AgBioForum, 12(3&4): 291-302. ©2009 AgBioForum.

Effects of Weed-Resistance Concerns and Resistance-Management Practices on the Value of Roundup Ready® Crops

Terrance M. Hurley
University of Minnesota

Paul D. Mitchell
University of Wisconsin

George B. Frisvold
University of Arizona

This study estimates grower benefits of Roundup-Ready® (RR) weed management programs and how weed-resistance concerns and resistance-management practices affect those benefits. Direct survey methods were used to elicit grower valuation of pecuniary and non-pecuniary benefits. We illustrate a hedonic strategy combined with principal component analysis to address part-whole bias present in previous assessments of non-pecuniary benefits of RR crops. Based on a national telephone survey of 1,205 growers, the mean reported benefit of RR relative to conventional seed varieties was more than $20 per acre for corn and soybean growers and about $50 per acre for cotton growers. Growers concerned about weed resistance reported lower benefits, but this effect was statistically significant only for cotton growers, reducing their perceived benefits by about 20% ($10 per acre). Use of a residual herbicide and annual rotation of herbicides are two practices to reduce the risk of weed resistance. Corn growers using residual herbicides perceived lower, though still positive, benefits. Soybean growers rotating herbicides perceived benefits to be higher. Growers more concerned about herbicide application costs and crop safety report lower benefits, while those more concerned about the flexibility of timing herbicide applications report higher RR benefits.

Key words: corn, cotton, soybeans, non-pecuniary benefits, principal components analysis, part-whole bias, glyphosate.

Introduction

Growers have rapidly adopted genetically modified (GM) crops since commercialization more than a decade ago. Globally, total planted acres of GM varieties reached one billion in 2005, ten years after commercial release, then doubled to two billion acres by 2008 (James, 2009). The United States dominates in use of GM crops, planting about half of the world's total GM acres in 2008 (James, 2009). Herbicide tolerance is a popular GM trait in the United States, with approximately 63% of corn, 68% of cotton, and 92% of soybean acres in 2008 planted with an herbicide-tolerant variety, with Roundup Ready® (RR) varieties by far the most popular (Duke & Powles, 2008; US Department of Agriculture National Agricultural Statistics Service [USDA NASS], 2008a).

Such rapid adoption of the new herbicide-tolerance technology suggests that growers perceive significant benefits. Marra, Pardey, and Alston's (2002) review of the literature generally supports this hypothesis, though a few exceptions exist (e.g., Bethour, 2002; Fernandez-Cornejo, Klotz-Ingram, & Jans, 2002; Fernandez-Cornejo & McBride, 2002). More recently, in a global analysis of the various GM crops, Brookes and Barfoot (2008) find that herbicide-tolerant crops have generated substantial value to farmers. Bonny (2008) reaches a similar conclusion in a review of RR soybeans in the United States. Not all the value of RR crops is monetary. Besides cost savings and/or yield enhancement, important sources of value also include non-pecuniary factors such as the simplification of weed control, greater flexibility in weed control, and ease of integration into conservation tillage (Bonny, 2008; Brookes & Barfoot, 2008; Piggott & Marra 2008; Sydorovych & Marra, 2007, 2008).

The evolution of weed resistance to glyphosate poses challenges for the sustainable use of RR crops. Resistance would likely reduce their benefits (Duke & Powles, 2008). Table 1 shows how the number and range of glyphosate-resistant weeds has been increasing in the United States since commercialization of RR crops (Heap, 2009). The evolution of weed resistance to herbicides also poses problems for other herbicide-tolerant crops, such as LibertyLink® or Clearfield® crops. As a result, there is increasing interest in identifying production practices to reduce the risk of weed resistance to glyphosate and other herbicides to maintain the benefits of RR and other herbicide-tolerant crops (Appleby,

Table 1. Glyphosate resistant weeds by state and year of discovery.

States	Year discovered
Common ragweed (*Ambrosia artemisiifolia*)	
Arkansas & Missouri	2004
Kansas	2007
Common waterhemp (*Amaranthus rudis*)	
Missouri	2005
Illinois & Kansas	2006
Minnesota	2007
Giant ragweed (*Ambrosia trifida*)	
Ohio	2004
Arkansas & Indiana	2005
Kansas & Minnesota	2006
Tennessee	2007
Hairy fleabane (*Conyza bonariensis*)	
California	2007
Horseweed (*Conyza Canadensis*)	
Delaware	2000
Kentucky & Tennessee	2001
Indiana, Maryland, Missouri, New Jersey & Ohio	2002
Arkansas, Mississippi, North Carolina & Pennsylvania	2003
Illinois, Kansas & California	2005
Michigan	2007
Italian ryegrass (*Lolium multiflorum*)	
Oregon	2004
Mississippi	2005
Johnsongrass (*Sorghum halepense*)	
Arkansas	2007
Palmer amaranth (*Amaranthus palmeri*)	
Georgia & North Carolina	2005
Arkansas & Tennessee	2006
Mississippi	2008
Rigid ryegrass (*Lolium rigidum*)	
California	1998

Source: Heap (2009).

2005; Green, Hazel, Forney, & Pugh, 2008). Proposed practices include incorporation of a residual herbicide into the RR weed-management program and rotation of herbicides from one growing season to the next (Gustafson, 2008; Neve, 2008; Reddy, 2001; Sammons, Heering, Dinicola, Glick, & Elmore, 2007). Using a residual herbicide with glyphosate helps mitigate or reduce the risk of resistance because residual herbicides control weeds that escape glyphosate control and prevent them from setting seed. Rotating between herbicides with different modes of action helps reduce the risk of weed resistance to herbicides by reducing the selection pressure for resistance to any one herbicide.

The primary purpose of this study is to reevaluate the benefits of the RR weed-management program for corn, cotton, and soybean growers, focusing on how these benefits are affected by grower practices and attitudes. In particular, we examine how grower benefits are affected by incorporation of residual herbicides into the RR program, the use of the RR program following a RR crop in the previous year, and grower concerns about weed resistance. Measuring the benefits growers enjoy from using the RR weed-management program is a challenge because not all of the benefits are pecuniary (i.e., measured in terms of grower profit). Carpenter and Gianessi (1999) and Marra, Piggott, and Carlson (2004) show that the RR program provides growers with substantial non-pecuniary benefits (e.g., increased flexibility and safety), implying that studies focusing only on profitability may be missing an important aspect of grower benefits.

To capture both the pecuniary and non-pecuniary benefits of planting herbicide-tolerant and insect-resistant crop varieties, Alston, Hyde, Marra, and Mitchell (2002) and Marra et al. (2004) use a survey methodology that asks growers direct questions regarding these benefits. As examples, the types of questions are similar to the following: “What value, if any, would you place on the flexibility the RR weed-management program provides?” or “What value, if any, would you place on all the benefits the RR weed-management program provides?” A key advantage of this methodology is that the authors are able to place dollar-denominated values on the various non-pecuniary benefits growers enjoy. However, results based on this methodology have also raised questions because the sum of the benefits growers report for specific non-pecuniary factors often exceeds the reported total benefit of the program (e.g., Marra & Piggott, 2006). This phenomenon has been referred to as the part-whole bias and has been observed in studies using similar methodologies to measure the benefits provided by particular attributes of non-market goods (Mitchell & Carson, 1989).

A secondary purpose of this study is to evaluate an alternative method for measuring how pecuniary and non-pecuniary factors affect grower benefits from RR crops. Like Alston et al. (2002) and Marra et al. (2004), the methodology directly asks growers how much they benefit from adopting the RR program. Unlike these studies, it does not ask growers to value specific factors contributing to the benefits of the RR program separately. Instead, it asks growers to report on a Likert scale how important various pecuniary and non-pecuniary factors are to them when making weed-management choices. These Likert rankings are then used within a hedonic framework to determine how various pecuniary and non-pecuniary factors contribute to the RR program's benefits. The value of this hedonic framework is that it imposes the restriction that the parts must add up to the whole, and so it is not subject to part-whole bias.

The study makes three contributions. First, it provides updated estimates of the benefits of RR crops to growers, taking into account weed-resistance concerns. Second, it provides estimates of how the adoption of management practices to reduce the risk of glyphosate weed resistance affects the benefit of the RR program to growers. Finally, it illustrates an alternative hedonic strategy to avoid part-whole bias when estimating how pecuniary and non-pecuniary factors affect the benefits of RR crops.

Data & Methods

The primary data for this study are from a telephone survey of 1,205 randomly selected growers who in 2007 produced more than 250 acres of the crop of interest (corn, cotton, or soybeans). Respondents included 402 corn, 401 cotton, and 402 soybean growers from 22 states. The survey instrument was designed by Monsanto and Marketing Horizons in consultation with the authors and administered by Marketing Horizons in November and December of 2007. The survey collected general information about the grower and his farming operation in 2007, as well as detailed information on the grower's 2007 production practices, including how often the grower used various weed best-management-practices and crop acreage plans for 2008. Growers were also asked how important various factors were to them when making herbicide choices and their total benefit from planting RR varieties. Annual county average crop yields for the previous ten years were linked to each grower (USDA NASS, 2008b). Finally, growers were asked an unprompted, open-ended question regarding their biggest weed management concerns.

Based on these survey responses, we developed a dependent variable and several independent variables for this study. The dependent variable was taken from the grower's response to the following question:

> Please think about all the reasons why you chose to plant Roundup Ready corn/cotton/soybean this year when you could have planted conventional herbicide corn/cotton/soybean on these acres instead. Compared to planting conventional herbicide corn/cotton/soybean (that is, corn/cotton/soybean not planted to Roundup Ready or LibertyLink), what would you say is the additional value per acre to you as a result of planting Roundup Ready corn/cotton/soybean this year?

Each grower's response was interpreted as the total benefit of planting a RR variety relative to a conventional variety including all pecuniary and non-pecuniary benefits. To encourage growers to think carefully about all of the benefits and costs of planting RR and conventional varieties, this question was asked after first asking growers about their weed-management practices and reasons for making the herbicide choices they make.

Independent variables for the analysis were selected to control for the extent to which growers were using various weed management BMPs, plus individual grower characteristics, operation-specific characteristics, and geographic differences across the physical, geopolitical, and cultural landscape in which growers operated. Table 2 reports the final set of independent variables used as control variables for the analysis.

The percentage RR acres planned to be treated with a residual herbicide and the percentage of RR acreage planned to be planted in 2008 following a RR crop planted in 2007 were included to measure grower adoption of two important weed best-management practices: use of multiple herbicides and annual herbicide rotation. From a pecuniary perspective, including a residual herbicide in the RR program can drive up weed-management costs, while from a non-pecuniary perspective, the use of a residual herbicide can decrease the risk of glyphosate resistance making the RR program more sustainable, which growers might value. Thus, reported RR benefits may increase or decrease with the percentage of RR acres treated with a residual herbicide. Planting a RR crop following another RR crop can make control of volunteer crops as weeds more difficult and costly and can increase the risk of glyphosate resistance, but it may also be more convenient for growers to use the same weed-management program repeatedly. Thus again, reported RR benefits may increase or decrease with the percentage of RR crop acres planted following a RR crop.

Variables to control for individual grower characteristics included each grower's formal education, years of farming experience, expected productivity, and weed-resistance concerns. For formal education, growers were

Table 2. Mean (standard deviation) of control variables used in Tobit regressions.

Variable	Corn	Cotton	Soybean
RR benefit ($/acre)	22.5 (24.0)	51.4 (45.6)	23.2 (19.7)
2008 RR acreage with residual planned (%)	70.4 (43.4)	64.5 (46.2)	29.6 (42.8)
2008 RR following RR acreage planned (%)	71.7 (37.3)	69.0 (37.9)	48.3 (40.5)
Education (years)	13.8 (1.74)	14.6 (1.88)	13.9 (1.78)
Experience farming (years)	30.3 (11.5)	28.4 (12.5)	29.6 (10.6)
Difference in expected and county average yield (%)	17.5 (17.5)	51.1 (50.2)	23.9 (52.6)
Resistance concerns	0.481 (0.501)	0.590 (0.493)	0.536 (0.500)
2007 crop acres	1295 (1033)	1895 (1698)	1259 (803)
2007 Herfindahl crop diversity index	0.53 (0.15)	0.60 (0.21)	0.49 (0.10)
2007 crop acreage owned (%)	43.6 (31.8)	36.3 (32.5)	41.3 (31.7)
2007 livestock enterprise	0.49 (0.50)	0.29 (0.46)	0.32 (0.47)
10-year county average yield	142 (20.9)	608 (172)	41 (6.0)
Coefficient of variation of county yield over the previous 10 years	0.14 (0.06)	0.26 (0.09)	0.14 (0.04)
Alabama	--	0.056	--
Arkansas	--	0.072	0.050
Georgia	--	0.084	--
Illinois	0.177	--	0.165
Indiana	0.078	--	0.104
Iowa	0.173	--	0.180
Kansas	0.058	--	--
Louisiana/Mississippi	--	0.056	--
Minnesota	0.136	--	0.129
Missouri	0.045	0.048	0.086
Nebraska	0.148	--	0.094
North Carolina/South Carolina/Virginia	--	0.084	--
North Dakota	--	--	0.058
Ohio	0.049	--	0.065
South Dakota	0.086	--	0.068
Tennessee	--	0.036	--
Texas/Oklahoma	--	0.546	--
Wisconsin	0.049	--	--

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. Education and experience are common measures of human capital that are often found to relate to increased productivity. If this is the case for RR weed management, then grower benefits should increase with education and experience. For expected productivity, growers were asked what they expected for their average yield in 2008. This expected yield was normalized as the grower's percentage difference from the 10-year county average yield. If the RR program is responsible for enhancing grower productivity, then reported benefits should increase with expected productivity.

Growers were asked an open-ended question regarding their biggest concerns in terms of weed management. An indicator variable was constructed from these responses, equal to 1 if the grower reported any concern with weed resistance and 0 otherwise. Note that during the survey, growers were not asked any questions about weed resistance and weed resistance was never mentioned. If glyphosate resistance is a source of a grower weed-resistance concerns, the benefits from the RR program are likely to be decreasing in these concerns.

Variables to control for operation-specific characteristics included each grower's reported 2007 crop acres, a Herfindahl index of crop diversity, whether a grower had livestock operations, and the percentage of operated land that the grower owned. The grower's 2007 crop acres were used to control for the size of the operation. Whether RR benefits are increasing or decreasing in operation size will depend on whether the primary benefit of the RR program is extensive (letting the grower operate more acres at an increasingly lower marginal net benefit) or intensive (letting the grower operate the same number of acres at a higher net benefit).

The Herfindahl index for crop diversity was constructed based on the proportion of the total crop acreage planted to corn, cotton, soybean, and other crops in 2007. The maximum value for this index is 1.0, while the minimum here is 0.25, with higher values indicating less crop diversification. We used an indicator variable of 1 if the grower raised livestock in 2007 and 0 otherwise so that we could control for differences in diversification across operations. More diversified operations spread labor, management, and capital resources more broadly. If the RR program increases the amount of labor, management, and capital that growers can devote to other enterprises, the RR benefits are likely to increase with increased diversification.

Finally, the proportion of crop acreage owned by the grower in 2007 was constructed to control for differences in stewardship incentives. Growers renting land may have reduced incentives to invest in weed BMPs and practices that sustain the long-term land productivity. To the extent that the RR program promotes the sustainability of agricultural production, program benefits should increase with the percentage of operated land owned by the grower, but if the RR program reduces the sustainability of agricultural production, the benefits of the RR program could decrease with the percentage of operated land owned by the grower.

The final set of control variables were employed to account for systematic variation in RR benefits related to unobservable geographic (e.g., climate, landscape, and soil), cultural (e.g., conservation and stewardship norms), and political (e.g., regulatory and extension services) differences. The 10-year county average yield and yield coefficient of variation were the primary variables used to control for geographic differences. The 10-year county average yield serves as a measure of the inherent productivity of the land in the grower's region, while the county yield coefficient of variation is a measure of the local crop-specific production risk. State indicator variables were used 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; for North Carolina, South Carolina, and Virginia; and for Texas and Oklahoma.

The response summaries in Table 2 describe the typical respondent for each crop. Corn and soybean growers tended to report similar benefits from planting RR varieties, averaging over $20 per acre, while the benefits reported by cotton growers were much higher, averaging a little more than $50 per acre. Corn and cotton growers planned to treat about two-thirds of their RR acreage with residual herbicides and to plant more than two-thirds of their RR acreage following a RR crop. Soybean growers, however, only planned to treat about a third of their RR acreage with a residual herbicide and to plant about half of their RR acreage following a RR crop. Weed resistance is a common concern among most growers—59% of cotton growers, 54% of soybean growers, and 48% of corn growers mentioned it as a concern.

The years of education were similar for all three groups of growers, as were the years of farming experience. Compared to corn and soybean growers, cotton growers reported higher yield expectations relative to the county average, planted about a third more crop acreage, were less diversified with their crop acreage, and rented a higher percentage of the land they operated in 2007. About half of the corn growers reported having livestock operations in 2007, while only about a third of the cotton and soybean growers did. Cotton growers appear to face more production risk (as measured by the county yield coefficient of variation) when compared to corn and soybean growers. The majority of corn growers surveyed operated in Illinois, Iowa, Minnesota, and Nebraska, which were the four largest corn-producing states in 2008 in terms of acreage. The majority of cotton growers surveyed operated in Texas and Oklahoma. In 2008, Texas was responsible for almost half of the cotton acres planted in the United States. The majority of soybean growers surveyed operated in Illinois, Indiana, Iowa, and Minnesota, which were the four largest soybean-producing states in 2008 in terms of acreage.

Table 3. Factors influencing herbicide choices.

Abbreviation	Factor
Cost	The cost of the herbicide application
Yield loss	Reducing yield loss due to weed competition
Consistency	The consistency of the herbicide's effectiveness at controlling weeds
Application frequency	Reducing the number of herbicide applications you have to make
Crop safety	Crop safety
Clean field	Having a clean field
Time to apply	The time it takes to apply the herbicide
Flexibility	The flexibility of application timing
Family health	You, your family's and your employees' health
Public health	The public's health
Wildlife quality	The effect of the herbicide on wildlife
Water quality	The effect of the herbicide on water quality
Soil erosion	Erosion control

To understand how alternative pecuniary and non-pecuniary factors affect RR program benefits, growers were also asked to report how important each factor in Table 3 was to them when making herbicide choices. Specifically, growers were asked:

> When choosing whether to use a particular herbicide, how important is <u>the cost of the herbicide application</u>?

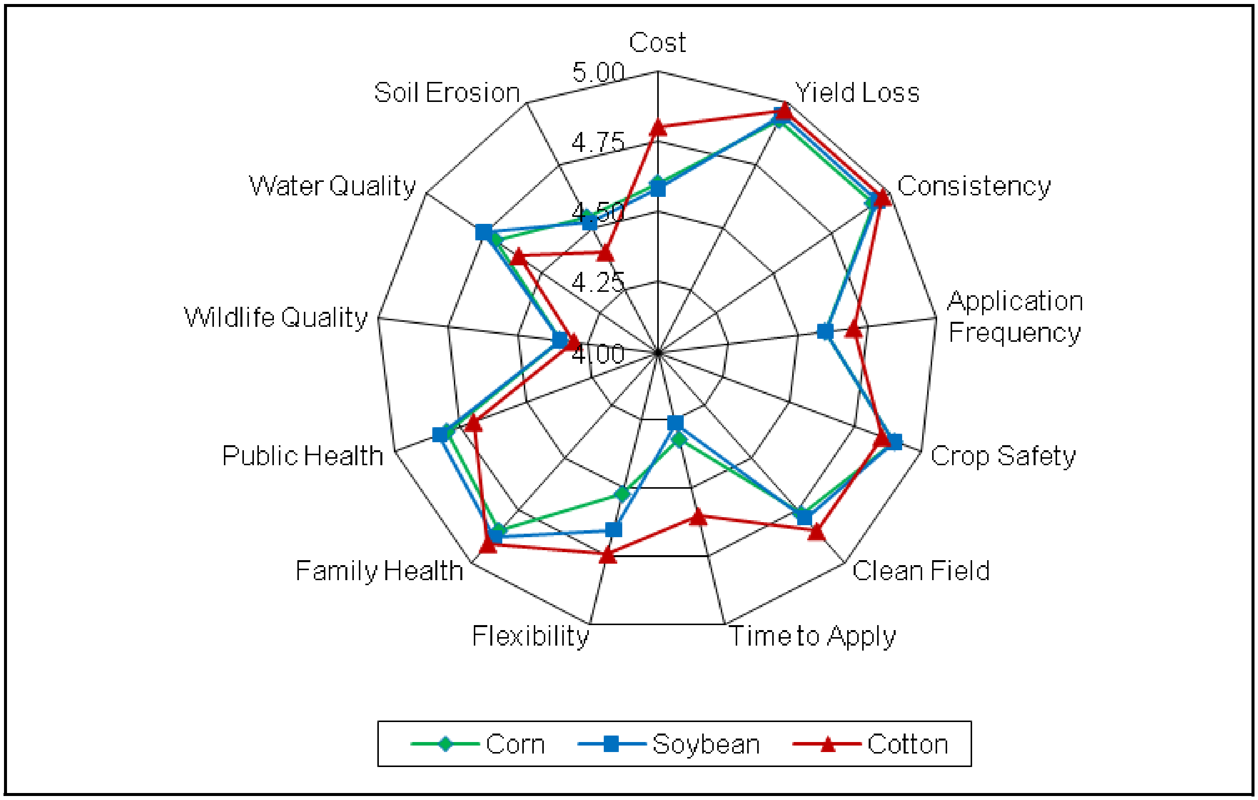

Figure 1. Average response to intensity of grower concerns for various factors when making herbicide choice decisions (5 for *very important*, 4 for *somewhat important*, 3 for *neither important or unimportant*, 2 for *not too important*, and 1 for *not at all important*).

The underlined phrase was changed to ask the question for each factor in Table 3. Possible responses included very important (5), somewhat important (4), neither important nor unimportant (3), not too important (2), and not at all important (1). Responses measure the intensity of grower concerns for these various non-pecuniary factors when making herbicide choices. Following a hedonic strategy, we use these responses as regressors to estimate how pecuniary and non-pecuniary factors affect the reported benefits of RR crops. Figure 1 presents the average grower response for each factor by crop—all factors are considered fairly important, with all averages well above 4.0. Yield loss, consistency, and family health are considered among the most important factors for growers, while wildlife quality, time to apply, and soil erosion are considered relatively less important.

Statistical Methods

Several issues emerged when choosing the statistical model to explore how the benefits of the RR program relate to weed BMP adoption, individual grower and operation-specific characteristics, and the various pecuniary and non-pecuniary factors. First, a non-trivial portion (6-10%) of growers who planted RR crops in 2007 reported zero benefits for RR varieties relative to conventional varieties. Second, preliminary least squares estimates indicated significant heteroscedasticity. Third, grower responses to the importance of the factors in Table 2 for determining herbicide choices were substantially correlated. To address the first two issues, Tobit regression models were estimated using STATA's tobit command with robust standard errors. To address the third issue, grower responses to the questions regarding herbicide choice factors were transformed using principal components, producing 13 new variables as uncorrelated linear combinations of the original 13 variables (Johnson & Wichern, 2007). Principal components analysis was chosen because the transformation can easily be reversed to obtain results in terms of the original variables while using the procedure developed by Krinsky and Robb (1986) to obtain standard errors.

To derive the final model for each crop, we used a forward selection procedure to eliminate herbicide choice principal component variables. The forward selection procedure started with a model including no

Table 4. Regression coefficients (t-statistics) for control variables and state indicator variables with principal component transformation of herbicide choice variables.

Variable	Corn	Cotton	Soybean
2008 RR acreage with residual planned (%)	-0.0754* (1.79)	-0.0522 (0.86)	-0.0135 (0.50)
2008 RR acreage following RR acreage planned (%)	-0.0597 (1.14)	-0.0459 (0.59)	0.0656** (2.01)
Education (years)	-0.883 (0.82)	-3.59** (2.44)	0.0484 (0.08)
Experience farming (years)	0.306* (1.95)	-0.389 (1.52)	-0.118 (0.77)
% difference in expected and county average yield	0.0425 (0.40)	0.0796 (1.23)	0.0146 (1.17)
Resistance concerns	-4.85 (1.62)	-10.3* (1.66)	-3.13 (1.10)
2007 crop acres	0.00012 (0.10)	-0.0056*** (2.94)	-0.0020 (1.29)
2007 Herfindahl crop diversity index	10.1 (0.80)	8.37 (0.56)	9.48 (0.38)
2007 crop acreage owned (%)	0.0584 (1.00)	0.236** (2.17)	0.0203 (0.51)
2007 livestock enterprise	-4.02 (1.16)	2.16 (0.33)	0.801 (0.32)
10-year county average yield	0.00475 (0.04)	-0.0257 (0.85)	-0.197 (0.48)
10-year county yield coefficient of variation	32.4 (0.93)	-71.2 (1.52)	15.2 (0.34)
Constant	23.9 (1.13)	169.7*** (3.91)	23.8 (0.96)
Standard deviation	23.9*** (8.21)	43.0*** (14.93)	19.4*** (8.33)
Difference by state joint test	0.34	5.77***	2.32**
Regression significance	2.07**	3.63***	1.58**
Log-Pseudolikelihood	-1028.62	-1222.19	-1159.17
Pseudo R^2	0.015	0.022	0.016
Observations	243	249	278
Observations equal to zero	25	16	18
State[a]	**Corn[b]**	**Cotton**	**Soybean**
Alabama	--	-60.4*** (4.70)	--
Arkansas	--	-2.27 (0.16)	5.73 (0.43)
Georgia	--	-5.74 (0.34)	--
Illinois		--	4.05 (0.66)
Indiana		--	7.57 (1.05)
Iowa		--	3.86 (0.56)
Kansas		--	--
Louisiana/Mississippi	--	-21.0 (1.40)	--
Minnesota		--	0.447 (0.08)
Nebraska		--	-3.14 (0.53)
North Carolina/South Carolina/Virginia	--	-34.5*** (2.75)	--
North Dakota		--	-8.90 (1.24)
Ohio		--	14.0* (1.96)
South Dakota		--	4.49 (0.57)
Tennessee	--	-5.56 (0.27)	--
Texas/Oklahoma	--	-16.7 (1.39)	--
Wisconsin		--	--

[a] Missouri, the only state with responses for all three crops, dropped to avoid singularity of data.

[b] Due to lack of significance, all state variables were dropped from corn estimates.

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

Table 5. Principal component coefficients (t statistics) for each crop's final model and factor weights for the herbicide choice variables for the principal component transformations.

Principal component	Corn	Cotton		Soybean	
4th	--	--		-3.84 (2.23)	
9th	3.96 (2.16)	--		--	
10th	--	--		-2.39 (1.80)	
11th	--	6.91 (1.71)		--	
12th	--	6.43 (1.80)		--	
	Factor weights by principal component				
Factor	**9th**	**11th**	**12th**	**4th**	**10th**
Cost	-0.21	-0.05	-0.03	0.31	0.44
Yield loss	0.43	-0.29	-0.07	-0.09	0.11
Consistency	-0.17	0.15	0.08	-0.12	-0.11
Application frequency	0.42	0.17	-0.16	-0.54	0.33
Crop safety	-0.09	-0.12	-0.60	0.63	0.03
Clean field	-0.29	0.00	0.04	0.16	-0.21
Time to apply	-0.24	-0.04	0.10	-0.02	-0.48
Flexibility	0.14	0.00	0.19	-0.08	-0.08
Family health	-0.15	0.36	0.40	-0.17	0.07
Public health	-0.06	-0.04	-0.19	0.18	-0.36
Wildlife quality	-0.38	-0.34	0.58	0.23	0.35
Water quality	0.23	0.66	-0.10	-0.05	0.29
Soil erosion	0.41	-0.40	-0.11	-0.22	-0.23

principal components of the herbicide choice factors and then added these principal components one at a time, choosing the principal component most significant when added to the model individually. The procedure stopped when no other principal component could be added to the model with a significance level exceeding 10%. Because a single principal component places non-zero weights on some or all of the original variables, dropping some does not necessarily eliminate effects from all the original herbicide choice variables. We estimated models for each crop using the actual herbicide choice variables rather than the principal components model (results not shown). The Pseudo R^2 favored the principal components models for all three crops, as did the Log-Pseudolikelihood.

Results

Regression results reported in Table 4 are the coefficients for control variables and state indicator variables when using the principal components of the herbicide choice variables. Table 5 reports the coefficients of the principal components for the final model for each crop and the factor weights assigned to each herbicide choice variable by each principal component used. Table 6 reports the coefficients for the herbicide choice variables after reversing the principal component transformation to obtain results in terms of the original variables.

Results in Table 4 indicate that grower-reported RR benefits per acre consistently decrease as the percentage of RR acreage treated with a residual herbicide increases for all three crops, although the decrease is only significant for corn growers. The magnitude of the effect suggests that corn growers who use a residual on 100% of their RR acres report about $7.50/acre lower RR benefits compared to growers who use no residual herbicide on their RR acreage. Planting more RR acres following a RR crop is associated with significantly higher RR benefits for soybean growers—about $6.50/acre more for those planting 100% of their RR soybeans following another RR crop compared to those planting none of their RR soybeans following another RR crop. Comparable estimates for corn and cotton are not significant. Growers concerned about weed resistance consistently reported lower RR benefits, significantly so for cotton growers and almost so for corn growers. Results suggest that cotton growers with weed-resistance concerns value the RR program more than $10/acre less than those who were not concerned.

Table 6. Benefit coefficients (t statistics) for herbicide choice variables implied by the principal component coefficient estimates.

Factor	Corn	Cotton	Soybean
Cost	-1.46**	-1.17**	-3.57***
	(2.22)	(2.27)	(2.83)
Yield loss	8.96**	-12.26**	0.27
	(2.22)	(2.03)	(0.39)
Consistency	-3.38**	9.39**	3.85***
	(2.22)	(2.25)	(2.86)
Application frequency	3.01**	0.23	2.08
	(2.22)	(0.14)	(1.28)
Crop safety	-1.51**	-9.78**	-9.62**
	(2.22)	(2.10)	(2.30)
Clean field	-2.70**	0.60	-0.24
	(2.22)	(1.60)	(0.26)
Time to apply	-1.37**	0.54	1.62*
	(2.22)	(0.83)	(1.90)
Flexibility	1.10**	2.19*	1.01***
	(2.22)	(1.79)	(2.86)
Family health	-1.49**	14.17**	1.59
	(2.22)	(2.43)	(1.56)
Public health	-0.53**	-1.90**	0.43
	(2.22)	(2.09)	(0.35)
Wildlife quality	-1.91**	1.40	-1.99***
	(2.22)	(0.55)	(2.82)
Water quality	1.53**	4.66	-0.92
	(2.22)	(1.47)	(1.31)
Soil erosion	2.10**	-3.51**	1.67***
	(2.22)	(2.08)	(2.86)

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

Crop acres in 2007 were negatively related to RR benefits reported by cotton growers, suggesting that extensive effects of RR adoption may be larger than intensive effects. The percentage of owned cropland is positively related to reported RR benefits, significantly so for cotton growers. This suggests these cotton growers believe RR crops provide substantial long-term benefits to their land. A higher 10-year county average yield was generally associated with lower RR benefits for all growers. More educated cotton growers reported significantly lower RR benefits, but more experienced corn growers reported significantly higher benefits.

A joint test of significant differences across states found none for corn, but strongly failed to reject such differences for cotton and soybean growers. Thus, all state indicators were dropped for corn and were included for cotton and soybeans, though not all state variables were individually significant. Compared to Missouri growers (the base case), cotton growers in Alabama and in North Carolina/South Carolina/Virginia reported significantly lower benefits, while Ohio soybean growers reported significantly higher benefits.

Table 5 shows that only the 9th principal component was significant for corn, while the 11th and 12th were significant for cotton and the 4th and 10th for soybeans. The principal components for corn and cotton have positive coefficient estimates, so the signs of the weights in Table 5 are the same sign as the effect each herbicide choice factor has on reported RR benefits for that crop, and the larger the weight, the greater the effect. For example, the factors most heavily weighted by the 9th component for corn are *yield loss*, *application frequency*, *soil erosion*, and *wildlife quality*. *Yield loss*, *application frequency*, and *soil erosion* have positive weights, and therefore are positively related to RR benefits for corn growers, but *wildlife quality* has a negative weight, and therefore is negatively related to RR benefits. The weights for the 11th and 12th principal components for cotton can be interpreted similarly. For soybeans, however, the estimated coefficients for the 4th and 10th principal components are negative, so the effect of each herbicide choice factor on reported RR benefits is opposite in sign to the weights. For example, *crop safety* has the largest weight and is positive, indicating that for soybean growers it has a negative effect on reported RR benefits.

Most factors have multiple weights and in some cases, weights from different principal component offset one another (e.g., *wildlife quality* for cotton), making interpretation of net effects difficult. Table 6 presents the net effect of each herbicide choice factor on reported RR benefits after reversing the principal component transformations and so are comparable to the coefficient estimates in Table 4.

Only three factors have consistent and significant effects on reported RR benefits across all three crops: *cost*, *crop safety*, and *flexibility*. Growers more concerned about cost and crop safety tend to value RR crops less, with cost concerns having larger effects for soybean growers and crop safety concerns having larger effects for cotton and soybean growers. Growers more concerned about flexibility tend to value RR crops more, with the magnitude of this effect similar across the three crops.

For corn growers, all herbicide choice concerns in Table 6 have significant effects (and identical standard errors) because only one principal component was significant. Concern about yield loss has by far the largest positive effect, while corn growers more concerned about application frequency and soil erosion also report notably larger RR benefits. Corn growers more concerned about consistency of control and having a clean field report lower RR benefits. For cotton growers, several herbicide choice concerns in Table 6 also have significant effects. Concern about family health has a large positive effect on reported RR benefits for cotton growers, as do concerns about consistency of control and water quality. Concern about yield loss has the largest negative effect, as do concerns about crop safety and soil erosion. For soybean growers, fewer herbicide choice concerns in Table 6 have significant effects. The largest positive effects on reported RR benefits for soybean growers are greater concern for consistency of control and soil erosion. Concern about crop safety has by far the largest negative effect on reported RR benefits, while soybean growers more concerned about cost also report smaller RR benefits.

Discussion and Conclusion

The weight of evidence examined here suggests that Roundup Ready® crops offer substantial benefits to growers. Based on a 2007 telephone survey of US growers, the average reported benefit for a directly asked, stated preference question regarding the additional benefit for a RR variety relative to a conventional variety was more than $20/acre for corn and soybean growers and about $50/acre for cotton growers. These large values indicate the continued benefits that growers derive from RR crops after more than a decade of availability.

The emergence of glyphosate-resistant weed populations across the United States threatens the sustainability of these benefits. Resistance of weeds to glyphosate and other herbicides is a concern among US growers, with more than half of them mentioning it in an unprompted, open-ended question. Growers concerned about resistance consistently reported lower benefits to RR crops. Our analysis finds that cotton growers concerned about weed resistance value the RR cotton program $10/acre less than growers not reporting a concern about resistance. For corn growers, the estimated decrease in the value of the RR program for growers concerned about weed resistance is about $5/acre less and almost statistically significant. The estimated decrease for soybean growers is about $3/acre, but not significant. The implication is that many US growers are concerned about weed resistance and that this concern reduces, but does not eliminate, the value of RR crops to these growers.

Two weed-management practices that are important for reducing the risk that glyphosate-resistant weed populations evolve: using a residual herbicide with glyphosate and rotating herbicides annually. The telephone survey found that in 2007, less than 30% of RR soybean growers report using a residual herbicide with glyphosate, but 65%-70% of corn and cotton growers report doing so. Though not asked directly about annual rotation of herbicides, the survey found that about 70% of RR corn and cotton growers were planting their RR crop following a RR crop planted the previous year, while slightly less than half of RR soybean growers were doing so. These numbers indicate that growers have plenty of room for increasing their adoption of these key weed-resistance management practices.

Our analysis found that a grower using a residual herbicide on 100% of his RR corn acres reported a $7.50/acre lower benefit for RR corn than a grower using a residual herbicide on no acres. Negative, but statistically insignificant, effects were also observed for cotton and soybeans. Regarding RR crops planted following RR crops, our analysis found that growers planting RR soybeans following a RR crop reported higher benefits for RR soybeans. For those planting 100% of their RR soybeans following a RR crop, the benefit was about $6.50/acre more than for those planting none of their RR soybeans following a RR crop.

Growers including residual herbicides reported lower benefits of RR crops, but this difference was only statistically significant for corn growers. Rotating herbicides annually had a statistically significant, positive effect on soybean grower valuations. As such, growers would likely be receptive to additional research and education regarding the net value of these practices—not only the cost of adoption, but also the net long-term gains realized from preserving the efficacy of RR crops.

Non-pecuniary benefits are an important source of total grower benefits from RR crops, but the part-whole bias problem has plagued other assessments of the monetary value of these benefits. Our analysis illustrated the use of a hedonic strategy to estimate the non-pecuniary benefits of RR crops as a way to address the part-whole bias problem. The method uses measures of grower concern for non-pecuniary factors as regressors to explain the total grower-reported benefits from RR crops, employing principal component analysis to address multicollinearity problems among these measures.

For all crops, growers more concerned with herbicide application costs and crop safety reported lower RR benefits, and growers more concerned with the flexibility of timing herbicide applications report higher RR benefits. Concern about soil erosion had a positive effect on benefits for corn and soybean growers, but a negative effect for cotton growers. Expressing greater concern about yield loss had by far the largest positive effect on reported benefits for corn growers, while corn growers more concerned about consistency of control and having a clean field reported lower RR benefits. For cotton growers, greater concern about family health has a large positive effect on reported RR benefits, as did concerns about consistency of control and water quality, while concern about yield loss, crop safety, and soil erosion had the largest negative effects. For soybean growers, fewer herbicide choice concerns had significant effects. The largest positive effect on reported RR benefits for soybean growers was greater concern for consistency of control and application frequency and concern about crop safety had by far the largest negative effect. The implication is that growers derive different types of both pecuniary and non-pecuniary benefits from the different RR crops, making generalizations about these benefits difficult across growers, crops, and regions. Apparently, one of the benefits of RR crops is the ability for each grower to adapt them to his or her specific situations.

Our final assessment based on this analysis is that growers continue to derive substantial benefits from RR crops and that many of these benefits are non-pecuniary in nature. Weed resistance and the need to adopt new management practices to address resistance are concerns among RR growers. However, while these problems reduce the value of RR crops to growers, they do not completely eliminate their value. Hence, there is a need for greater education and research to help growers understand the net benefits of weed-resistance management and to encourage them to preserve the benefits of RR crops for the future.

References

Alston, J.M., Hyde, J., Marra, M.C., & Mitchell, P.D. (2002). An ex ante analysis of the benefits from the adoption of corn rootworm resistant transgenic corn technology. *AgBioForum*, *5*(3), 71-84. Available on the World Wide Web: http://www.agbioforum.org.

Appleby, A.P. (2005). A history of weed control in the Unites States and Canada—A sequel. *Weed Science*, *53*(6), 762-768.

Bethour, C. (2002). *Agronomic, economic and environmental impacts of the commercial cultivation of glyphosate tolerant soybeans in Ontario*. Guelph, Ontario: George Morris Centre.

Bonny, S. (2008). Genetically modified glyphosate-tolerant soybean in the USA: Adoption factors, impacts and prospects. A review. *Agronomy for Sustainable Development*, *28*(1), 21-32.

Brookes, G., & Barfoot, P. (2008). Global impact of biotech crops: Socio-economic and environmental effects, 1996-2006. *AgBioForum*, *11*(1), 21-38. Available on the World Wide Web: http://www.agbioforum.org.

Carpenter, J., & Gianessi, L. (1999). Herbicide tolerant soybeans: Why growers are adopting roundup ready varieties. *AgBioForum*, *2*(2), 65-72. Available on the World Wide Web: http://www.agbioforum.org.

Duke, S.O., & Powles, S.B. (2008). Glyphosate: A once-in-a-century herbicide. *Pest Management Science*, *64*(4), 319-325.

Fernandez-Cornejo, J., Klotz-Ingram, C., & Jans, S. (2002). Farm-level effects of adopting herbicide-tolerant soybeans in the U.S.A. *Journal of Agricultural and Applied Economics*, *34*(1), 149-163.

Fernandez-Cornejo, J., & McBride, W. (2002). *Adoption of bioengineered crops* (Agricultural Economic Report No. 810). Washington, DC: US Department of Agriculture, Economic Research Service (USDA ERS).

Green, J.M., Hazel, C.B., Forney, D.R., & Pugh, L.M. (2008). New multiple-herbicide crop resistance and formulation technology to augment the utility of glyphosate. *Pest Management Science*, *64*(4), 332-339.

Gustafson, D.I. (2008). Sustainable use of glyphosate in North American cropping systems. *Pest Management Science*, *64*(4), 409-416.

Heap, I.M. (2009). *The international survey of herbicide resistant weeds* [dataset]. Available on the World Wide Web: http://www.weedscience.org/.

Krinsky, I., & Robb, A.L. (1986). On approximating the statistical properties of elasticities. *Review of Economic and Statistics*, *68*(4), 715-719.

James, C. (2009). Global status of commercialized biotech/GM crops: 2008 (Executive Summary. ISAAA Brief 39-2008). New York: International Service for the Acquisition of Agri-Biotech Applications (ISAAA). Available on the World Wide Web: http://www.isaaa.org/resources/publications/briefs/39/executivesummary/default.html.

Johnson, R.A., & Wichern, D.W. (2007). *Applied multivariate statistical analysis* (6^{th} ed.). Upper Saddle River, NJ: Prentice Hall.

Marra, M.C., Pardey, P., & Alston, J. (2002). The payoffs to transgenic field crops: an assessment of the evidence. *AgBioForum*, *5*(2), 43-50. Available on the World Wide Web: http://www.agbioforum.org.

Marra, M.C., & Piggott, N.E. (2006). The value of non-pecuniary characteristics of crop biotechnologies: a new look at the evidence. In R.E. Just, J.M. Alston, & D. Zilberman (Eds.), *Regulating agricultural biotechnology: Economics and policy* (pp. 145-177). New York: Springer Publishers.

Marra, M.C., Piggott, N.E., & Carlson, G.A. (2004). *The net benefits, including convenience, of roundup ready soybeans: results from a national survey* (Technical Bulletin 2004-3). Raleigh, NC: NSF Center for Integrated Pest Management.

Mitchell, R., & Carson, R. (1989). *Using surveys to value public goods: The contingent Valuation method*. Washington, DC: Resources for the Future.

Neve, P. (2008). Simulation modeling to understand the evolution and management of glyphosate resistance in weeds. *Pest Management Science*, *64*(4), 392-401.

Piggott, N.E., & Marra, M.C. (2008). Biotechnology adoption over time in the presence of non-pecuniary characteristics that directly affect utility: a derived demand approach. *AgBioForum*, *11*(1), 58-70. Available on the World Wide Web: http://www.agbioforum.org.

Reddy, K.N. (2001). Glyphosate-resistant soybean as a weed management tool: Opportunities and challenges. *Weed Biology and Management*, *1*(4), 193-202.

Sammons, R.D., Heering, D.C., Dinicola, N., Glick, H., & Elmore, G. (2007). Sustainability and stewardship of glyphosate and glyphosate-resistant crops. *Weed Technology*, *21*(2), 347-354.

Sydorovych, O., & Marra, M.C. (2007). A genetically engineered crop's impact on pesticide use: a revealed-preference index approach. *Journal of Agricultural and Resource Economics*, *32*(3), 476-491.

Sydorovych, O., & Marra, M.C. (2008). Valuing the changes in herbicide risks resulting from adoption of roundup ready soybeans by U.S. farmers: A revealed preference approach. *Journal of Agricultural and Applied Economics*, *40*(3), 777-787.

US Department of Agriculture, National Agricultural Statistics Service (USDA NASS). (2008a, June). *Acreage report*. Washington, DC: Author. Available on the World Wide Web: http://usda.mannlib.cornell.edu/usda/nass/Acre//2000s/2008/Acre-06-30-2008.pdf.

USDA NASS. (2008b). *Quick stats: State and county data* [dataset]. Washington, DC: Author. Available on the World Wide Web: http://www.nass.usda.gov/.

Acknowledgements

Support for this project was provided by the Arizona, Minnesota, and Wisconsin Agricultural Experiment Stations, Monsanto, and HarvestChoice (http://www.harvestchoice.org). The authors gratefully acknowledge the helpful comments and data collection efforts of Michelle Obermeier-Starke, John Soteres, and other researchers at Monsanto. All conclusions and any remaining errors are the authors'.