 kg ha⁻¹; Amuri et al. 2008), and surface residue coverage after imposing the burn and CT treatment combinations was also < 10%.

Total Weed Species. During the 2006 and 2007 soybean growing seasons, 29 weed species were observed (Table 1). Of the species observed, weed population densities throughout

Table 2. Effect of tillage (conventional tillage [CT] and no tillage [NT]) and season on the densities of total weed species, broadleaf, perennial weeds, carpetweed (MOLVE), and goosegrass (ELEIN) in 2006 and 2007 in a wheat-soybean double-crop system in the Mississippi River Delta region of eastern Arkansas.

Year	Season	Tillage	All				
			species	Broadleaf	Perennial	MOLVE	ELEIN
			Plants m ⁻²				
2006	Early	CT	513	349	99	153	20
		NT	340	200	60	35	10
	Late	CT	48	18	4	1	0
		NT	48	20	< 1	1	< 1
2007	Early	CT	149	50	5	10	2
		NT	151	66	25	2	2
	Late	CT	32	30	1	0	0
		NT	60	55	2	< 1	< 1
¹ LSD _{0.05} ^a			57	43	20	14	5
² LSD _{0.05}			34	20	17	19	3
³ LSD _{0.05}			19	12	15	14	1

^a Least significant difference (LSD) at 0.05 level; ¹LSD_{0.05} for comparison of means within a column with different season at same year and tillage level; ²LSD_{0.05} for comparison of means within a column with different year at same tillage; ³LSD_{0.05} for comparison of means within a column with different tillage at the same year and season.

the whole study area were generally low, ranging from 0.02 aboveground shoots m⁻² for bermudagrass to 76 plants m⁻² for smooth pigweed (*Amaranthus hybridus* L.).

Total weed densities differed among tillage-year-season treatment combinations (P = 0.011). Total weed density was greater under CT (513 plants m⁻²) than NT (340 plants m⁻²) early in the 2006 growing season (Table 2). However, in 2007, NT had a greater total weed species density (60 plants m⁻²) than CT (32 plants m⁻²) late in the season (Table 2). Thus, reducing soil disturbance has the potential to reduce weed infestations early in the soybean growing season in the wheat-soybean double-crop system. Comparing between years, there was a greater total weed density in 2006 than 2007, but only early in the soybean growing season before herbicide application, whereas late in the soybean growing season, total weed density did not differ between years. These results indicate that the effectiveness of glyphosate on total weeds differed between CT and NT.

Other weed species with high densities (i.e., > 5 plants m⁻²) were carpetweed (*Mollugo verticillata* L.), cheat (*Bromus secalinus* L.), henbit (*Lamium amplexicaule* L.), red sprangletop [*Leptochloa filiformis* (Lam.) Beauv.], rice flatsedge (*Cyperus iria* L.), prickly sida (*Sida spinosa* L.), and pitted morningglory (*Ipomoea lacunosa* L.), which mostly occurred early in the soybean growing season before herbicide application, except for henbit, which only occurred late in the season. Other weed species with moderate densities (i.e., 2 to 5 plants m⁻²) included Palmer amaranth (*Amaranthus palmeri* S. Wats.), goosegrass [*Eleusine indica* (L.) Gaertn.], spotted spurge [*Chamaesyce maculata* (L.) Small], yellow woodsorrel (*Oxalis stricta* L.), fall panicum (*Panicum dichotomiflorum* Michx.), entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* Gray.), and large crabgrass [*Digitaria sanguinalis* (L.) Scop.] (Table 1).

The weed species observed in this study were similar to the most common weed species reported in a weed survey in the Mississippi River Delta region after 10 yr of adoption of glyphosate as the major weed control practice in the glyphosate-resistant soybean production system (Rankins et

Table 3. Effect of tillage (conventional tillage [CT] and no tillage [NT]), burning, residue level, and season on the density of grass weeds, red sprangletop (LEFFI), and prickly sida (SIDSP) in 2006 in a wheat-soybean, double-crop system in the Mississippi River Delta region of eastern Arkansas.

Year-Season	Tillage	Burning	Residue	Plants m ⁻²		
				Grasses	LEFFI	SIDSP
2006-Early	CT	Burn	High	71	43	11
			Low	44	24	
		No burn	High	73	35	4
			Low	74	43	
	NT	Burn	High	68	53	13
			Low	167	137	
		No burn	High	47	25	4
			Low	41	22	
2006-Late	CT	Burn	High	25	0	4
			Low	30	1	
		No burn	High	32	0	3
			Low	20	0	
	NT	Burn	High	68	0	21
			Low	47	0	
		No burn	High	10	0	3
			Low	22	0	
¹ LSD _{0.05} ^a				35	29	6
² LSD _{0.05}				17	14	NA
³ LSD _{0.05}				21	16	2
⁴ LSD _{0.05}				181	22	25

^a Least significant difference (LSD) at 0.05 level; ¹LSD_{0.05} for comparison of means within a column with different season at the same tillage and burning; ²LSD_{0.05} for comparison of means within a column with different burning at the same tillage and season; ³LSD_{0.05} for comparison of means within a column with different tillage at the same or different burning and season; ⁴LSD_{0.05} for comparison of means within a column with different burning at the same tillage, residue, and season; not applicable (NA).

al. 2005). Similar to this study, an abundance of carpetweed was observed early in the soybean growing season, which was attributed to the lack of use of preemergence herbicides (Rankins et al. 2005). Puricelli and Tuesca (2005) also reported a decrease in total weed density with the use of glyphosate, but late-emerging weed species increased in a wheat-soybean double-crop rotation and in continuous soybean and maize (*Zea mays* L.) systems in Argentina.

Grass Species. The density of grass weeds differed significantly among all treatment combinations (P = 0.023). The grass density early in the soybean growing season was greatest under the NT-burn-low-residue combination in 2006 (167 plants m⁻²) (Table 3) and NT-burn-high-residue combination in 2007 (139 plants m⁻²) (Table 4) compared to all other tillage-burning-residue treatment combinations within the given year. In contrast, the NT-no-burn combination had a lower grass density (41 to 47 plants m⁻² in 2006 and 56 to 63 plants m⁻² in 2007, respectively) than the CT-burn and no-burn and NT-burn (44 to 167 plants m⁻² in 2006 and 82 to 139 plants m⁻² in 2007, respectively) combinations early in the growing season in both years. Late in the growing season, the grass species density was lower (< 32 plants m⁻²) than early in the season at any tillage-burning-residue combination in 2007 (Tables 3 and 4), whereas in 2006 the NT-burn combination had a greater grass density (68 for the high- and 47 plants m⁻² for the low-residue treatment) than all other treatment combinations late in the season (Table 3). Though significant in only 1 of 2 yr, results suggest that retaining wheat residue (i.e., without burning) was sufficient to suppress the growth of grass weeds and that NT without surface residue was insufficient to reduce the grass density.

Table 4. Effect of tillage (conventional tillage [CT] and no tillage [NT]), burning, residue level, and season on the density of grass weeds, red sprangletop (LEFFI), and prickly sida (SIDSP) in 2007 in a wheat–soybean double-crop system, in the Mississippi River Delta region of eastern Arkansas.

Year–Season	Tillage	Burning	Residue	Plants m ⁻²		
				Grasses	LEFFI	SIDSP
2007–Early	CT	Burn	High	99	31	7
			Low	96	32	
	No burn	High	100	32	7	
		Low	88	16		
	NT	Burn	High	139	18	10
			Low	82	43	
No burn	High	63	18	6		
	Low	56	21			
2007–Late	CT	Burn	High	4	4	3
			Low	1	1	
	No burn	High	1	1	1	
		Low	2	0		
	NT	Burn	High	2	2	4
			Low	13	13	
No burn	High	3	2	1		
	Low	2	2			
¹ LSD _{0.05} ^a				35	29	6
² LSD _{0.05}				17	14	NA
³ LSD _{0.05}				21	16	2
⁴ LSD _{0.05}				181	22	25

^a Least significant difference (LSD) at 0.05 level; ¹LSD_{0.05} for comparison of means within a column with different season at the same tillage and burning level; ²LSD_{0.05} for comparison of means within a column with different burning at the same tillage and season level; ³LSD_{0.05} for comparison of means within a column with different tillage at the same burning and season level; ⁴LSD_{0.05} for comparison of means within a column with different burning at the same tillage, residue, and season; not applicable (NA).

Thus, retaining crop residues either on the soil surface or via incorporation into the soil by cultivation is an effective weed control method to suppress grasses. Davis (2007) suggested that the release of N from decomposing crop residue may provide microbes with additional inorganic N to increase weed seed predation, but reported that soil N fertility effects on weed seed mortality likely differed among weed species. Low grass species densities late in the growing season in all treatments indicated that no substantial residue interference occurred under either tillage treatment or in the presence of surface residue (i.e., in the no-burn treatment) for grass weed control.

Most grass weed seeds are small and require certain thermal fluctuations in the soil to trigger germination; thus placement of such seeds near the surface or at a shallow depth are essential for weed seed germination and growth (Liebman and Davis 2000). Cultivation or a soil disturbance that buries weed seed to a deeper depth and/or maintains a surface residue cover that affects soil thermal fluctuations can contribute to effective grass weed control (Cardina et al. 2002; Locke et al. 2002a,b) without repeated herbicide applications. Similar to this study, greater annual grass densities were observed under NT than CT when wheat residues were removed in clay–loam and sandy clay–loam soils (Fischer et al. 2002). Cardina et al. (2002) also observed greater grass seed densities under reduced tillage than NT in both continuous corn and in corn–soybean rotations in a silt–loam soil, suggesting greater survival of grass seed, hence greater grass weed occurrence under moderately disturbed soil than under nondisturbed soil. A greater total number of weed seedlings have also been observed under plowed than nonplowed soil (Froud-Williams et al. 1983). However, annual grasses were more prevalent in noncultivated and

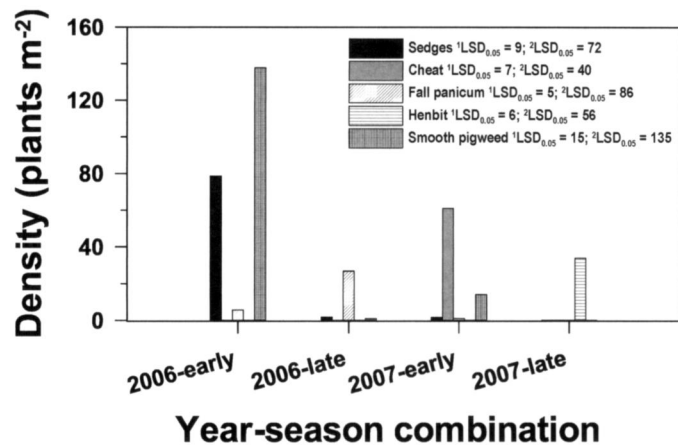
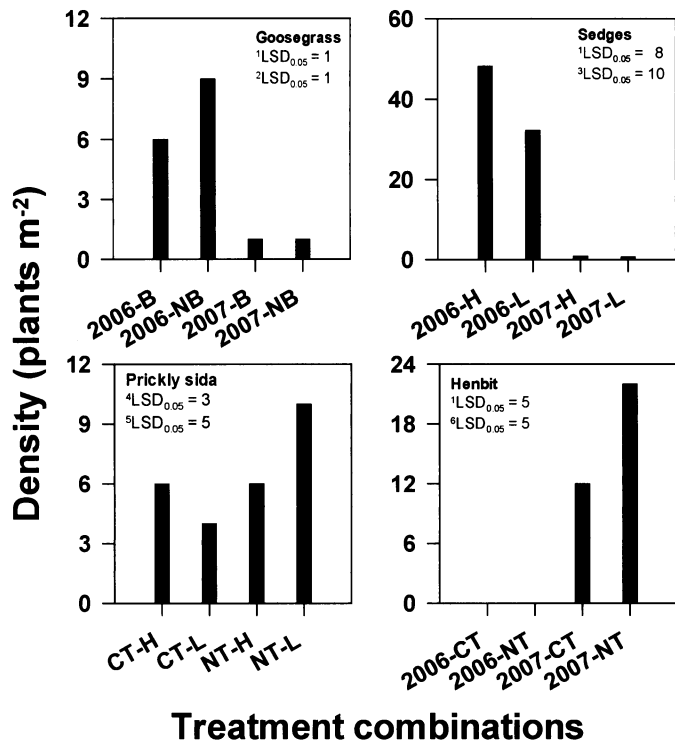


Figure 1. Effect of season (pre- [early] and postherbicide [late] application) on the population density of sedges, cheat, fall panicum, henbit, and smooth pigweed in 2006 and 2007 in a wheat–soybean double-crop production system in the Mississippi River Delta region of eastern Arkansas. LSD_{0.05} is the least significant difference at the 0.05 level. ¹LSD_{0.05} is for comparison of species means of different seasons in the same year. ²LSD_{0.05} is for comparison of species means with different years in the same or different season.

shallowly cultivated than in deep-plowed soil (Froud-Williams et al. 1983). Thus, greater grass weeds may occur under moderately disturbed soil than under undisturbed soil with a surface residue cover.

Among all grass weeds, cheat, fall panicum, goosegrass, and red sprangletop had moderate to high densities and were significantly affected by residue management practices. Cheat ($P = 0.001$) and fall panicum ($P = 0.001$) differed among year–season combinations, where cheat, a cool-season grass, was only observed in 2007 early in the soybean growing season (Figure 1). Fall panicum mostly occurred in 2006 and was greater late (27 plants m⁻²) than early in the soybean growing season (6 plants m⁻²) (Figure 1). Similarly, goosegrass was greater ($P = 0.037$) early (20 under CT and 10 plants m⁻² under NT) than late in the growing season (< 1 plants m⁻²) in both tillage treatments in 2006 (Table 2). Goosegrass density was greater ($P = 0.009$) under the no-burn (9 plants m⁻²) than under the burn treatment (6 plants m⁻²) in 2006 (Figure 2). In 2007, goosegrass densities were lower than in 2006 and did not differ among season and tillage treatment combinations (Table 2).

Similar to total grass density, red sprangletop density, which accounted for 40% of all grasses observed in this study, differed among tillage–burning–residue–year–season combinations. Red sprangletop density was greatest early in the soybean growing season under the NT–burn–low-residue combination (137 plants m⁻²) in 2006 compared to all other tillage–burning–residue–year–season combinations (< 53 plants m⁻²), whereas under CT, the burn and no-burn treatments had similar red sprangletop density (Table 3). Red sprangletop occurred mostly in 2006 early in the soybean growing season. The low red sprangletop density late in the soybean growing season shows that glyphosate was effective at controlling red sprangletop and other grasses. The red sprangletop density late in the soybean growing season did not differ between burning treatments in 2006 (Table 3), but in 2007, red sprangletop density was greater under the NT–burn–low-residue (13 plants m⁻²) than under NT–no-burn combination at either residue level (2 plants m⁻²) (Table 4). These results also suggest that the presence of wheat residue



Treatment combinations

Figure 2. Effect of tillage (conventional tillage [CT] and no-tillage [NT]), burning (burn [B] and no burn [NB]), and residue level (low [L] and high [H]) on the density of goosegrass, sedges, prickly sida, and henbit in 2006 and 2007 in a wheat–soybean double-crop production system in the Mississippi River Delta region of eastern Arkansas. $LSD_{0.05}$ is least significant difference at the 0.05 level. ¹ $LSD_{0.05}$ is for comparison of means of goosegrass, sedges, and henbit between years among the same tillage, burn, or residue level; ² $LSD_{0.05}$ is for comparison of means of goosegrass under different burn levels; ³ $LSD_{0.05}$ is for comparison of sedges under different residue levels; ⁴ $LSD_{0.05}$ is for comparison of means of prickly sida under different residue levels at the same level of tillage; ⁵ $LSD_{0.05}$ is for comparison of means of prickly sida under different tillage levels; ⁶ $LSD_{0.05}$ is for comparison of means of henbit under different tillage levels.

has the added advantage for red sprangletop control in addition to the use of glyphosate when using NT in the wheat–soybean double-crop rotation.

Sedge Species. Wheat residue management practices affected sedge species density, where the sedge density differed among year–residue ($P = 0.040$), year–season ($P = 0.001$), and tillage–burning–season ($P = 0.041$) treatment combinations. Sedge density was greater in 2006 than in 2007 and greater early than late in the growing season (Figure 1). In 2006, sedge density was greater under the high- (48 plants m^{-2}) than the low-residue treatment (32 plants m^{-2}) (Figure 2). Among tillage–burn–season combinations, sedge density was greater under CT–no-burn (201 plants m^{-2}) and CT–burn (198 plants m^{-2}) than under NT in combination with either burn (149 plants m^{-2}) or no burn (116 plants m^{-2}) early in the growing season before herbicide application in 2006 (Figure 3). In this study, sedge density was reduced with application of glyphosate. In contrast, Rankins et al. (2005) reported an increase in the occurrence of yellow nutsedge in glyphosate-resistant soybean production systems relative to preuse of glyphosate to control weeds, which was likely due to the known ineffectiveness of glyphosate on yellow nutsedge.

Broadleaf Species. Averaged across years, the density of broadleaf weeds was greater (99 standard error [SE] = 9

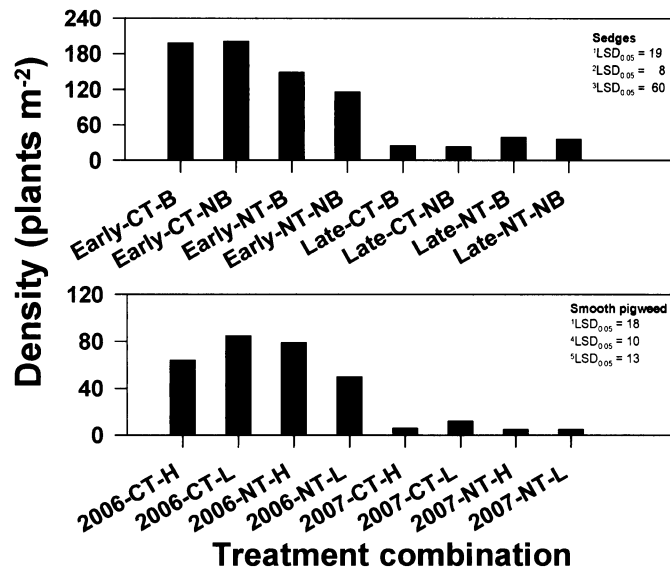


Figure 3. Effect of tillage (conventional tillage [CT] and no-tillage [NT]), burning (burn [B] and no burn [NB]), and residue level (low [L] and high [H]) on the density of sedges and smooth pigweed early and late in the soybean growing season in 2006 and 2007 in a wheat–soybean double-crop production system in the Mississippi River Delta region of eastern Arkansas. $LSD_{0.05}$ is the least significant difference at the 0.05 level. ¹ $LSD_{0.05}$ is for comparison of means of sedges and smooth pigweed with different seasons and years at the same burning or residue level, respectively, and same tillage; ² $LSD_{0.05}$ is for comparison of means of sedges with different tillage at same level of burning and season; ³ $LSD_{0.05}$ is for comparison of means of sedges with different burning level; ⁴ $LSD_{0.05}$ is for comparison of smooth pigweed with different residue level; ⁵ $LSD_{0.05}$ is for comparison of means of smooth pigweed with different tillage at the same residue and year level.

plants m^{-2}) compared to that of grass (49 [SE = 5] plants m^{-2}) and sedge (21 [SE = 4] plants m^{-2}) weed species throughout the whole study area. Mean broadleaf density was greater in 2006 (147 [SE = 17] plants m^{-2}) than in 2007 (50 [SE = 5] plants m^{-2}). Similar to grass and sedge species, broadleaf density was affected by tillage–year–season combinations ($P = 0.001$). The broadleaf density was greater early (349 for CT and 200 plants m^{-2} for NT) than late (18 plants m^{-2} for CT and 20 plants m^{-2} for NT) in the growing season at same level of tillage in 2006 (Table 2). In 2007, broadleaf density did not differ between seasons (< 67 plants m^{-2}) (Table 2).

Among broadleaf weeds, the density of carpetweed, henbit, pitted morningglory, prickly sida, and smooth pigweed were affected by the residue management practices investigated. Carpetweed density differed among tillage–year–season combinations ($P = 0.001$) and was greater in 2006 early in the growing season under CT (153 plants m^{-2}) than NT (35 plants m^{-2}). In 2007, carpetweed density did not differ between season and tillage treatments (Table 2). Pitted morningglory density differed among tillage–burning–residue–year combinations ($P = 0.047$) and was greater in 2006 under CT in combination with all burn–residue combinations (7 to 14 plants m^{-2}) than in 2007 (1 to 3 plants m^{-2}), but under NT, pitted morningglory density did not differ between years (Table 5). These results show that NT maintained a relatively low pitted morningglory density in both years. Norsworthy and Frederick (2005) also reported a lower pitted morningglory abundance under NT than CT in loamy sand soil in South Carolina, which was attributed to increased emergence under CT because of pitted morningglory’s large

Table 5. Effect of tillage (conventional tillage [CT] and no tillage [NT]), burning, and residue level on pitted morningglory (IPOLA) density in 2006 and 2007 in the Mississippi River Delta region of eastern Arkansas.

Year	Tillage	Burning	Residue	IPOLA Plants m ⁻²		
2006	CT	Burn	High	7		
			Low	10		
		No burn	High	14		
	NT	Burn	High	7		
			Low	< 1		
		No burn	High	3		
2007	CT	Burn	High	2		
			Low	1		
		No burn	High	2		
	NT	Burn	High	3		
			Low	2		
		No burn	High	6		
			Low	8		
		¹ LSD _{0.05} ^a				4
		² LSD _{0.05}				5
³ LSD _{0.05}				28		

^a Least significant difference (LSD) at 0.05 level; ¹LSD_{0.05} is for comparison of means with different year at same level of tillage, burning, and residue level; ²LSD_{0.05} is for comparison of means with different residue level at same level of tillage, burning, and year; ³LSD_{0.05} is for comparison of means with different burning at same level of tillage, residue, and year level.

seed size. Though not assessed in this study, relatively large weed seeds may become preferentially stratified near the soil surface during tillage such that they result in having better soil–seed contact for moisture and can receive more sunlight for germination than relatively small weed seeds that may fall deeper into the soil following surface disturbance by tillage.

The density of prickly sida was affected by tillage–residue ($P = 0.024$) and tillage–burning–year–season ($P = 0.045$) combinations. Prickly sida density was greater under the NT–low-residue (10 plants m⁻²) than all other tillage–residue combinations (Figure 2). In addition, prickly sida density was greater under burning in combination with NT in both years and in both seasons (10 to 20 plants m⁻²) than under nonburning at any tillage–year–season combination (1 to 7 plants m⁻²) (Tables 3 and 4). Similar to grasses, surface residue removal in the absence of cultivation appears to have stimulated germination and growth of prickly sida.

The results of this study indicate that CT and NT in the presence of a high level of surface residue can reduce the density of most broadleaf weeds. In contrast, Reddy (2001) reported no effect of surface residue on prickly sida density. Similar to this study, Anderson (2005) reported reduced weed seedling emergence under NT with > 2,000 kg ha⁻¹ of crop residue. In this study, the high-residue treatment with the low prickly sida density had average surface residue cover of 14.7 Mg ha⁻¹ in 2006 and 9.8 Mg ha⁻¹ in 2007 at the time of soybean planting compared to 8.7 and 6.2 Mg ha⁻¹ in 2006 and 2007, respectively, in the low-residue treatment. Nguojio et al. (2003) also reported few weed species and a low weed density under NT with surface residue both early and late in the season in sandy loam soils in California.

The density of smooth pigweed differed among year–season ($P = 0.001$) and tillage–residue–year ($P = 0.013$) combinations. Most of the smooth pigweed occurred in 2006 early in the season with a mean density of 138 plants m⁻² compared to 14 plants m⁻² in 2007 (Figure 1), which did not differ

among tillage and residue treatments (Figure 3). With the incidence of glyphosate-resistant pigweed increasing in eastern Arkansas and the mid-South in general, the combination of alternative residue management practices and chemical control measures may also become increasingly important for pigweed management.

Cutleaf eveningprimrose (*Oenothera laciniata* Hill), henbit, and northern jointvetch (*Aeschynomene virginica* L.) were affected by residue management practices, and some management practices appeared to have effective control of these species. Cutleaf eveningprimrose also occurred in low densities under the NT–low-residue treatment combination only in both years, which was similar to that previously observed by Locke et al. (2002b). Henbit, a winter annual, was not observed in 2006, but was present in 2007 late in the growing season only (Figure 1) and was greater under NT than CT (Figure 2). Legere et al. (2008) also reported greater weed species diversity under NT than CT despite statistically similar weed species densities between tillage treatments in soybean production in clay and clay–loam soils in Canada.

Perennial Species. Perennial weed density was affected by tillage–year–season ($P = 0.006$) and burn–year–season ($P = 0.020$) combinations. Similar to total weeds and broadleaf weeds, perennial weed density was greater early than late in the growing season in 2006 (Table 2). In 2007, perennial weed density was also greater early than late in the season, but only under NT (Table 2). Under CT, the perennial weed density was similar between seasons (5 and 2 plants m⁻² early and late in the season, respectively) (Table 2). Though weed control was not measured in this study, results indicate that perennial weeds were effectively controlled by glyphosate application under both CT and NT.

Among burning–year–season treatment combinations, perennial weed density was greater under burn (99 plants m⁻²) than no burn (59 plants m⁻²) early in the growing season in 2006, but did not differ between burn treatments in 2007 (12 and 18 plants m⁻² under burn and no burn, respectively). The lack of a burning effect in 2007 may be due to retaining crop residues under the burn treatment in 2007, because the burn treatment was not possible to impose because of prolonged wet conditions in spring 2007. However, in both burn–year combinations, perennial weed density was similar late in the season after herbicide application (< 5 plants m⁻²). Retaining crop residue without burning suppressed perennial weeds by 40% early in the season before herbicide application. Similar to these results, Norsworthy (2008) reported an increase in perennial weed density under NT in the absence of glyphosate application, but no increase occurred when glyphosate was applied in a soybean–corn rotation in South Carolina.

Among the perennial weeds observed in this study, rice flatsedge and yellow woodsorrel had moderated to high densities throughout the study and were also significantly affected by residue management practices. The density of rice flatsedge differed among burning–year–season ($P = 0.020$) combinations and was greater under burn (31 and 64 plants m⁻² in 2006 and 2007, respectively) than under no burn (22 and 31 plants m⁻² in 2006 and 2007, respectively) in both years early in the growing season, but was lower later in the season under both burning treatments (Figure 4). Yellow woodsorrel occurred in low density under NT only in 2006 (1

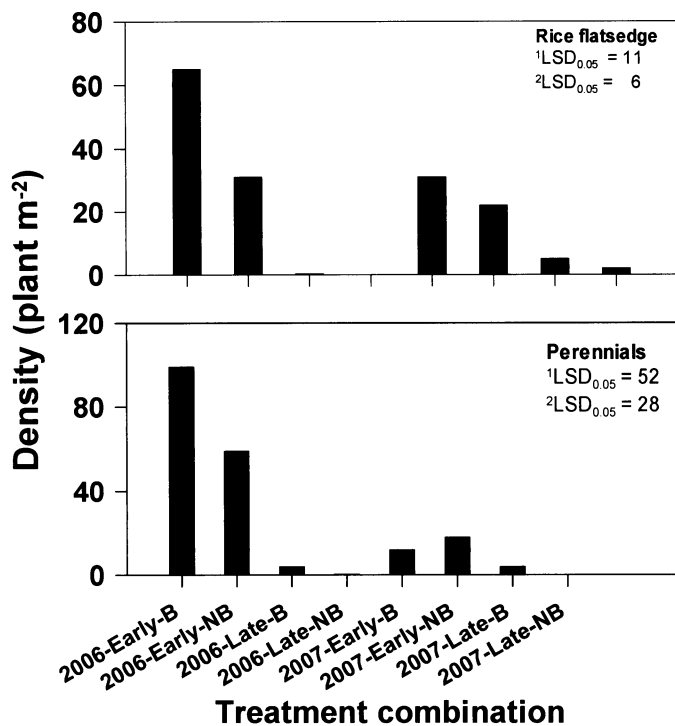


Figure 4. Effect of wheat residue burning (burn [B] and no burn [NB]) and season (pre- [early] and postherbicide [late] application) on rice flatsedge and perennial weed density in 2006 and 2007 in a wheat–soybean double-crop system in the Mississippi River Delta region of eastern Arkansas. LSD_{0.05} is least significant difference at the 0.05 level. ¹LSD_{0.05} is for comparison of means with different year–season combinations at same burning level; ²LSD_{0.05} is for comparison of means with different burning at the same year–season combination.

plant m⁻²). In 2007, yellow woodsorrel density was greater under NT in combination with either residue level early in the growing season (13 to 36 plants m⁻²) than in all other tillage–residue–year–season combinations. However, in both years, yellow woodsorrel density was lower late than early in the growing season, indicating effective control by glyphosate application.

Although the density of trumpetcreeper [*Campsis radicans* (L.) Seem. ex Bureau] was unaffected by residue management practices, trumpetcreeper was not observed under CT in either year. These results suggest that cultivation and retaining crop residue without burning may be an effective control measure for perennials by disrupting the rhizomes. Bilalis et al. (2003) observed the greatest perennial weed biomass under NT with no surface cover compared to CT with and without the presence of surface cover in a clay–loam soil in Greece, which was attributed to the lack of disturbance of lateral roots, stolons, and rhizomes under NT.

In this study, a low density of Virginia pepperweed (*Lepidium virginicum* L.) (1.5 plant m⁻²) occurred in the NT treatment only. Although in low densities, it appears that the NT and low- residue/residue-removal treatments are likely to have more diverse weed species than the CT–high-residue treatments before or in the absence of herbicide applications. These results show that reduced tillage or NT can decrease weed densities, but without sufficient crop residues covering the soil surface, weed species composition may be increased under NT.

The difference in weed densities between the 2 yr of this study could be associated with differences in weather conditions. The mean precipitation early in the soybean season (June and July) was 67% greater in 2007 than in 2006.

Table 6. Summary of soybean yields under tillage (conventional tillage [CT] and no-tillage [NT]) –burn–residue treatment combinations during the weed assessment period in 2006 and 2007 in the Mississippi River Delta region of eastern Arkansas. Standard errors are reported in parentheses.

Tillage	Burning	Residue	Soybean yield	
			2006	2007
			Mg ha ⁻¹	
CT	Burn	Low	2.57 (0.6)	1.96 (0.2)
	No burn	High	2.57 (0.5)	2.13 (0.3)
	Burn	Low	2.23 (0.5)	1.72 (0.2)
NT	No burn	High	2.15 (0.5)	2.02 (0.2)
	Burn	Low	2.29 (0.6)	1.97 (0.3)
	No burn	High	2.39 (0.6)	1.86 (0.2)
	Burn	Low	1.79 (0.4)	1.98 (0.3)
	No burn	High	2.09 (0.3)	2.07 (0.2)

Adequate moisture supplied by rainfall early in the growing season may have favored faster soybean growth and canopy closure in 2007 than in 2006, resulting in a reduction of most weed species in 2007 compared to that in 2006. In addition, the absence of the actual burn treatment in 2007 may have contributed to a reduction of most weed species in 2007 compared to that in 2006. Norsworthy (2008) also reported variation in weed species density from year to year and a general decrease in density of grass and broadleaf weeds after 4 yr of tillage and herbicide application.

Weed Effects on Grain Yield. Successful integrated weed management practices in agricultural systems are determined not only by adequate levels of weed control, but also by their effect on crop yield. Because most weed species densities differed between tillage, burn, and residue-level treatments, soybean yield under these treatment combinations were used to assess the effect of weeds on crop production. In the 2 yr of weed assessment, which corresponded to the fifth and sixth year of consecutive residue management practices, soybean yield was unaffected by tillage, burn, and residue treatments (Table 6; Verkleer 2007). Soybean yields under CT were numerically greater than under NT, despite greater weed species density under CT early in the soybean growing season and similar weed density between tillage treatments late in the season, indicating no significant effect of weed pressure early in the season before herbicide application on soybean yield.

Similar to this study, Swanton et al. (2002) reported similar soybean and corn yields among weed management practices despite differences in weed densities under NT in a silt–loam soil in Canada. In this study, NT appears to have greater weed species composition and numerically lower soybean yields than CT. Reddy et al. (2003) also reported similar soybean yield between CT and NT treatments and crop covers (i.e., rye cover crop and no cover crop), but greater yield when herbicide was applied postemergence than when no herbicide was applied in a silt–loam soil in Mississippi. In addition, pre- and postemergence herbicide applications had similar soybean yields as the postemergence herbicide application in the presence of a surface residue cover (Reddy et al. 2003). The results of this and previous studies show that integrating weed control with a herbicide and retaining soil surface residue cover have the potential to reduce weed problems relative to burning and CT, and maintain soybean yields while reducing the frequency of herbicide applications and improving farm profitability.

Management Implications. The results of this study, which represents the cumulative effects of 5 and 6 yr of consistent residue management, provide evidence that if properly managed, little to no increase over time in weed problems can be realized in a continuous, wheat–soybean double-crop rotation. However, it appears that the effectiveness of glyphosate on total weed density may differ between tillage treatments. Though weed control was not specifically measured, low densities of early emerging weed species and grasses late in the soybean growing season show that glyphosate applied at recommended rates appears to provide sufficient control of weeds in soybean in eastern Arkansas. Retaining crop residues on the surface without burning combined with either shallow cultivation or NT reduced densities of grasses, prickly sida, and cutleaf eveningprimrose. Therefore, the NT, no-burn, and high-residue treatments appeared to contribute significantly to the suppression of most weed species, which suggests that alternative residue management practices could at least delay the development of potential glyphosate resistance due to their effective weed suppression. The CT, residue burning, and low-residue treatments likely had more safe sites associated with them for weed germination and growth than the NT, no-burn, and high-residue treatments. In addition, this study provides a baseline for future weed assessments to determine trends in potential weed species shift after a greater duration of consistent alternative residue management practices in a wheat–soybean double-crop system in the Mississippi River Delta region of eastern Arkansas.

Sources of Materials

¹ SAS 2002 (version 9.1) SAS Institute, Inc., 100 SAS Campus Drive, Cary, NC 27513-2414.

Acknowledgments

We thank the Lon Mann Cotton Research Station field personnel, Claude Kennedy, and Bill Apple for maintaining the research plots and for assistance in various field activities. The assistance from Tarra Verkler and Lee Riley and technical support on weed identification from the weed science research group, especially Dr. Mohammed Bararpour, Dr. Chad Brewer, and Franklin Lyons is highly appreciated. Funding for this study was provided by the Arkansas Soybean Research and Promotion Board.

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Received May 26, 2009, and approved August 18, 2009.