Survey of Tillage Trends Following the Adoption of Glyphosate-Resistant Crops

Wade A. Givens, David R. Shaw, Greg R. Kruger, William G. Johnson, Stephen C. Weller, Bryan G. Young, Robert G. Wilson, Micheal D. K. Owen, and David Jordan*

A phone survey was administered to 1,195 growers in six states (Illinois, Indiana, Iowa, Mississippi, Nebraska, and North Carolina). The survey measured producers' crop history, perception of glyphosate-resistant (GR) weeds, past and present weed pressure, tillage practices, and herbicide use as affected by the adoption of GR crops. This article describes the changes in tillage practice reported in the survey. The adoption of a GR cropping system resulted in a large increase in the percentage of growers using no-till and reduced-till systems. Tillage intensity declined more in continuous GR cotton and GR soybean (45 and 23%, respectively) than in rotations that included GR corn or non-GR crops. Tillage intensity declined more in the states of Mississippi and North Carolina than in the other states, with 33% of the growers in these states shifting to more conservative tillage practices after the adoption of a GR crop. This was primarily due to the lower amount of conservation tillage adoption in these states before GR crop availability. Adoption rates of no-till and reduced-till systems increased as farm size decreased. Overall, producers in a crop rotation that included a GR crop shifted from a relatively more tillage-intense system to reduced-till or no-till systems after implementing a GR crop into their production system.

Nomenclature: 2,4-D, glyphosate; corn, *Zea mays* L.; cotton, *Gossypium hirsutum* L; soybean, *Glycine max* (L.) Merr.
Key words: Tillage system, glyphosate, farmer survey.

Tillage has been an integral part of production agriculture and is synonymous with seedbed preparation and POST weed control (Reicosky and Allmaras, 2003). Tillage has also been important for insect and disease management through the burial of crop residue. Since the early 1920s, there have been advocates for the reduction of tillage (Graber 1928) to minimize the detrimental effects of tillage to the landscape, such as soil erosion and runoff of pesticide residues and mineral nutrients (Fawcett et al. 1994; Karlen et al. 1994; Smart and Bradford 1999; Swanton and Weise 1991). Reduced-tillage systems also have the potential to decrease input costs because of fewer tillage operations (CTIC 2008).

Despite the negative environmental effects of tillage, it remained an important tool for managing weeds before the planting of crops and after their emergence, but before full crop canopy (Gunsolus 1990; Stoller and Wax 1973). Tillage was used to destroy perennial crops before seeding annual crops (Tripplett 1985). With the introduction of 2,4-D in the mid-1940s, producers were, for the first time, given an economical chemical alternative to tillage for preplant weed control (Burnside, 1996). The introduction of numerous other herbicides in the succeeding decades allowed reduced and conservation tillage systems to become more feasible and popular. The introduction of glyphosate-resistant (GR) crops in 1996 brought a technology that enabled many producers to adopt reduced-tillage production systems.

Glyphosate controls a wide spectrum of broadleaf and grass weeds (Burke et al. 2005; Corbett et al. 2004, Culpepper and York 1998; Wilcut and Askew 1999; Wilcut et al. 1999). In 2005, more than 90% of the total U.S. soybean and cotton crops produced, along with nearly 50% of the corn crop produced, contained an herbicide-tolerant gene (Sankula 2006). In 2003, global use of herbicide-tolerant soybean reached 60% (James 2005). The introduction of GR crops allowed producers to apply POST glyphosate as an effective tool for weed management. The use of glyphosate for weed control quickly began to replace preplant tillage, POST cultivation, and other selective herbicides as a more economical method of weed control.

Grower surveys have been used in the past to document changes in management practices and grower perceptions to potential problems. Issues that surveys have measured include irrigation practices, insect pressure, pesticide use, and herbicide-resistant weeds and the use of herbicide-resistant crops (Dillard 1993; Snyder 1996). Grower surveys have been especially important to weed science because they have allowed scientists to gain insight on a number of grower perceptions and practices. Examples include grower herbicide use and grower perceptions of items such as herbicide resistance in weeds and herbicide-resistant crop use (Charles 1991; Gibson et al 2005, 2006; Johnson and Gibson 2006; Llewellyn et al. 2002).

It has been a decade since the introduction of the first GR crop. During that time, herbicide use patterns have changed as growers have learned to optimize weed management with this technology. Shifts in weed species and biotypes have been observed, and growers' use of tillage has changed. The purpose of this article is to document the effect of GR crop use on producer's tillage practices. The data for this article is a subset from a data set generated from a telephone survey of 1,195 producers in six states that was conducted between November 9, 2005, and January 6, 2006 (Shaw et al. 2008).

DOI: 10.1614/WT-08-038.1

* Research Associate and Professor, Mississippi State University, Box 9652, Mississippi State, MS 39762; Graduate Research Assistant, Associate Professor, and Professor, Purdue University, West Lafayette, IN 47907; Professor, Southern Illinois University, Carbondale, IL 62901; Professor, University of Nebraska, Scottsbluff, NE 69361; Professor, Iowa State University, Ames, IA 50011; and Professor, North Carolina State University, Raleigh, NC 27606. Corresponding author's E-mail: wgivens@gri.msstate.edu

Table 1. Answer matrix showing computation of change variable. The change variable is used in all corresponding analyses.

Tillage before	Value assigned	Tillage after	Value assigned	Equation	Change value
Conventional tillage	3	No till	1	$3 - 1$	2
Conventional tillage	3	Reduced till	2	$3 - 2$	1
Reduced till	2	No till	1	$2 - 1$	1
Conventional tillage	3	Conventional tillage	3	$3 - 3$	0
Reduced till	2	Reduced till	2	$2 - 2$	0
No till	1	No till	1	$1 - 1$	0
No till	1	Reduced till	2	$1 - 2$	-1
Reduced till	2	Conventional tillage	3	$2 - 3$	-1
No till	1	Conventional tillage	3	$1 - 3$	-2

Materials and Methods

The survey was developed by a team of weed scientists and was used in a telephone poll of producers from Iowa, Illinois, Indiana, Mississippi, North Carolina, and Nebraska. A total of 1,195 producers were surveyed (~200 per state). The survey consisted of four sections: cropping history, weed pressure and tillage practices, herbicide use, and GR weeds. Respondents were asked to focus their answers on one specific representative field. Complete details on the survey, including the methodology used, are reported in an introductory article for this series by Shaw et al. (2009). This article focuses on the tillage practice data generated from the weed pressure and tillage section of the survey; in particular, what tillage practices were used before and after the adoption of GR crops.

SAS[1] was used to test for marginal homogeneity using the procedure CATMOD. This procedure is a different technique for doing categorical data analysis that is based on the transformation of cell probabilities. Marginal homogeneity, in the context of this study, is the likelihood that a producer remains in a particular tillage system after the adoption of a GR crop. Data were tested overall for marginal homogeneity and then tested by each crop rotation, state, and farm size (small, medium, and large). Farm size categories were determined by the hectares in production for each grower with < 220 ha $=$ small, 220 to 440 ha $=$ medium, and > 440 ha $=$ large.

For multiple comparisons tests, a change variable was calculated to determine whether farm size, crop rotation, or state affected the change in tillage practice. Each tillage system was coded from 1 to 3, with no-till systems receiving a value of 1, reduced-tillage receiving a value of 2, and conventional tillage receiving a value of 3. The difference was calculated by subtracting the tillage after GR crop adoption from tillage before GR crop adoption. The values for the change variable are presented in Table 1. The generalized linear model (GLM) procedure in SAS was used on the absolute value of the change variable to separate the means at the 0.05 significance level for each set of analyses.

Results and Discussion

Change in Tillage Practice After Adoption of GR Crop. A large percentage of growers surveyed shifted toward reduced-till or no-tillage systems after adopting GR crops as part of their crop rotation. Of producers who had been in conventional tillage, 25% transitioned to no-till and 31% transitioned to reduced-till systems after adopting GR crops (Table 2). Twenty-five percent of producers who had been in reduced-till systems converted to no-till systems, and 74% remained in reduced-till after adopting GR crops. The majority (92%) of producers that were in a no-till system before GR crop introduction remained in a no-till system after their implementation of a GR cropping system. Each tillage system differed from the other with respect to the amount of change after adopting a GR crop, with growers in conventional tillage having the largest amount of change after adopting a GR crop.

Table 2. Analysis of survey data highlighting shifts in tillage systems before and after implementation of a glyphosate-resistant (GR) cropping system, averaged across states and cropping systems. Individual values represent the current distribution (in percent) among the tillage practices for farms that originated in each of the three tillage system (before implementation of GR crops).[a]

Tillage system before GR crop	Tillage system after GR crop: No till	Reduced till	Conventional till	Total	Separated means[b,c]
	% (No. of responses)				
Conventional till	25 (119)	31 (150)	44 (214)	37 (483)	a
Reduced till	25 (122)	74 (365)	2 (9)	38 (496)	b
No till	92 (293)	6 (18)	3 (8)	25 (319)	c
Total	41 (534)	41 (533)	18 (231)	100 (1,298)[d]	

[a] Vertical totals indicate the percentage in each tillage system before GR crop implementation; horizontal totals indicate the percentage in each tillage system after GR crop implementation. All changes in tillage practices were significant at the 0.05 level.

[b] Tillage practices before GR crop adoption sharing the same letter(s) are not significantly different ($P = 0.05$) with respect to change in tillage practices.

[c] Mean separation is based on analysis of the absolute value of the change variable as calculated in Table 1.

[d] Number of responses is larger than total respondents in survey. Respondents were able to answer for up to two crop rotations.

Changes in Tillage System as Affected by Cropping System. Marginal homogeneity tests demonstrated significant effects by cropping systems on the change of tillage practices. Data in Table 3 show that farmers in all cropping systems increased their use of conservation tillage systems after adopting GR crops. The largest decline in conventional tillage occurred in continuous GR cotton, with 46% of the growers in conventional tillage systems shifting to reduced-till or no-till systems (Table 3). These results agree with reports from Gianessi (2005) and Toler et al. (2002), who found that cotton producers made fewer tillage operations after planting GR cotton. Cotton producers were often reluctant to adopt reduced-till or no-till systems before the introduction of GR cotton because of low yields and poor quality from early season weed competition (Derting 1990). An integrated program that used tillage and PRE herbicides was typically the only means of successful weed control and maximized returns (Barnes and Whitmore 1990; Keeling and Abernathy 1989). Thus, conservation tillage adoption in cotton had been low, which also meant that the opportunity for adoption was greatest when an effective weed control tool, such as a GR system, became available. These data clearly demonstrate that

Table 3. Analysis of survey data highlighting shifts in tillage systems before and after implementation of a glyphosate-resistant (GR) cropping system by cropping system. Individual values represent the current distribution (in percent) among the tillage practices for farms that originated in each of the three tillage system (before implementation of GR crops).[a]

		Tillage system after GR crop				
Crop rotation	Tillage system before GR crop	No till	Reduced till	Conventional till	Total	Separated means[b,c]
		% (No. of responses)				
Continuous GR cotton	No till	93 (14)	7 (1)	0 (0)	16 (15)	a
	Reduced till	10 (1)	90 (9)	0 (0)	11 (10)	
	Conventional till	29 (19)	33 (22)	38 (25)	73 (66)	
	Total	37 (34)	35 (32)	28 (25)	100 (91)	
Continuous GR soybean	No till	90 (77)	5 (4)	5 (4)	29 (85)	a
	Reduced till	44 (37)	52 (43)	4 (3)	28 (83)	
	Conventional till	36 (47)	24 (31)	40 (51)	43 (129)	
	Total	54 (161)	26 (78)	20 (58)	100 (297)	
GR soybean/non-GR crop	No till	89 (81)	9 (8)	2 (2)	20 (91)	b
	Reduced till	19 (37)	78 (153)	3 (5)	43 (195)	
	Conventional till	17 (29)	39 (66)	44 (73)	37 (168)	
	Total	32 (147)	50 (227)	18 (80)	100 (454)	
GR corn/GR soybean	No till	94 (103)	4 (4)	2 (2)	29 (109)	b
	Reduced till	23 (39)	76 (129)	1 (1)	44 (169)	
	Conventional till	20 (20)	26 (27)	54 (55)	27 (102)	
	Total	43 (162)	42 (160)	15 (58)	100 (380)	
GR corn/non-GR crop	No till	95 (18)	5 (1)	0 (0)	25 (19)	b
	Reduced till	21 (8)	79 (31)	0 (0)	51 (39)	
	Conventional till	22 (4)	22 (4)	56 (10)	24 (18)	
	Total	40 (30)	47 (36)	13 (10)	100 (76)	

[a] Vertical totals indicate the percentage in each tillage system before GR crop implementation; horizontal totals indicate the percentage in each tillage system after GR crop implementation. Changes in tillage practices were significant at the 0.05 level for each crop rotation.

[b] Crop rotations sharing the same letter or letters are not significantly different ($P = 0.05$) with respect to change in tillage practices.

[c] Mean separation is based on analysis of the absolute value of the change variable as calculated in Table 1.

cotton producers were quite willing to adopt conservation tillage when there was a means of effectively controlling weeds, especially when it was a tool as simple as POST glyphosate.

Continuous GR soybean had the next highest adoption rates of conservative tillage practices, with 23% of the growers in conventional tillage systems shifting to reduced-till or no-till systems (Table 3). Weed control in no-till cropping systems is dependent on effective POST options for weed control (Kapusta and Krausz 1993). The introduction of selective broadleaf herbicides, such as chlorimuron, imazaquin, and imazethapyr, gave growers more effective POST options for weed control. POST grass herbicides, such as sethoxydim, fluazifop, and quizalofop, came to market soon after, but their use was somewhat limited because of price and antagonism when tank-mixed with the broadleaf herbicides (Krumm and Martin 1999; Pike et al. 1991). With the introduction of GR soybean in 1996, growers were able to use a single, wide-spectrum material for weed control, enabling rapid adoption of no-till systems. Between 1990 and 2000, no-till acreage rose from 6,474,980 to 21,043,690 ha, an increase of 225% (CTIC 1999).

Growers in GR soybean/non-GR crop rotations reported a shift of 17 and 39% to no-till and reduced-tillage, respectively (Table 3). GR technology has enabled many producers to remove fall and spring tillage practices from their management operations and to use herbicides exclusively for weed control. This finding is supported by Moseley and Hagood (1990), who found that glyphosate provided effective control of weeds before crop emergence. With an economical alternative to tillage, preplant tillage operations can justifiably be replaced with an herbicide treatment to remove winter annuals before planting. This can make conservative tillage practices more feasible.

In the corn production systems, the change in tillage practice from conventional till to no-till or reduced-till were lower (12 and 11%, respectively) (Table 3). Many of the growers in corn production systems had already adopted conservative tillage practices. Growers in 76% of GR corn/non-GR crop rotations, 73% of GR corn/GR soybean rotations, and 63% of GR soybean/non-GR crop rotations were already using conservative tillage practices before the adoption of a GR crop into their rotations.

Many portions of the Corn Belt's topography range from level to gently rolling to hilly, heavily dissected landscapes. This region falls into the 30% of the nation's cropland in which soil erosion is the dominant limitation in agricultural production. This cropland's potential contribution to watershed sediment yield is very high (USDA-ARS 1975). In response, conservation efforts were targeted in these areas, and from 1973 to 1981, the number of reduced-till hectares increased 125%, and no-till planting increased 78% (Christensen and Magleby 1983). These areas were using conservation tillage practices before the introduction of GR crops.

Changes in Tillage System as Affected by State. The states with the highest percentage of growers shifting from conventional tillage to reduced-till and no-till were Mississippi and North Carolina; 33% of growers from each state shifting to more conservation tillage practices after adopting a

Table 4. Analysis of survey data highlighting shifts in tillage systems before and after implementation of a glyphosate-resistant (GR) cropping system by state. Individual values represent the current distribution (in percent) among the tillage practices for farms that originated in each of the three tillage system (before implementation of GR crops).[a]

State	Tillage system before GR crop	Tillage system after GR crop				Separated means[b,c]
		No till	Reduced till	Conventional till	Total	
		% (No. of responses)				
Illinois	No till	83 (38)	15 (7)	2 (1)	21 (46)	bc
	Reduced till	22 (19)	77 (68)	1 (1)	40 (88)	
	Conventional till	11 (9)	21 (18)	68 (57)	39 (84)	
	Total	30 (66)	43 (93)	27 (59)	100 (218)	
Indiana	No till	94 (73)	5 (4)	1 (1)	34 (78)	b
	Reduced till	29 (25)	70 (61)	1 (1)	38 (87)	
	Conventional till	27 (18)	27 (18)	46 (30)	28 (66)	
	Total	50 (116)	36 (83)	14 (32)	100 (231)	
Iowa	No till	98 (44)	2 (1)	0 (0)	20 (45)	c
	Reduced till	11 (14)	88 (108)	1 (1)	55 (123)	
	Conventional till	11 (6)	35 (19)	54 (29)	24 (54)	
	Total	29 (64)	58 (128)	13 (30)	100 (222)	
Mississippi	No till	68 (15)	5 (1)	27 (6)	11 (22)	a
	Reduced till	25 (13)	65 (34)	10 (5)	27 (52)	
	Conventional till	22 (27)	41 (49)	37 (45)	62 (121)	
	Total	28 (55)	43 (84)	29 (56)	100 (195)	
Nebraska	No till	97 (57)	3 (2)	0 (0)	26 (59)	b
	Reduced till	31 (36)	68 (80)	1 (1)	52 (117)	
	Conventional till	33 (16)	46 (22)	21 (10)	22 (48)	
	Total	49 (109)	46 (104)	5 (11)	100 (224)	
North Carolina	No till	96 (66)	4 (3)	0 (0)	33 (69)	a
	Reduced till	52 (15)	48 (14)	0 (0)	14 (29)	
	Conventional till	39 (43)	22 (24)	39 (43)	53 (110)	
	Total	60 (124)	20 (41)	20 (43)	100 (208)	

[a] Vertical totals indicate the percentage in each tillage system before GR crop implementation; horizontal totals indicate the percentage in each tillage system after GR crop implementation. Changes in tillage practices were significant at the 0.05 level for each state.

[b] States sharing the same letter or letters are not significantly different ($P = 0.05$) with respect to change in tillage practices.

[c] Mean separation is based on analysis of the absolute value of the change variable as calculated in Table 1.

GR crop into their crop rotations (Table 4). In Mississippi, 22 and 41% of the growers in conventional tillage systems shifted to no-till and reduced-till systems, and in North Carolina, 39 and 22% of growers in conventional tillage shifted to no-till and reduced-till farming. These states are also the areas of cotton production in the survey. Results from the crop rotation analysis indicated that areas in continuous GR cotton production had the highest shifts from conventional tillage to reduced-till and no-till systems. This, coupled with the continuous GR soybean production in these two states, validates the results of the tillage system change by state analysis.

Nebraska, Indiana, Illinois, and Iowa also saw an increase in the percentage of growers adopting reduced-till and no-till practices with increases of 17, 14, 12, and 11%, respectively (Table 4). These states are major corn-producing states. These results are in agreement with those of the crop-rotation analysis in that the lowest adoption of conservation tillage practices occurred within rotations that contained GR corn or conventional corn. Of the corn producing states, Nebraska had the highest percentage of growers adopting conservation tillage practices, with 49 and 46% of the growers in conventional tillage shifting to no-till and reduced-till, respectively.

A topic of interest is that Nebraska, Iowa, Indiana, and Illinois also had the highest percentages of growers using no-till and reduced-till practices before the adoption of a GR crop. Seventy-eight percent of growers in Nebraska, 75% of growers in Iowa, 72% of growers in Indiana, and 61% of growers in Illinois were using conservative tillage practices before the adoption of GR crops into their crop rotations. The previous analysis indicated that crop rotations containing corn had higher percentages of growers using conservative tillage practices before adopting a GR crop. Reasons for this are discussed in the previous section.

Changes in Tillage System as Affected by Farm Size. The largest reduction in conventional tillage came from producers with smaller farms, with 30 and 25% of growers shifting from conventional tillage to no-till and reduced-till practices, respectively (Table 5). One possible reason for this high rate of adoption is that GR crops have enabled producers to eliminate tillage trips across the fields and to control weeds using glyphosate vs. PRE and selective herbicides in season, resulting in a savings to the producer. Taking into account the decrease in the number of small farms, no-till has the capacity to be a vital tool to keep production agriculture a viable enterprise for small farm operators because of its potential to lower labor input and overall production costs (Smart and Bradford 1999). Production practices that growers with small farms can readily recognize as resulting in cost savings are usually implemented quickly. In contrast, research conducted by Fernandez-Cornejo et al. (2001) found that, for site-

Table 5. Analysis of survey data highlighting change in tillage system used after adoption of glyphosate resistant (GR) crops as affected by cropping system.[a]

Farm size	Tillage system before GR crop	Tillage system after GR crop: No till	Reduced till	Conventional till	Total	Separated means[b,c]
		% (No. of responses)				
Small farms (< 220 ha)	No till	95 (53)	2 (1)	3 (2)	22 (56)	a
	Reduced till	34 (25)	65 (49)	1 (1)	29 (75)	
	Conventional till	30 (37)	25 (31)	45 (56)	49 (124)	
	Total	45 (115)	32 (81)	23 (59)	100 (225)	
Medium farms (220–440 ha)	No till	92 (126)	7 (10)	1 (1)	27 (137)	a
	Reduced till	28 (54)	69 (132)	3 (5)	38 (191)	
	Conventional till	21 (37)	38 (65)	41 (71)	35 (173)	
	Total	43 (217)	41 (207)	16 (77)	100 (501)	
Large farms (> 440 ha)	No till	90 (114)	6 (7)	4 (5)	23 (126)	b
	Reduced till	19 (43)	80 (184)	1 (3)	43 (230)	
	Conventional till	24 (45)	29 (54)	47 (87)	34 (186)	
	Total	37 (202)	45 (245)	18 (95)	100 (542)	

[a] Vertical totals indicate the percentage in each tillage system before GR crop implementation; horizontal totals indicate the percentage in each tillage system after GR crop implementation. Changes in tillage practices were significant at the 0.05 level for each farm size.

[b] Farm sizes sharing the same letter(s) are not significantly different ($P = 0.05$) with respect to change in tillage practices.

[c] Mean separation is based on analysis of the absolute value of the change variable as calculated in Table 1.

specific technologies and agrobiotechnologies, small farmers were less likely to adopt these technologies because of the higher perceived risk.

GR cropping systems have become very popular over the past decade. This survey gives beneficial insight into how these systems impact producers' tillage management systems. In particular, large percentages of producers reduced tillage intensity after implementing a GR cropping system by adopting no-till or reduced-tillage cropping systems. Important environmental benefits, such as reduced soil erosion and reduced energy consumption by tillage operations, have been experienced because of the introduction of GR technology. It is imperative that we understand the impacts of different weed management strategies as weed management programs are adjusted over time. Data such as these aid researchers in understanding the long-term environmental and ecological impacts of GR cropping systems as well as the socioeconomical reasons that dictate growers' management decisions.

Sources of Materials

[1] SAS, Version 9.1, SAS Institute, Inc., SAS Campus Dr., Cary, NC 27513.

Acknowledgments

This research was funded by Monsanto Agricultural Products Company. The manuscript was approved for publication as journal article J-11452 of the Mississippi Agricultural and Forestry Experiment Station, Mississippi State University.

Literature Cited

Barnes, L. D. and R. W. Whitmore. 1990. The use of Prowl herbicide as a preemergence treatment in an irrigated reduced tillage cotton production system. Proc. Beltwide Cotton Conf. 14:349–350.

Burke, I. C., S. C. Troxler, S. D. Askew, J. W. Wilcut, and W. D. Smith. 2005. Weed management systems in glyphosate-resistant cotton. Weed Technol. 19:422–429.

Burnside, O. C. 1996. The history of 2,4-D and its impact on development of the discipline of weed science in the United States. Pages 5–15 *in* O. C. Burnside, ed. Biologic and Economic Assessment of Benefits from Use of Phenoxy Herbicides in the United States. Washington, DC: U.S. Department of Agriculture NAPIAP Rep. 1-PA-96.

Charles, G. W. 1991. A grower survey of weeds and herbicide use in the New South Wales cotton industry. Aust. J. Exp. Agric. 31:387–392.

Christensen, L. A. and R. S. Magleby. 1983. Conservation tillage use. J. Soil Water Conserv. 38:156–157.

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

[CTIC] Conservation Technology Information Center. 1999. Better Soil, Better Yields. http://www.conservationinformation.org/Publications/BetterSoilBetterYields.pdf.

[CTIC] Conservation Technology Information Center. 2008. http://conservationinformation.org/action=learningcenter_cone4_convetill.

Culpepper, A. S. and A. C. York. 1998. Weed management in glyphosate-tolerant cotton. J. Cotton Sci. 4:174–185.

Derting, C. W. 1990. Return on investment in no-tillage vs. conventional tillage cotton. Proc. South. Weed Sci. Soc. 43:76–81.

Dillard, H. R., T. J. Wicks, and B. Philp. 1993. A grower survey of diseases, invertebrate pests, and pesticide use on potatoes grown in South Australia. Aust. J. Exp. Agric. 33:653–661.

Fawcett, R. S., B. R. Christensen, and D. P. Tierney. 1994. The impact of conservation tillage on pesticide runoff into surface water: a review and analysis. J. Soil Water Conserv. 49:126–135.

Fernandez-Cornejo, J., S. Daberkow, and W. D. McBride. 2001. Decomposing the size effect on the adoption of innovations: agrobiotechnology and precision agriculture. Agbioforum 4:124–136.

Gianessi, L. P. 2005. Economic and herbicide use impacts of glyphosate-resistant crops. Pest Manag. Sci. 61:241–245.

Gibson, K. D., W. G. Johnson, and D. E. Hillger. 2005. Farmer perceptions of problematic corn and soybean weeds in Indiana. Weed Technol. 19:1065–1070.

Gibson, K. D., D. E. Hillger, and W. G. Johnson. 2006. Farmer perceptions of weed problems in corn and soybean rotation systems. Weed Technol. 20:751–755.

Graber, L. F. 1928. Evidence and observations on establishing sweet clovers in permanent bluegrass pastures. Agron. J. 20:1197–1205.

Gunsolus, J. L. 1990. Mechanical and cultural weed control in corn and soybeans. Am. J. Altern. Agric. 5:114–119.

James, C. 2005. Global status of commercialized transgenic crops: 2005. Ithaca, NY: International Service for the Acquisition of Agri-Biotech Applications Briefs 34.

Johnson, W. G. and K. D. Gibson. 2006. Glyphosate-resistant weeds and resistance management strategies: an Indiana grower perspective. Weed Technol. 20:768.

Kapusta, G. and R. F. Krausz. 1993. Weed control and yield are equal in conventional, reduced-, and no-till soybean (*Glycine max*) after 11 years. Weed Technol. 7:443–451.

Karlen, D. L., N. C. Wollenhaupt, D. C. Erbach, E. C. Berry, J. B. Swan, N. S. Eash, and J. L. Jordahl. 1994. Crop residue effects on soil quality following 10-years of no-till corn. Soil Tillage Res. 31:149–167.

Keeling, J. W. and J. R. Abernathy. 1989. Preemergence weed control in conservation tillage cotton (*Gossypium hirsutum*) cropping system on sandy soils. Weed Technol. 3:182–185.

Krumm, J. T. and A. P. Martin. 1999. Weed control in no-till soybeans at Lincoln, NE, in 1998. North Central Weed Sci. Soc. Res. Rep. 55:448–451.

Moseley, C. M. and F. S. Hagood Jr. 1990. Reducing herbicide inputs when establishing no-till soybeans (*Glycine max*). Weed Technol. 4:14–19.

Llewellyn, R. S., R. K. Lindner, D. J. Pannell, and S. B. Powles. 2002. Resistance and the herbicide resource: perceptions of Western Australian grain growers. J. Crop Prot. 21:1067–1075.

Pike, D. R., M. D. McGlamery, and E. L. Knake. 1991. A case study of herbicide use. Weed Technol. 5:639–646.

Reicosky, D. C. and R. R. Allmaras. 2003. Advances in tillage research in North American cropping systems. Pages 75–125 *in* A. Shrestha, ed. Cropping Systems: Trends and Advances. New York, NY: Haworth.

Sankula, S. 2006. Quantification of the impacts on U.S. agriculture of biotechnology-derived crops planted in 2005. National Center for Food and Agriculture Policy, http://www.ncfap.org/whatwedo/pdf/2005biotecimpacts-finalversion.pdf. Washington, DC: National Center for Food and Agricultural Policy. Accessed: November 12, 2007.

Shaw, D. R., W. A. Givens, L. A. Farno, P. D. Gerard, J. W. Wilcut, W. G. Johnson, S. C. Weller, B. G. Young, R. G. Wilson, and M.D.K. Owen. 2009. Using a grower survey to assess the benefits and challenges of glyphosate-resistant cropping systems for weed management in U.S. corn, cotton, and soybean. Weed Technol. 23:134–149.

Smart, J. R. and J. M. Bradford. 1999. Conservation tillage with Roundup can decrease cotton production costs. Page 735 in Proceedings of the Beltwide Cotton Conference. Cordova, TN: National Cotton Council of America.

Snyder, R. L., M. A. Plas, and J. I. Grieshop. 1996. Irrigation methods used in California: grower survey. J. Irrig. Drain. Eng. 122:259–262.

Stoller, E. W. and L. M. Wax. 1973. Periodicity of germination and emergence of some annual weeds. Weed Sci. 21:574–580.

Swanton, C. J. and S. F. Weise. 1991. Integrated weed management: the rationale and approach. Weed Technol. 5:657–663.

Toler, J. E., E. C. Murdock, and A. Keeton. 2002. Weed management systems for cotton (*Gossypium hirsutum*) with reduced tillage. Weed Technol. 16: 773–780.

Tripplett, G. B. Jr. 1985. Principles of weed control for reduced-tillage corn production. Pages 6–40 *in* A. F. Wiese, ed. Weed Control in Limited Tillage Systems. Champaign, IL: Weed Science Society of America.

[USDA-ARS] U.S. Department of Agriculture, Agricultural Research Service. 1975. Control of Water Pollution from Cropland, I: A Manual for Guideline Development. Washington, DC: USDA-ARS.

Wilcut, J. W. and S. D. Askew. 1999. Chemical approaches to weed management. Pages 627–661 *in* J. R. Ruberson, ed. Handbook of Pest Management. New York: Marcel Dekker.

Wilcut, J. W., S. D. Askew, and B. J. Brecke, et al. (1999). A Beltwide evaluation of weed management systems in transgenic and nontransgenic cotton. Proc. South. Weed Sci. Soc. 52:189–190.

Received September 13, 2008, and approved October 15, 2008.