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Weed Management Costs, Weed Best Management Practices, and the Roundup Ready® Weed Management Program

Terry M. Hurley
University of Minnesota

Paul D. Mitchell
University of Wisconsin

George B. Frisvold
University of Arizona

Roundup Ready® (RR) crops have been widely adopted because they provide significant benefits to growers, but glyphosate-resistant weeds threaten the sustainability of these benefits. Weed best-management practices (BMPs) help manage resistance, but could increase weed-control costs, limiting their adoption. We use survey results to explore how adoption of BMPs affects weed-management costs in corn, cotton, and soybeans, controlling for farmer and regional characteristics. More experienced growers had lower weed-control costs. Cleaning equipment, using herbicides with different modes of action, and using supplemental tillage are BMPs associated with increased costs for some crops, which may explain why they are less widely adopted than other BMPs. However, growers commonly use other weed BMPs that also increase costs. Regression results suggest adoption of RR crops reduces weed-control costs and that weed scouting reduces costs for cotton and soybean growers. Use of residual herbicides was associated with higher costs for cotton growers, but not for corn or soybean growers. Rotating RR and non-RR crops on the same acreage was associated with higher costs for soybeans, but not for corn or cotton growers.

Key words: glyphosate, resistance management, BMP adoption, telephone survey, herbicide.

Introduction

Roundup Ready® (RR) crop varieties that can be safely treated with glyphosate herbicide to control weeds were first commercialized for soybeans in 1996, for cotton in 1997, and for corn in 1998 (Green, 2007). By 2008, approximately 63% of corn, 68% of cotton, and 92% of soybean acreage in the United States was planted with herbicide-tolerant crop varieties, the majority of which were RR crop varieties (US Department of Agriculture National Agricultural Statistical Service [USDA NASS], 2008a). The rapid and widespread adoption of RR crop varieties suggests that growers using these varieties enjoy substantial benefits. Research has shown that these benefits are both pecuniary (e.g., lower production costs, higher yields, higher profits) and non-pecuniary (e.g., increased flexibility, crop safety, reduced herbicide toxicity), with the pecuniary benefits not significant in some cases (Bonny, 2008; Brookes & Barfoot, 2008; Carpenter & Gianessi, 1999; Fernandez-Cornejo, Klotz-Ingram, & Jans, 2002; Ferrell & Witt, 2002; Marra, Pardey, & Alston, 2002; Marra, Piggott, & Carlson, 2004; Sydorovych & Marra, 2008). However, there is increasing concern that these benefits may not be sustainable because of the emergence of glyphosate-resistant weeds and shifts in weed species prevalence (Benbrook, 2001; Green, 2007; Kruger et al., 2009; Legleiter & Bradley, 2008; Norsworthy, Smith, Scott, & Gbur, 2007; Scott & VanGessel, 2007).

In 1996, no weed species in the United States were known to be resistant to glyphosate, but by 2008, glyphosate resistance had been confirmed for 16 weed species around the world and for 9 species in the United States: common ragweed (*Ambrosia artemisiifolia*), giant ragweed (*Ambrosia trifida*), common waterhemp (*Amaranthus rudis*), Palmer amaranth (*Amaranthus palmeri*), horseweed (*Conyza Canadensis*), hairy fleabane (*Conyza bonariensis*), Italian ryegrass (*Lolium multiflorum*), rigid ryegrass (*Lolium rigidum*), and Johnsongrass (*Sorghum halepense*) (Heap, 2009). Figure 1 shows the trend in the number of glyphosate-resistant weed species and the number of states with glyphosate-resistant weed populations since commercialization of RR crop varieties. Currently, these resistant populations in the United States are spread across 19 states, with populations in new states under investigation (e.g., Boerboom, 2009).

Weed resistance to herbicides is not a novel problem (Heap, 2009; Holt & LeBaron, 1990), so weed scientists have had the opportunity to develop and promote a variety of best-management practices (BMPs) to address it. For example, tank-mixing herbicides with different modes of action is the most common practice, as using

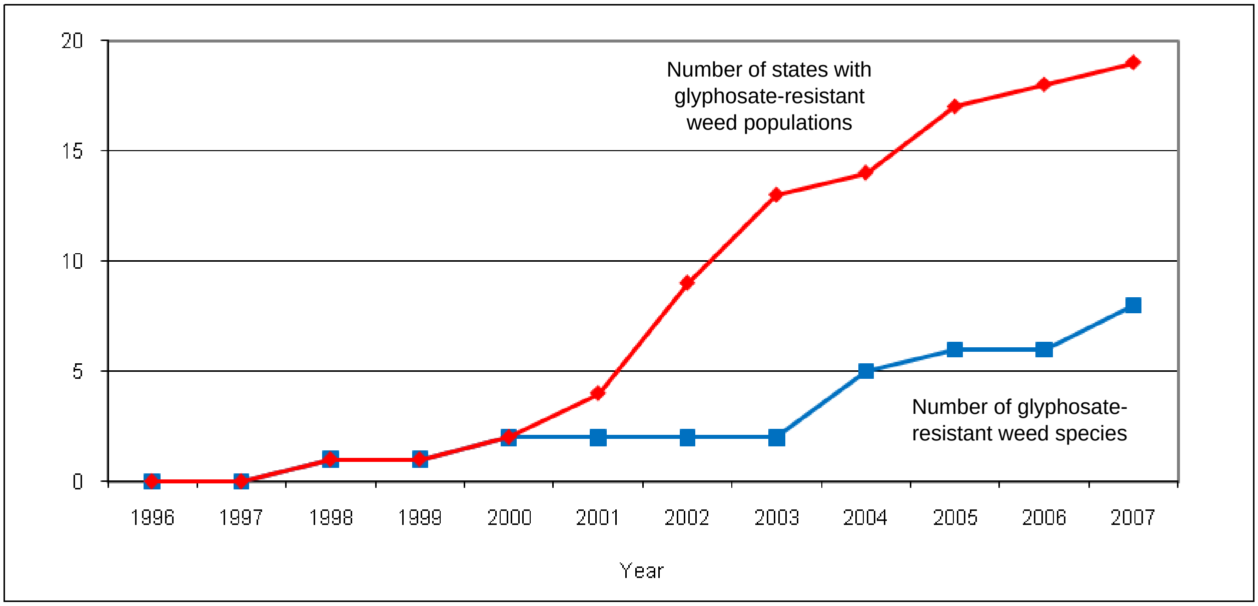

Figure 1. Number of weed species with glyphosate resistant populations and number of states with glyphosate-resistant weed populations (Source: Heap, 2009).

different modes of action reduces selection pressure (Culpepper, 2006; Diggle, Neve, & Smith, 2003). Given the emergence of glyphosate-resistant weeds over the past decade, it is clear that growers will need to incorporate weed-resistance BMPs into their RR weed-management programs if these programs are to remain sustainable (Green, 2007). However, growers may be unwilling to incorporate weed BMPs into their RR weed-management programs if they are too costly or if the long-term gains do not seem to justify the short-term costs (Llewellyn, Lindner, Pannell, & Powles, 2002; Weersink, Llewellyn, & Pannell, 2005). Costs other than just direct costs of these BMPs are also important barriers to their adoption, such as the loss of convenience or reduced applicator safety (Mueller, Mitchell, Young, & Culpepper, 2005; Pannell & Zilberman, 2001). Therefore, the sustainability of the weed-management program for RR and other herbicide-resistant crops hinges crucially on the identification of weed BMPs that can be implemented without substantially increasing weed-management costs (WMCs).

The objective of this article is to determine the extent to which growers are adopting various weed BMPs and how the adoption of these weed BMPs relates to WMCs in corn, cotton, and soybean production systems. This objective is accomplished using data collected from a random telephone survey of 1,205 growers in 22 states. The states selected for the survey include the primary corn-, cotton-, and soybean-growing regions of the United States. The survey collected information on a grower's average weed-control costs and their adoption of a variety of weed BMPs, as well as information on the growers and their operations. Multiple regression analysis is used to relate grower adoption of various weed BMPs to the grower's reported WMCs while controlling for individual and operational differences across growers. While a variety of studies have looked at the profitability and benefits of RR weed-management programs (Bonny, 2008; Brookes & Barfoot, 2008; Ferrell & Witt, 2002; Marra et al., 2002, 2004; Sydorovych & Marra, 2008), none of these studies focus explicitly on WMCs and their relationship with adoption of weed BMPs.

The next section of the article details the survey design and administration and provides an overview of the statistical methods used to analyze the survey data. We then report analysis results and conclude with a review of the key findings and a discussion of their implications.

Materials and Methods

The primary data for this study are from a telephone survey of corn, cotton, and soybean growers. The survey instrument was designed by Monsanto and Marketing Horizons, in consultation with the authors. The survey was administered in November and December of 2007 by Marketing Horizons. For each crop, Marketing Horizons randomly contacted growers from its national database and asked if they would be willing to participate in

Table 1. Weed best management practices.

Abbreviation	Practice
Scout before	Scout fields before an herbicide application
Scout after	Scout fields after an herbicide application
Start clean	Start with a clean field, using a burndown herbicide application or tillage
Control early	Control weeds early when they are relatively small
Prevent escapes	Control weed escapes and prevent weeds from setting seeds
Clean equipment	Clean equipment before moving between fields to minimize weed seed spread
Buy new seed	Use new commercial seed that is as free from weed seed as possible
Multiple herbicides	Use multiple herbicides with different modes of action during the cropping season
Supplemental tillage	Use tillage to supplement weed control provided by herbicide applications
Recommended rate	Use the recommended application rate from the herbicide label

the survey in exchange for modest compensation for their time. Growers who agreed to participate, were administered the survey and issued a check for their participation. Marketing Horizons continued contacting growers until a sample of at least 400 respondents who produced more than 250 acres of the crop of interest had completed the survey. The final tally of respondents included 402 corn, 401 cotton, and 402 soybean growers from 22 different states (Alabama, Arkansas, Georgia, Illinois, Indiana, Iowa, Kansas, Louisiana, Minnesota, Mississippi, Missouri, Nebraska, North Carolina, North Dakota, Ohio, Oklahoma, South Carolina, South Dakota, Tennessee, Texas, Virginia, and Wisconsin). The final tally included slightly more than 400 growers for each crop because multiple surveyors were contacting growers at the same time.

The survey collected general information on the grower and his/her farming operation in 2007, including adoption of the weed BMPs listed in Table 1. In addition, growers were asked to estimate their average WMCs with the following question:

> Please think about all of the time, effort, chemicals and equipment you devote to controlling weeds in your corn/cotton/soybean crop. On average, how much per acre would you say it costs you?

Finally, growers were asked about their plans to plant the crop of interest in 2008, including their plans to plant RR varieties, to plant these RR varieties following RR varieties planted in 2007, and to treat these RR varieties with a residual herbicide. This information was supplemented with county average yield data (USDA NASS, 2008b).

The survey and supplemental data were used to construct several variables to explain observed differences in grower-reported WMCs. These variables can be grouped into two categories: control variables and weed BMP variables. Control variables included individual specific information on the grower's education, farming experience, and expected productivity. Growers were asked their highest level of educational attainment: high school (12 years), some college (14 years), vocational/technical training (14 years), college graduate (16 years), or advanced degree (18 years). For experience, growers were asked how many years they had been farming. For expected productivity, growers were asked their expected average yield in 2008. This expected yield was transformed into the percentage difference from the 10-year county average yield reported by USDA NASS (2008b). Education, experience, and productivity variables were chosen to control for differences in WMCs attributable to differences in human capital that may make some growers more productive than others.

Control variables included operation-specific information. The number of crop acres planted in 2007 controlled for the size of the grower's operation. A Herfindahl index based on the proportion of crop acreage planted to corn, cotton, soybean, and other crops in 2007 was constructed to control for cost differences related to the degree of crop diversification by each farmer. The maximum value for this index is 1.0, while the minimum is 0.25 (as there are four crops), with higher values indicating less crop diversification. An indicator variable equal to 1 (if the grower raised livestock in 2007) and 0 (otherwise) was also constructed to control for differences in diversification across cropping and livestock enterprises. Finally, the proportion of planted crop acreage owned by the grower in 2007 was constructed to control for differences in stewardship incentives across growers, since growers who rent land may have reduced incentives to invest in weed BMPs and other practices that help sustain long-term land productivity.

The final set of variables were developed to control for systematic variation in WMCs related to unobservable geographic (e.g., climate, landscape, and soil), cultural (e.g., conservation and stewardship norms), and political (e.g., regulatory and investments in extension services) differences. The 10-year county average yield and yield coefficient of variation were used to control for geographic differences, while state indicator variables were constructed to account for cultural and political differences. Due to a limited number of observations for some states, a single dummy variable was constructed for Louisiana and Mississippi; North Carolina, South Carolina, and Virginia; and for the Southern Plains states of Texas and Oklahoma.

Two groups of variables were constructed to assess the extent to which growers are adopting various weed BMPs. The first group includes the percentage of RR acreage planned for 2008, the percentage of RR acreage planned for 2008 that would be treated with a residual herbicide, and the percentage of RR acreage planned for 2008 that would follow 2007 RR acres. The percentage of RR acreage planned for 2008 measures the extent to which growers use a range of weed-management tactics within a particular growing season. The percentage of RR acreage planned for 2008 that will follow 2007 RR acres measures the extent to which growers use a range of weed-management tactics over time. Relying exclusively on RR varieties and glyphosate for weed management within a particular season or over time increases the risk of glyphosate resistance, particularly if other weed BMPs are not incorporated into the management program. The percentage of RR acres planned to be treated with a residual herbicide measures the extent to which growers employ additional herbicides with different modes of action in their RR program for weeds not controlled by glyphosate, which reduces the risk of glyphosate resistance.

The second group of variables was constructed based on grower responses to direct questions regarding how often they used each weed BMP listed in Table 1. For example, for the first BMP—scouting fields before herbicide application (Table 1)—growers were asked specifically:

> When managing weeds in your corn/soybean/cotton crop, how often do you scout fields before a herbicide application? Would you say always, often, sometimes, rarely, or never?

The underlined section was changed for each weed BMP listed in Table 1 and grower responses were coded as 1.0, 0.75, 0.50, 0.25, and 0.0 for “always” to “never,” respectively. Note that growers were asked to respond to this series of questions just before they were asked to estimate their average weed-control costs in order to encourage them to think more holistically about these costs.

Scouting fields before an herbicide application allows growers to determine if an application is actually necessary or when weed growth has reached the stage when they are most effectively controlled. Scouting fields after an herbicide application allows growers to determine if the herbicide was effective and to comeback with supplemental control if it was not. Controlling weeds early when they are small gives better control, since smaller weeds tend to be more susceptible to herbicides. Preventing weed escapes using supplemental control provides an opportunity to control weeds that may be resistant before they set seed and produce weeds that are more resistant. Cleaning equipment between fields helps to stop the spread of weed seeds, including resistant weed seeds. Buying new seed that has been cleaned to reduce weed seed contamination helps stop the introduction of new (possibly resistant) weeds into a field. Using multiple herbicides reduces selection pressure by making it more difficult for weeds to survive control. Using supplemental tillage can control weeds that have developed herbicide resistance. Using the recommended herbicide application rate ensures that weeds are treated with enough herbicide to control them. We hypothesized that the frequency of growers’ historic use of these various weed BMPs could have an important influence on weed-control costs.

Grower-reported costs and the natural logarithm of costs were regressed on these control and weed BMP adoption variables using ordinary least squares, with separate regressions for corn, cotton, and soybeans. The regressions using cost as the dependent variable exhibited heteroscedasticity, while the regression using the natural logarithm of cost did not, so the natural logarithm of cost regressions were chosen as the preferred model.

Results

Table 2 provides a comparison of the survey sample with results from the 2007 USDA Census of Agriculture based on average yields and the distribution of crop acreage across various farm sizes. While our survey intentionally excluded farms with less than 250 acres of the targeted crop, census data reveal that these smaller farmers accounted for only 22% of the corn, 24% of the soybean, and 8% of the cotton acres harvested in 2007. For farms producing more than 250 acres of the targeted crop, the distribution of farms in the survey are almost identical to the 2007 census distribution for corn and

Table 2. Acreage distribution of sampled farms: Comparison of the telephone survey and the 2007 USDA Census of Agriculture.

		2007 census	
Variable	Telephone survey	All farms	> 250 acres
Average cotton acres	977	564	902
Farms harvesting < 249 acres (% total acres)		8	
Farms harvesting 249 to 999 acres (% total acres)	34	38	41
Farms harvesting 1,000 to 4,999 acres (% total acres)	63	51	55
Farms harvesting > 5,000 acres (% total acres)	3	4	4
Average corn acres	653	248	675
Farms harvesting < 249 acres (% total acres)		22	
Farms harvesting 249 to 999 acres (% total acres)	59	46	59
Farms harvesting 1,000 to 4,999 acres (% total acres)	39	30	38
Farms harvesting > 5,000 acres (% total acres)	2	2	2
Average soybean acres	567	229	596
Farms harvesting < 249 acres (% total acres)		26	
Farms harvesting 249 to 999 acres (% total acres)	71	50	69
Farms harvesting 1,000 to 4,999 acres (% total acres)	29	22	30
Farms harvesting > 5,000 acres (% total acres)	0	1	1

Source: USDA NASS (2009).

soybean. For cotton, our survey appears to over-represent farms in the 1,000 to 4,999 acres category. Average corn and soybean acres for the survey are within 5% of the census average. For cotton, the survey average is within 10% of the census average. Based on these broad characterization, the corn and soybean sample appears reasonably representative of US corn and soybean producers with more than 250 acres, while the cotton sample appears to be somewhat skewed toward larger producers.

Table 3. Dependent and control variable means and standard deviations (in parentheses) by crop.

Variable	Corn	Soybean	Cotton
Weed management costs ($/acre)	40.17	33.45	55.57
	(33.68)	(26.73)	(40.74)
Education (years)	13.8	13.8	14.6
	(1.73)	(1.74)	(1.87)
Experience farming (years)	30.6	29.5	28.8
	(11.9)	(10.7)	(13.1)
Difference in grower expected yield and county average yield (%)	16.9	23.3	50.9
	(16.8)	(48.9)	(53.1)
2007 crop acres	1232	1292	1819
	(1007)	(887)	(1592)
2007 Herfindahl crop diversity index	0.53	0.49	0.60
	(0.15)	(0.10)	(0.21)
2007 crop acreage owned (%)	44.8	41.4	37.0
	(31.7)	(31.4)	(32.2)
2007 livestock enterprise	0.48	0.33	0.29
	(0.50)	(0.47)	(0.45)
10-year county average yield	142.2	40.5	599.4
	(19.8)	(6.0)	(173.7)
10-year county yield coefficient of variation	0.14	0.14	0.27
	(0.05)	(0.04)	(0.09)
Alabama			0.052
Arkansas		0.049	0.061
Georgia			0.084
Illinois	0.186	0.169	
Indiana	0.101	0.095	
Iowa	0.189	0.184	
Kansas	0.055		
Louisiana /Mississippi			0.055
Minnesota	0.116	0.132	
Missouri	0.046	0.101	0.042
Nebraska	0.131	0.077	
North Carolina/South Carolina/Virginia			0.087
North Dakota		0.067	
Ohio	0.049	0.064	
South Dakota	0.067	0.061	
Tennessee			0.048
Texas/Oklahoma			0.555
Wisconsin	0.061		
Observations[a]	328	326	310

[a] *Sample sizes based on observations used in regression analysis. Some respondents were dropped from analysis because they did not provide complete information for all regression variables.*

Table 4. Weed BMP variable means and standard deviations (in parentheses) by crop.

Variable	Corn	Soybean	Cotton
2008 RR acreage planned (%)	73.3	95.5	91.8
	(36.2)	(17.2)	(23.1)
2008 RR acreage with residual planned (%)	66.0	27.6	65.8
	(45.5)	(42.0)	(45.9)
2008 RR acreage following RR acreage planned (%)	62.9	46.9	67.9
	(42.3)	(39.9)	(39.1)
Scout before	0.78	0.85	0.86
	(0.28)	(0.19)	(0.22)
Scout after	0.79	0.81	0.85
	(0.23)	(0.22)	(0.22)
Start clean	0.78	0.75	0.84
	(0.31)	(0.34)	(0.27)
Control early	0.85	0.84	0.87
	(0.20)	(0.19)	(0.17)
Prevent escapes	0.77	0.80	0.81
	(0.25)	(0.25)	(0.21)
Clean equipment	0.32	0.35	0.50
	(0.32)	(0.33)	(0.37)
Buy new seed	0.96	0.96	0.92
	(0.15)	(0.15)	(0.21)
Multiple herbicides	0.62	0.47	0.54
	(0.29)	(0.32)	(0.30)
Supplemental tillage	0.38	0.31	0.42
	(0.33)	(0.31)	(0.34)
Recommended rate	0.91	0.92	0.93
	(0.18)	(0.15)	(0.15)

Table 3 reports the means and standard deviations for reported WMCs and the control variables. Average reported WMCs were highest for cotton, followed by corn and then soybeans. Years of education and farming experience were similar across corn, cotton, and soybean growers. The percentage difference in grower expected yield from the 10-year county average was highest for cotton, followed by soybeans and corn. Cotton growers operated about 700 more crop acres on average compared to corn and soybean growers, while corn and soybean growers tended to own more of the land they operated and were more diversified than cotton farms in terms of crops and livestock. In addition, cotton farmers tend to face greater year-to-year yield variability. Finally, the average of the state indicator variables indicates the proportion of observations for each crop from each state, which because of the survey sampling method generally follow the proportion of total US crop acres in each state.

Table 4 reports the average and standard deviation for the weed BMP variables. Cotton and soybean growers both planned to plant more than 90% of their crop with RR varieties, while corn growers planned to plant more than 70% with RR varieties. Compared to soybean growers, corn and cotton growers planned to treat a higher percentage of their RR acres with a residual herbicide and planned to plant a higher percentage of their RR acres following an RR crop. The remaining variables in Table 2 are the average (and standard deviation) of responses, where always, often, sometimes, rarely, and never were coded as 1.0, 0.75, 0.50, 0.25, and 0.0, respectively. On average, most corn, cotton, and soybean growers reported often or always scouting fields for weeds before and after herbicide applications, starting with a clean field using a burndown herbicide or tillage, controlling weeds early when they are small, preventing weed escapes, buying new seed, and using the recommended herbicide application rate. On average, cotton growers reported sometimes cleaning their equipment between fields to stop the spread of weed seeds, while corn and soybean reported sometimes or rarely cleaning their equipment. On average, corn and cotton growers reported using multiple herbicides often or sometimes, while soybean growers reported using multiple herbicides sometimes or rarely. Finally, on average, most corn, cotton, and soybean growers reported using supplemental tillage to control weeds sometimes or rarely.

Table 5 presents the regression coefficients and t-statistics for the control variables, while Table 6 presents the regression coefficients and t-statistics for the weed BMP variables and statistics for the regression fit. Since the dependent variable was the natural logarithm of costs, these regression coefficients can be interpreted in terms of the proportional change in costs.

Table 5 shows that, with the one exception, none of the control variables appear to be significantly related to reported weed-control cost. Even ignoring statistical significance, the signs of the coefficients are inconsistent across crops. The exception is years of farming experience, which is related to significantly lower weed-control costs. With the average farmer having about 30 years of experience, these regression results suggest that the average grower has 15-18% lower WMCs when compared to a first-year grower. This result is consistent with the notion that growers gain valuable experience on the job that helps them manage weeds at a lower cost. A joint test of the state indicator variables (bottom of

Table 5. Control variable coefficient estimates and t-statistics (in parentheses) by crop for the natural logarithm of weed control cost regressions.

Variable	Corn	Soybean	Cotton
Education (years)	-0.00057 (0.03)	-0.0137 (0.69)	0.00044 (0.02)
Experience farming (years)	-0.00562* (1.73)	-0.00636* (1.85)	-0.00671** (2.20)
% difference in expected & county average yield	0.00249 (1.09)	-0.00025 (0.35)	0.00045 (0.54)
2007 crop acres	-0.000058 (1.58)	0.000023 (0.57)	0.000039 (1.49)
2007 Herfindahl crop diversity index	-0.18424 (0.71)	0.39925 (1.09)	-0.07905 (0.37)
2007 crop acreage owned (%)	-0.00066 (0.55)	-0.00083 (0.72)	0.00118 (0.91)
2007 livestock enterprise	0.054 (0.75)	-0.015 (0.21)	0.082 (0.91)
10-year county average yield	-0.0024 (0.66)	0.01686 (1.45)	0.00062 (1.40)
10-year county yield coefficient of variation	-0.62 (0.51)	1.69 (1.33)	-0.55 (0.75)
Alabama			-0.391* (1.68)
Arkansas		0.327* (1.67)	0.150 (0.66)
Georgia			0.046 (0.21)
Illinois	-0.037 (0.19)	0.029 (0.19)	
Indiana	0.213 (1.02)	-0.020 (0.12)	
Iowa	0.022 (0.11)	-0.234 (1.52)	
Kansas	0.023 (0.10)		
Louisiana /Mississippi			0.012 (0.05)
Minnesota	-0.108 (0.51)	-0.142 (0.99)	
Nebraska	0.107 (0.53)	-0.181 (1.06)	
North Carolina/South Carolina/Virginia			0.164 (0.80)
North Dakota		-0.066 (0.33)	
Ohio	-0.134 (0.56)	0.186 (1.06)	
South Dakota	-0.011 (0.05)	-0.106 (0.55)	
Tennessee			0.034 (0.14)
Texas/Oklahoma			0.055 (0.29)
Wisconsin	-0.025 (0.11)		
Joint F-test for state variables	0.74	1.93**	1.09

** Significant at 10%   ** Significant at 5% *** Significant at 1%*

Table 4) suggests that no systematic differences in weed control cost exist across states for corn or cotton, but do exist for soybeans. The excluded state in the regression is Missouri, so all coefficient estimates are relative to Missouri. Significant coefficients imply that, compared to Missouri, Arkansas soybean growers reported about 33% higher WMCs and Alabama cotton growers about 40% lower WMCs.

Table 6 shows that a variety of weed BMPs appear to have a significant influence on grower-reported WMCs. The percentage of RR acreage planned for 2008 was negatively related to weed management cost for corn, suggesting that corn growers using RR varieties enjoy lower WMCs. Coefficient values imply that on average, corn growers exclusively planting RR varieties enjoy 39% lower WMCs.

The percentage of RR acreage planned to be treated with a residual herbicide was positively related to WMCs for cotton, suggesting that it is indeed more costly for cotton growers to add a residual herbicide to their RR weed-management program. Coefficient values imply that treating all RR acres with a residual herbicide could increase WMCs for cotton growers by almost 20%. The planned percentage of RR acreage to follow an RR crop was significantly related to lower costs in soybeans, suggesting a 19% cost savings for growers who planned to plant all of their RR soybean acres following other RR crops.

For the weed BMP coefficients, 9 of the 30 estimates were significant. Soybean growers who scout fields before an herbicide application and cotton growers who scout fields after an herbicide application more often reported significantly lower WMCs. Corn and cotton

Table 6. Weed BMP variable coefficient estimates, t-statistics (in parentheses), and regression statistics by crop for the natural logarithm of weed control cost regressions.

Variable	Corn	Soybean	Cotton
2008 RR acreage planned (%)	-0.00385***	-0.00105	-0.00247
	(3.11)	(0.48)	(1.34)
2008 RR acreage with residual planned (%)	0.00092	0.00105	0.0019**
	(1.01)	(1.17)	(2.09)
2008 RR acreage following RR acreage planned (%)	0.00092	-0.0019**	0.00116
	(0.92)	(2.10)	(1.01)
Scout before	-0.134	-0.314*	0.097
	(0.89)	(1.66)	(0.47)
Scout after	-0.019	0.137	-0.354*
	(0.11)	(0.79)	(1.67)
Start clean	0.319***	-0.061	0.441***
	(2.71)	(0.59)	(2.85)
Control early	0.056	0.139	0.235
	(0.32)	(0.74)	(0.91)
Prevent escapes	0.219	-0.037	-0.099
	(1.47)	(0.26)	(0.48)
Clean equipment	-0.126	0.202*	0.064
	(1.07)	(1.82)	(0.56)
Buy new seed	-0.14	0.549**	-0.156
	(0.59)	(2.22)	(0.76)
Multiple herbicides	-0.085	0.325***	0.326**
	(0.68)	(2.70)	(2.25)
Supplemental tillage	0.182*	-0.088	-0.045
	(1.65)	(0.76)	(0.35)
Recommended rate	0.291	0.348	-0.094
	(1.45)	(1.50)	(0.34)
R^2	0.151	0.183	0.204
Adjusted R^2	0.061	0.096	0.117
χ^2 test for heteroscedasticity	0.40	0.33	2.30

** Significant at 10%   ** Significant at 5%   *** Significant at 1%*

growers who start with a clean field more often reported significantly higher WMCs. Soybean growers who clean their equipment before changing fields and buy new seed more often reported significantly higher WMCs. Reported WMCs were significantly higher for soybean and cotton growers using multiple herbicides more often and corn growers using supplemental tillage.

The R^2 values range from 0.15 to 0.20, indicating that the regressions are significant, but a substantial amount of variation in reported WMCs remains unexplained. Potentially, additional factors besides the control variables and weed BMP adoption variables used here could explain more of the observed variability in reported costs. Alternatively, there was likely significant variation in how each grower interpreted the weed-control cost question, contributing to measurement error. For example, some growers may have considered fuel, depreciation, and RR seed costs, while others did not. Nevertheless, results in Tables 5 and 6 indicate that several of the weed BMP adoption measures included in these regressions had significant effects on weed-control costs.

Discussion and Conclusions

RR crop varieties have been widely adopted because they provide growers with significant benefits, both pecuniary and non-pecuniary. However, glyphosate resistance threatens the benefits growers currently enjoy from RR crops. Weed resistance to herbicides is not a new phenomena and weed scientist have developed a variety of weed best-management practices (BMPs) to help growers manage resistance. However, the use of these weed BMPs could substantially increase weed-management costs (WMCs), which would discourage adoption.

This article evaluated the extent to which growers are adopting various weed BMPs and assessed how BMP adoption affects weed-control costs. Results suggest that the adoption of RR crop varieties reduces weed-control costs for corn growers, which is one of several reasons why so many corn growers have adopted these varieties. Incorporating a residual herbicide into the RR weed-management program clearly increases costs for cotton growers, which has likely discouraged further adoption among cotton farmers, even though the practice can help reduce the risk of glyphosate resistance. About two-thirds of RR corn and cotton acres are planted following another RR crop, which likely promotes glyphosate resistance if other weed BMPs are not employed. Planting RR corn or cotton following another RR crop does not appear to yield any significant WMC savings, except for RR soybean growers, implying that benefits other than lower WMCs are driving grower decisions to plant RR crops following RR crops.

Scouting fields before and after an herbicide application are widely adopted BMPs that appear to yield some cost savings for cotton and soybean growers. Starting with a clean field is also widely adopted, even though it appears to increase the cost of weed management for corn and cotton growers, suggesting that growers receive other advantages from this practice, such as higher yields due to reduced early weed competition. Controlling weeds early and preventing weed escapes are two other widely adopted BMPs that do not appear to significantly increase WMCs. Cleaning equipment between fields, using multiple herbicides, and using supplemental tillage are less widely adopted weed BMPs that also appear to be associated with increased weed-control costs for some crops, which might help explain why these practices are not as widely adopted. Using the recommended herbicide application rate is the most widely adopted weed BMP and does not appear to significantly increase WMCs.

Overall, growers commonly use a wide variety of weed best-management practices, even when some of these widely adopted practices appear to increase costs. However, some practices are not as widely adopted, possibly because they raise weed-management costs. Two opportunities for improving grower adoption of key weed BMPs to reduce the risk of glyphosate resistance would seem to be encouraging corn and cotton growers to not plant as many of their RR acres following another RR crop and encouraging more soybean growers to incorporate a residual herbicide into their RR weed-management program. These weed BMPs did not have a significant effect on reported costs and are among the most effective practices for reducing the development of resistance (Herbicide Resistant Action Committee [HRAC], 2005).

This survey and the analysis results provide a first step to understanding the obstacles growers face as they work to design more sustainable weed-management programs. Future research should consider collecting more detailed information on the cost of adopting alternative weed-management BMPs to help reduce the potential for differences in interpretation among growers that contributes to measurement error and thus to increase the precision of the estimated cost relationships. However, more detailed cost studies may miss important non-pecuniary costs or benefits associated with alternative BMPs. Therefore, the development and implementation of new survey strategies that provide less room for differences in interpretation while still allowing sufficient flexibility to capture both pecuniary and non-pecuniary benefits and costs is desirable.

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