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Characteristics of Herbicides and Weed-Management Programs Most Important to Corn, Cotton, and Soybean Growers

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The introduction and rapid adoption of herbicide-tolerant crops has renewed interest in better understanding the characteristics of herbicides and weed-management programs that are important to growers besides profitability. This study explores the importance of 13 characteristics, including characteristics that influence profitability, using data from a telephone survey of 1,205 corn, cotton, and soybean growers. We estimate a multivariate probit model to explore how the importance of these 13 characteristics varies with observable grower and farm-operation differences. Factor analysis based on the multivariate probit error correlations is conducted to gain further insight into the types of distinctions growers make between these 13 characteristics. Results show that growers rate characteristics such as consistency of control, crop safety, and family and employee health as very important more often than herbicide cost. The factor analysis suggests that health and environmental concerns, yield concerns, and herbicide-application concerns capture important unobservable preferences that influence grower decisions. These results imply that attempts to decompose the benefits of herbicide-tolerant crops by assigning unique values to specific characteristics that influence grower decisions can be confounded due to the difficulty in developing unique indirect measures of directly unobservable grower preferences.

Key words: glyphosate, multivariate probit, principal components, Roundup Ready®, factor analysis.

Introduction

Genetically-engineered (GE) crop varieties such as herbicide-tolerant Roundup Ready® (RR) soybean and insect-resistant *Bacillus thuringiensis* (Bt) corn first reached commercial farm fields in the United States in 1996. Since introduction, these and others GE crops have been adopted rapidly and widely in the United States (Figure 1) and around the world (James, 2009). Early efforts to understand the benefits these crops provided to growers and their rapid adoption focused on profitability, yields, and costs (Carpenter & Gianessi, 2000; 2001; Faircloth, Patterson, Monks, & Goodman, 2001; Ferrell & Witt, 2002; Klotz-Ingram, Jans, Fernandez-Cornejo, & McBride, 1999; Pilcher et al., 2002; Reddy & Whiting, 2000). While many early studies found that these GE crops did provide substantial benefits in terms of profitability, yields, and costs (e.g., Lin, Price, & Fernandez-Cornejo, 2001), there were also examples where the new varieties did not appear to dominate their conventional counterparts on these terms (Hyde, Martin, Preckel, & Edwards, 1999; Marra, Pardey, & Alston, 2002; Webster, Bryant, & Earnest, 1999).

Efforts to understand why farmers continue to adopt new GE varieties, even without clear profit, yield, or cost advantages, indicated that farmers also consider other types of advantages. These include simplicity, convenience, flexibility, and safety (Alston, Hyde, Marra, & Mitchell, 2002; Carpenter & Gianessi, 1999; Marra, Piggott, & Carlson, 2004). For example, Fernandez-Cornejo, Hendricks, and Mishra (2005) found that while adoption of RR soybeans was not associated with higher farm income, it was associated with higher off-farm income and overall farm-household income. Gardner, Nehring, and Nelson (2009) found advantages in terms of savings of household management labor. Glyphosate often substitutes for herbicides with higher toxicity and persistence in the environment (Fernandez Cornejo, Klotz-Ingram, & Jans, 2002). These other types of advantages were particularly important for the rapid adoption of RR soybeans, where early experimental plot studies found evidence of yield drag or lag (Elmore et al., 2001; Minor, 1998; Oplinger, Martinka, & Schmitz, 1998), while studies examining actual farm production found no gain in profitability (Bethour, 2002; Fernandez-Cornejo & McBride, 2002; Fernandez-Cornejo et al., 2002).

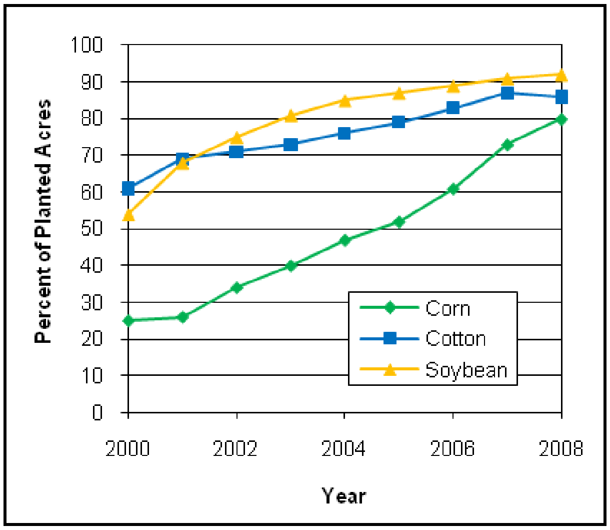

Figure 1. Percent of acres planted to genetically engineered corn, cotton, and soybean (2000-2008).

Source: USDA NASS (2001; 2002; 2003; 2004; 2005; 2006; 2007; 2008a).

Understanding how advantages such as simplicity, convenience, flexibility, and safety can affect the benefits growers receive from planting GE crops is complicated because these concepts are not objectively defined and depend on individual tastes and preferences—what one farmer considers convenient and simple may be inconvenient and complicated to another. However, this ambiguity does not diminish the fact that growers may have underlying preferences for characteristics of GE and non-GE crop-production systems that systematically influence their choices, but these preferences are not directly observable. The challenge is to tease out these directly unobservable preferences indirectly.

The objective of this study is to better understand the types of advantages that GE herbicide-tolerant crops can offer growers and how these advantages vary with observable grower and operation differences, as well as geographic and crop-specific differences, and other unobservable differences. To accomplish this objective, we use survey responses from corn, cotton, and soybean growers from across the United States regarding their weed-management programs and the characteristics of these programs that are most important to them. With this data, we estimate a multivariate probit model using simulated maximum likelihood to explore how the importance of the characteristics of herbicides and weed-management programs varies with observable grower and operation differences. We then use factor analysis based on the multivariate probit error correlation estimates to gain additional insight into the types of preferences that guide grower decisions.

Results show that growers rate several non-monetary concerns as very important more often than the cost of herbicide applications; for example, the consistency of herbicide effectiveness; crop safety; and personal, family, and employee health. The factor analysis identifies health and environmental concerns, yield concerns, and herbicide application concerns as related to important unobservable preferences that influence grower decisions. The grouping of health and environmental concerns by factor analysis suggests that growers do not consider factors related to health and the environment as separable, while the yield-concern results suggest that growers do not consider average yields and yield variability or risk as separable. The results for application concerns suggest that growers do not consider factors related to the simplicity, convenience, and flexibility of herbicide application as separable from costs. Together, these results imply that attempts to decompose the benefits of GE crops into separate components with individual values could be subject to double counting unless care is taken to ensure that the decomposition defines mutually exclusive benefits and adequately controls for important interactions (Alston et al., 2002; Marra et al., 2004; Marra & Piggott, 2006).

In the remainder of the article, we first provide an overview of the survey design and administration and of the statistical methods used for analysis. Next, we report results of the analysis, and then conclude with a review of key findings and a discussion of the implications.

Data and Methods

The primary data for this analysis are from a telephone survey of randomly selected growers producing at least 250 acres of the target crop—either corn, cotton, or soybeans. The survey instrument was designed by Monsanto and Marketing Horizons in consultation with the authors and was administered by Marketing Horizons in November/December of 2007. A total of 1,205 growers were surveyed (402 corn, 401 cotton, and 402 soybean growers) from 22 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).

Respondents provided a variety of information about themselves and their farming operations, including detailed information regarding their 2007 production practices and 2008 plans for the target crop. In addition,

Table 1. Herbicide characteristics or producer concerns that may potentially influence 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

growers were asked specific questions regarding their costs for weed management, the total benefit they perceive from planting RR varieties, and how their crop plans for 2008 might change if the cost of RR seed or residual herbicide applications changed. The survey also asked growers how important each characteristic listed in Table 1 was when making herbicide choices. Annual county average crop yields for the previous 10 years were linked to each grower (US Department of Agriculture National Agricultural Statistical Service [USDA NASS], 2008b).

Of particular interest for the objectives of this article was the importance growers assigned to the characteristics listed in Table 1, such as yields, costs, consistency, flexibility, and crop safety, when making their herbicide choices. Also of interest was how the importance of these characteristics related to observable grower, operation, geographic, and crop differences. Since many of these characteristics may have different meaning and implications for different growers, the survey asked growers to respond to specific statements. Specifically, for each characteristic listed in Table 1, growers were asked:

> When choosing whether or not to use a particular herbicide, how important is the cost of the herbicide application? Would you say very important, somewhat important, neither important nor unimportant, not too important, or not at all important?

The underlined portion was changed to include each characteristic listed in Table 1.

Economists typically consider profitability to be the most important factor guiding grower decisions. Two important components of profitability are costs and yields, which is why growers were asked to rate the importance of the cost of the herbicide application and reducing yield loss due to weed competition. Financial risk related to profitability is often another important factor guiding grower decisions. An important component of this risk is yield risk, which is why growers were asked about the importance of the consistency of the herbicide's effectiveness at controlling weeds. Growers were asked about the importance of crop safety because it has played an important role in herbicide adoption trends. The importance of having a clean field was queried because weedy fields are aesthetically unattractive to growers and can result in higher harvest costs and price discounts due to excessive foreign matter in the harvested crop. The importance of reducing the number of herbicide applications, the time it takes to apply the herbicide, and the flexibility of herbicide applications were used as less ambiguous measures of simplicity, convenience, and flexibility, while personal, family, employee health and the public's health were used as less ambiguous measures of safety from a human perspective. Finally, the effect of the herbicide on wildlife, the effect of the herbicide on water quality, and erosion control were used as less ambiguous measures of safety from an environmental perspective.

Factors Important to Herbicide Choices: Grower Assessments

Table 2 summarizes the distributions of grower responses for all 13 characteristics. For each, the large majority (more than 88%) indicated that it was either very important or somewhat important. Indeed, more than 99% of growers indicated that *yield loss*, *consistency*, *crop safety*, and *clean field* were either very important or somewhat important. More than 95% of growers also indicated that *cost*, *application frequency*, *flexibility*, *family health*, *public health*, and *water quality* were either very important or somewhat important. The only characteristic that fewer than 90% of growers rated as very important or somewhat important was *wildlife quality*. Also, note that *cost* was ranked as very important by only two-thirds of growers, while at the other extreme *consistency* and *yield loss* were ranked as very important by more than 95% of growers.

Table 2. Importance of characteristics influencing herbicide choices for all respondents (percent of respondents).

	No response	Not at all important	Not too important	Neither important nor unimportant	Somewhat important	Very important
Cost	0.0	0.6	0.9	1.5	30.4	66.7
Yield loss	0.0	0.1	0.0	0.1	4.6	95.2
Consistency	0.2	0.1	0.1	0.0	4.0	95.7
Application frequency	0.1	0.3	1.0	1.2	31.4	66.1
Crop safety	0.1	0.1	0.3	0.2	7.4	91.9
Clean field	0.2	0.0	0.2	0.4	17.0	82.2
Time to apply	0.4	0.9	2.5	3.1	43.8	49.3
Flexibility	0.0	0.2	0.6	0.5	34.2	64.5
Family health	0.3	0.3	0.4	0.3	4.6	94.1
Public health	0.3	1.2	1.0	0.9	15.3	81.4
Wildlife quality	0.4	3.0	3.5	4.3	37.2	51.6
Water quality	0.2	1.2	2.0	1.5	19.5	75.7
Soil erosion	0.5	2.9	3.7	2.5	24.0	66.5
Observations				1,176		

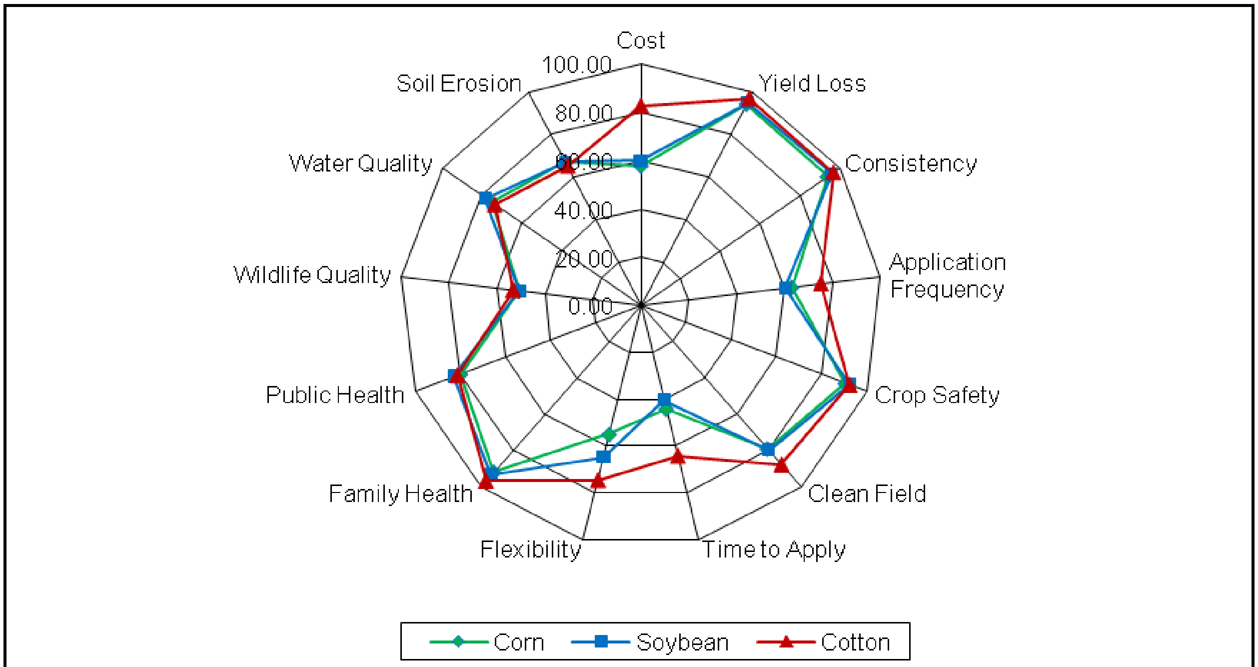

Figure 2. Percent of respondents reporting characteristics are very important.

Corn, cotton, and soybean growers rated most factors similarly. The radar plot in Figure 2 shows the proportion of corn, cotton, and soybean growers who rated each characteristic as very important. Corn and soybean growers rated characteristics very similarly, except for *flexibility*, with slightly more soybean growers rating it as very important. Ratings for cotton growers followed patterns similar to corn and soybean growers, except that a higher percentage rated *cost*, *application frequency*, *clean field*, *time to apply*, and *flexibility* as very important.

Grower-specific information considered for this analysis was the grower's education and farming experience. For education, growers were asked for 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

Table 3. Mean (standard deviation) for grower, operation, and geographic variables.

	Corn	Cotton	Soybean	All
Education	13.7	14.5	13.9	14.0
	(1.72)	(1.89)	(1.78)	(1.82)
Years farming	31.3	29.5	29.2	30.0
	(12.2)	(13.6)	(10.8)	(12.3)
2007 crop acres	1196	1827	1256	1423
	(955)	(1561)	(849)	(1195)
2007 crop diversity Herfindahl index	0.531	0.595	0.493	0.539
	(0.147)	(0.207)	(0.105)	(0.164)
2007 livestock enterprise	0.457	0.280	0.335	0.358
	(0.499)	(0.449)	(0.473)	(0.480)
2007 percent of operated land owned	46.3	37.8	41.3	41.8
	(32.3)	(32.7)	(31.6)	(32.3)
Percent of average county yield difference from US average	0.21	-14.68	2.77	-3.82
	(14.3)	(24.5)	(15.3)	(20.1)
County yield coefficient of variation	0.139	0.265	0.139	0.180
	(0.053)	(0.090)	(0.042)	(0.088)
Observations	396	386	394	1,176

were asked how long they had been farming. The average level of education was 14 years for all respondents (see Table 3), with little difference across the three crops. Growers averaged 30 years of farming experience, again with little difference across growers by crop.

Operation-specific information considered for this analysis was the size of the operation, the diversity of farm enterprises, and land tenancy. Total cropland acres operated in 2007 was used to measure the size of each grower's operation. Two measures of farm enterprise diversity were constructed. The first was a Herfindahl index of crop diversity constructed using the acres of corn, cotton, soybean, and other crops planted in 2007. The higher the Herfindahl index, the less diverse the cropping enterprises. The maximum value of the Herfindahl index is 1.0, indicating that the grower planted all crop acreage to a single crop, and the minimum is 0.25, indicating that the grower split crop acreage equally across corn, cotton, soybean, and other crops. The second was an indicator variable equal to 1 if the grower had livestock operations in 2007 and 0 otherwise. To measure land tenancy, the percentage of crop acres operated in 2007 that were owned by the grower was used.

Operation Characteristics

Table 3 summarizes the operation-specific data used for the analysis. The average number of crop acres was just under 1,500, with cotton growers reporting almost 600 more acres than corn and soybean growers. The diversity of cropping enterprises was similar for corn and soybean growers, but higher (a lower Herfindahl index) for cotton growers. A higher proportion of corn growers reported livestock enterprises followed by soybean growers and then cotton growers. On average, growers owned about 40% of the cropland they operated, with corn growers owning more of the land they operated, followed by soybean and then cotton growers.

Geographic information considered for this analysis included relative county-level productivity and yield risk. For the relative county-level productivity, the percentage difference in the average yield for the grower's county from the national average yield was calculated with USDA NASS (2008b) data using yields from the past 10 years (1998-2007). For county-level yield risk, the yield coefficient of variation was calculated for USDA NASS (2008b) county average yield for the 10 years of 1998-2007 for each grower's county. Table 3 shows that the percentage difference of the county average yield from the US average was less than one standard deviation away from zero for corn, cotton, and soybean growers, as expected for a sample that is reasonably representative of the population. The coefficient of variation of county average yield is equal for corn and soybean growers and much lower than for cotton growers, suggesting that cotton growers are subject to higher yield risk.

As Table 2 and Figure 2 indicate, 88% or more of the respondents chose either very important or somewhat important when rating all the characteristics in Table 1, with about half or more choosing very important. As a result, there is not enough variation in the data to use an ordered probit or multinominal logit model for each of the 13 characteristics. Instead, indicator variables equal to 1 if the respondent chose very important and 0 otherwise were constructed for each characteristic, making it possible to estimate a probit model. Another estimation issue is that each grower responded to all 13 characteristics. Correlation across individual grower responses seemed possible due to unobserved grower differences. To address this concern, the probit models for all 13 characteristics were estimated jointly using simulated maximum likelihood with STATA's mvprobit command.

The simulated maximum-likelihood procedure produces a correlation matrix for the individual errors from

Table 4. Multivariate probit coefficient estimates (absolute t-statistics). (*continued on next page*)

	Cost	Yield loss	Consistency	Application frequency	Crop safety	Clean field	Time to apply
Education	-0.046**	-0.015	0.034	-0.080***	-0.019	-0.083***	-0.058***
	(2.09)	(0.43)	(0.93)	(3.71)	(0.63)	(3.42)	(2.76)
Years farming	-0.0024	-0.0017	0.0090*	0.0021	0.0124***	0.0049	-0.00060
	(0.73)	(0.31)	(1.65)	(0.64)	(2.8)	(1.29)	(0.19)
2007 crop acres	0.0000026	-0.000014	0.000095	-0.0000043	-0.0000061	0.000033	0.0000040
	(0.08)	(0.25)	(1.35)	(0.13)	(0.14)	(0.84)	(0.12)
2007 crop diversity Herfindahl index	-0.15	-0.11	0.33	0.15	-0.38	0.55*	0.502**
	(0.59)	(0.26)	(0.75)	(0.58)	(1.15)	(1.83)	(2.07)
2007 livestock enterprise	-0.0052	-0.2192*	-0.034	-0.1258	-0.0642	-0.1317	-0.0614
	(0.06)	(1.68)	(0.25)	(1.54)	(0.57)	(1.43)	(0.77)
2007 percent of operated land owned	-0.00025	-0.0024	-0.0030	0.0028**	-0.0022	0.00091	0.0033***
	(0.20)	(1.19)	(1.46)	(2.25)	(1.30)	(0.64)	(2.68)
Percent of average county yield difference from US average	-0.0026	-0.0023	-0.0012	-0.0041	0.00042	-0.00096	-0.00062
	(0.82)	(0.44)	(0.22)	(1.33)	(0.1)	(0.27)	(0.21)
County yield coefficient of variation	-0.48	-0.66	0.18	-0.68	-1.37	-1.2	-0.12
	(0.52)	(0.45)	(0.12)	(0.76)	(1.13)	(1.18)	(0.14)
Cotton [a]	0.80***	0.27	0.16	0.43***	0.32*	0.503***	0.543***
	(5.86)	(1.25)	(0.71)	(3.24)	(1.75)	(3.28)	(4.28)
Soybean [b]	0.048	0.0063	0.24	-0.046	0.080	0.054	-0.058
	(0.52)	(0.04)	(1.56)	(0.5)	(0.61)	(0.52)	(0.64)
Intercept	1.07***	2.23***	0.66	1.32***	1.76***	1.67***	0.29
	(2.74)	(3.57)	(1.01)	(3.42)	(3.36)	(3.81)	(0.79)
Cotton = Soybean ($\chi^2(1)$)	31.57***	1.51	0.15	13.50***	1.81	8.82***	23.47***
Cotton = Soybean = 0 ($\chi^2(2)$)	37.37***	1.74	2.48	14.05***	3.07	11.23***	24.57***

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

[a] 0/1 dummy variable = 1 if targeted cotton grower in survey; = 0 otherwise.

[b] 0/1 dummy variable = 1 if targeted cotton grower in survey; = 0 otherwise; targeted corn grower is the default category.

the probit analysis across all 13 characteristics. This correlation matrix can be interpreted as capturing unobserved preferences or other characteristics that systematically influence how growers responded. To obtain a better understanding of this pattern of correlation, the correlation matrix was analyzed using factor analysis (Johnson & Wichern, 2007). First, STATA's factormat command was used with the pcf option (principal components method) to identify the number of factors to retain in further analysis. Second, STATA's factormat command was used with the pf option (principal factor method) with the number of factors retained set equal to the number of factors with an eigenvalue exceeding 1.0 in the first stage of analysis. The extracted factors were then rotated orthogonally using STATA's rotate command (StataCorp, 2009).

Results

Table 4 reports the multivariate probit coefficient estimates (absolute t-statistics in parentheses) for each characteristic in Table 1. In addition, Table 4 reports a Wald

Table 4. (Continued) Multivariate probit coefficient estimates (absolute t-statistics).

	Flexibility	Family health	Public health	Wildlife quality	Water quality	Soil erosion
Education	-0.096***	-0.012	-0.059**	-0.055***	-0.064***	-0.058***
	(4.47)	(0.38)	(2.54)	(2.68)	(2.89)	(2.71)
Years farming	0.0044	0.0011	0.0059*	0.0020	0.0021	0.0019
	(1.32)	(0.22)	(1.65)	(0.65)	(0.62)	(0.59)
2007 crop acres	0.000083**	-0.000029	-0.0000089	-0.000037	-0.000074**	-0.00010***
	(2.29)	(0.6)	(0.25)	(1.11)	(2.17)	(2.81)
2007 crop diversity Herfindahl index	0.093	-0.065	-0.067	0.14	-0.062	-0.037
	(0.37)	(0.16)	(0.25)	(0.61)	(0.24)	(0.15)
2007 livestock enterprise	-0.153*	-0.10	-0.059	-0.069	0.057	0.045
	(1.88)	(0.83)	(0.66)	(0.88)	(0.66)	(0.55)
2007 percent of operated land owned	-0.00015	-0.00049	-0.00068	-0.0012	0.0018	0.00098
	(0.12)	(0.26)	(0.5)	(1.03)	(1.35)	(0.79)
Percent of average county yield difference from US average	-0.0023	0.0034	0.0025	-0.00013	0.0069**	-0.0028
	(0.75)	(0.71)	(0.77)	(0.04)	(2.22)	(0.94)
County yield coefficient of variation	-0.92	0.57	-0.079	-1.43*	0.21	-0.55
	(1.05)	(0.41)	(0.08)	(1.73)	(0.23)	(0.64)
Cotton	0.61***	0.38*	0.11	0.27**	0.13	0.099
	(4.65)	(1.77)	(0.74)	(2.17)	(0.95)	(0.77)
Soybean	0.26***	0.030	0.073	-0.00043	0.099	0.025
	(2.85)	(0.22)	(0.7)	(0)	(0.99)	(0.26)
Intercept	1.38***	1.63***	1.61***	0.98***	1.5***	1.33***
	(3.58)	(2.78)	(3.9)	(2.68)	(3.82)	(3.54)
Cotton = Soybean ($\chi^2(1)$)	7.24***	2.72*	0.05	4.88**	0.05	0.35
Cotton = Soybean = 0 ($\chi^2(2)$)	23.01***	3.29	0.75	5.55*	1.35	0.59

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

[a] *0/1 dummy variable = 1 if targeted cotton grower in survey; = 0 otherwise.*

[b] *0/1 dummy variable = 1 if targeted cotton grower in survey; = 0 otherwise; targeted corn grower is the default category.*

test statistic at the bottom of each column for the equality of the cotton and soybean coefficients and for the equality of the cotton and soybean coefficients with zero. Finally, though not reported in Table 4, the test for all coefficients equal to 0 (with the exception of the intercepts) is rejected at a 1% level of significance ($\chi^2(130) = 309.72$), as is the test for no correlation in the errors for individuals across characteristics ($\chi^2(78) = 1{,}520.98$).

In Table 4, coefficient estimates for individual grower characteristics indicate that as the level of grower education increased, the probability that a grower rated *cost*, *application frequency*, *clean field*, *time to apply*, *flexibility*, *public health*, *wildlife quality*, *water quality*, and *soil erosion* as very important significantly decreased. The number of years a grower has been farming is positively and significantly related to a higher probability of rating *consistency*, *crop safety*, and *public health* as very important.

For operation characteristics, coefficient estimates imply that crop acres is significantly and positively related to the probability that growers rated *flexibility* as very important and negatively related to the probability that growers rated *water quality* and *soil erosion* as very important. Growers with less diverse cropping operations were significantly more likely to report that a *clean field* and the *time to apply* were very important, while growers with a livestock enterprise were significantly less likely to report *yield loss* and *flexibility* were very important. Growers who owned more of the land they operated were significantly more likely to report that *application frequency* and *time to apply* were very important.

Table 5. Correlation coefficients for the estimation errors associated with an individual grower's response to the 13 characteristics.

	Cost	Yield loss	Consistency	Application frequency	Crop safety	Clean field	Time to apply	Flexibility	Family health	Public health	Wildlife quality	Water quality
Yield loss	0.29											
Consistency	0.36	0.63										
Application frequency	0.32	0.15	0.20									
Crop safety	0.25	0.41	0.36	0.27								
Clean field	0.28	0.41	0.23	0.27	0.28							
Time to apply	0.46	0.23	0.31	0.44	0.32	0.32						
Flexibility	0.29	0.22	0.33	0.45	0.39	0.23	0.46					
Family health	0.20	0.22	0.50	0.37	0.31	0.27	0.37	0.25				
Public health	0.24	0.35	0.33	0.22	0.43	0.27	0.35	0.28	0.63			
Wildlife quality	0.25	0.14	0.28	0.23	0.35	0.18	0.36	0.27	0.52	0.59		
Water quality	0.21	0.17	0.16	0.28	0.38	0.22	0.32	0.26	0.52	0.62	0.60	
Soil erosion	0.25	0.20	0.40	0.30	0.30	0.32	0.38	0.28	0.46	0.46	0.45	0.44

Note. All estimates are significant at 10%.

For geographic characteristics, growers in counties with average yields higher than the national average were significantly more likely to rate *water quality* as very important. Alternatively, growers in counties with a higher yield coefficient of variation were significantly less likely to rate that *wildlife quality* as very important.

Based on the test results in the bottom rows of Table 4, no significant differences were found in the probability that corn, cotton, and soybean growers rated *yield loss*, *consistency*, *public health*, *water quality*, and *soil erosion* as very important. Cotton growers were significantly more likely than were corn and soybean growers to report that *cost*, *application frequency*, *clean field*, and *time to apply* were very important. Cotton growers were also significantly more likely than soybean growers were to rate *flexibility* as very important, and soybean growers were significantly more likely than corn growers were to rate *flexibility* as very important. These results are consistent with what Figure 2 suggests even after controlling for grower, operation, and geographic differences. However, contrary to what Figure 2 suggests, after controlling for grower, operation, and geographic differences, cotton growers were significantly more likely than corn and soybean growers to report that *crop safety*, *family health*, and *wildlife quality* were very important.

Table 5 reports correlation coefficients for the estimation errors associated with an individual grower's response to the 13 characteristics. Conceptually, these correlation coefficients capture unobserved grower preferences or characteristics related to the determinants of a grower's herbicide choices. All correlation coefficient estimates are individually greater than zero at a 10% level of significance, with all but five greater than zero at a 1% level of significance. The highest correlations (0.63) occur between the errors for *consistency* and *yield loss* and between the errors for *public health* and *family health*. However, other groupings seem to exist among these correlations—most apparent being the relatively high correlations among *family health*, *public health*, *wildlife quality*, *water quality*, and *soil erosion*. Factor analysis allows quantitative exploration of these and other apparent patterns among the correlations in Table 5.

Table 6 reports the factor loadings after rotation for the factor analysis. These factor loadings represent the weights assigned to each characteristic for the factor of interest. Determinants with relatively high factor loadings (e.g., greater than 0.3) are more strongly associated with the underlying unobservable preference or characteristic being measured by the factor of interest. Uniqueness measures the degree to which the variation in the response to a characteristic is not related to the variation in the responses to other characteristics. Relatively high values of uniqueness indicate that the characteristic is not as strongly associated with the underlying unobservable preference or characteristics being measured by the identified factors. We label the first factor *health & environmental concern* because it puts the most weight on *family health*, *public health*, *wildlife quality*, *water*

Table 6. Rotated factor loading and uniqueness for factor analysis.

	Factors			Uniqueness
	Health & environmental concern	Yield concern	Application concern	
Cost	0.14	0.30	0.46	0.68
Yield loss	0.11	0.78	0.10	0.37
Consistency	0.24	0.75	0.15	0.36
Application frequency	0.23	0.09	0.59	0.59
Crop safety	0.36	0.37	0.28	0.66
Clean field	0.19	0.35	0.32	0.74
Time to apply	0.30	0.19	0.60	0.51
Flexibility	0.21	0.21	0.56	0.60
Family health	0.70	0.25	0.17	0.42
Public health	0.77	0.26	0.10	0.34
Wildlife quality	0.71	0.08	0.18	0.46
Water quality	0.73	0.04	0.18	0.43
Soil erosion	0.52	0.22	0.28	0.60

quality, and *soil erosion*. All of these determinants of herbicide choices have relatively high positive loadings and low uniqueness, suggesting that they are strongly and positively related to some unobservable preference or characteristic. We label the second component *yield concern* because it puts most weight on *yield loss* and *consistency*, which have relatively low values for uniqueness, and less weight on *crop safety* and *clean field*, which are more unique. We label the third component *application concern* because it puts most weight on *time to apply*, *application frequency*, *flexibility*, and *cost*, though these characteristics are more unique.

These factor loadings suggest that growers with stronger *health & environmental concerns* were substantially more likely to report that *family health*, *public health*, *wildlife quality*, *water quality*, and *soil erosion* were very important when making herbicide choices. Similarly, growers with stronger *yield concerns* were substantially more likely to report that *yield loss* and *consistency*, and to a lesser extent *crop safety*, and *clean field*, were very important when making herbicide choices. Finally, growers with stronger *application concerns* were generally more likely to report that *time to apply*, *application frequency*, *flexibility*, and *cost* were very important when making herbicide choices.

Discussion

Profitability and two of its key components, yields and costs, are important factors guiding the production decisions of crop farmers. However, the introduction and rapid adoption of GE crops like RR soybeans and cotton serve as an important reminder that the calculus taking place in farm fields is often more subtle. Growers' production decisions are guided by factors like simplicity, convenience, flexibility, and safety, as well as profitability, yields, and costs. But what exactly does it mean for crop production to be simple, convenient, flexible, and safe? Furthermore, are simplicity, convenience, flexibility, and safety distinct variables in a grower's calculus? While 19 out of every 20 growers surveyed rated *yield loss* as a very important factor when making herbicide choices, only two out of every three growers rated *costs* as very important. Indeed, compared to *costs*, a higher proportion of growers rated *consistency*, *crop safety*, *clean field*, *family health*, *public health*, and *water quality* as very important.

Among the variables examined, a grower's education and the crop grown (corn, soybean, or cotton) were the two observable characteristics that were most often significantly related to the importance growers placed on the characteristics of herbicides and weed-management programs. For most of the characteristics, growers with more education were less likely to describe them as very important. We are unsure how to interpret this finding. Possibly, it is evidence that growers with more education generally try to consider a wider variety of factors when making their herbicide choices and so consider fewer factors as very important. Alternatively, growers that are more educated may have just been more critical in their responses. Other studies have found a variety of effects of education on farm and weed-management decisions and grower perceptions (e.g., Alexander, Fernandez-Cornejo, & Goodhue, 2003; Chimmuri, Tudor, & Spaulding, 2006; Fernandez-Cornejo & McBride, 2002; Llewellyn, Lindner, Pannell, &

Powles, 2007). To better understand the role of education in farmer herbicide choices and weed management, future research may need to control for the fields of study and the quality of the education, not just the years of education, or in some way measure farmer knowledge, not education.

The crop grown also was related to the importance growers placed on the characteristics. Cotton growers were often more likely to rate characteristics as very important. With the exception of *flexibility*, corn and soybean growers rated the various determinants similarly. For *flexibility*, soybean growers were more likely than corn growers to rate it as very important, but cotton growers were more likely than soybean growers to rate *flexibility* as very important.

To address possible correlation among the estimation errors, and because so few observable grower characteristics were significant, we used factor analysis to obtain a better understanding of how unobservable grower preferences or characteristics influence herbicide choices. Factor analysis suggests that growers' responses were influenced by three unobservable underlying preferences/characteristics. The first was associated with growers rating *family health*, *public health*, *wildlife quality*, *water quality*, and *soil erosion* as very important. The second was associated with growers rating *yield loss* and *consistency* as very important. The third was associated with growers rating *application frequency*, *time to apply*, *flexibility*, and *cost* as very important. This third factor supports arguments of Carpenter & Gianessi (2000; 2001) that flexibility in timing and costs are central considerations. These results suggest that the strength of a grower's *health & environmental*, *yield*, and *herbicide application* concerns are important characteristics in terms of making herbicide choices. Future research may find it useful to explore other ways to measure grower concerns about these and similar issues that could be incorporated more directly into the analysis.

Interestingly, while the literature often emphasizes the importance of yields for the adoption of RR crops (Faircloth et al., 2001; Ferrell & Witt, 2002; Reddy & Whiting, 2000), this emphasis has usually been in the context of yield loss without mention of consistency of weed control. *Yield loss* is an important component of profitability, while *consistency* relates to yield variability and risk. Our results, based on the importance of the *yield* concern component in the factor analysis, suggest that when growers think about yields, they do not appear to view their average yield and its variability as separable, which should come as little surprise to economists.

It is also interesting to note the interplay of *application frequency*, *time to apply*, *flexibility*, and *cost* with the *application* concern factor. *Application frequency*, *time to apply*, and *flexibility* all relate to what other researchers have referred to as simplicity, convenience, and flexibility. In this context, there is little new in the survey results. However, the relatively high factor loading on *cost* suggests that herbicide application costs may not be separable from simplicity, convenience, and the flexibility of applications.

Previous studies (e.g., Alston et al., 2002; Marra et al., 2004; Marra & Piggott, 2006) have attempted with mixed success to partition the benefits of GE crops into components similar to the characteristics used in this study. For example, Alston et al. (2002) asked growers to report separate values for six different benefits provided by a GE crop, as well as the total benefit provided by the GE crop, but the sum of the values for the six different benefits often exceeded the total value reported by growers. This part-whole bias problem has been observed in studies using similar methods (Mitchell & Carson, 1989). The factor analysis results reported here suggest that it can be a challenging task to identify mutually exclusive partitions for each benefit (i.e., convenience, simplicity, etc.). Indeed, it is not even clear that the growers themselves have mutually exclusive partitions for the benefits. If mutually exclusive partitions are not used, then there is the potential for double counting, which could result in the type of part-whole bias seen in previous studies.

This study explores only a limited set of characteristics that could be influencing growers' herbicide decisions. Future research could expand on this list in an effort to obtain a more complete picture. Future research might also use principal components or factor analysis to develop indices to use with information reported by growers on the value of RR crops in an effort to determine the benefits that factors other than increased profitability and yields, and decreased costs provide to growers.

Conclusions

Research on adoption of HR crops suggests that grower adoption decisions depend not only on simple measures of profitability, but on complex characteristics of herbicides and weed-management programs, such as simplicity, convenience, flexibility, and safety. This study explored the importance of 13 characteristics that influence weed-management decisions, using telephone survey data from 1,205 corn, cotton, and soybean growers.

These characteristics included attributes of the weed-management system (such as cost, flexibility, or effects on yield) and grower concerns or objectives (such as water quality, erosion control, or safety considerations).

The study first examined the relative importance growers placed on different characteristics for weed-management decisions. In making herbicide choices, more than 95% of growers rated protection from yield loss and consistency of weed control as very important. Growers rated family health, public health, and water quality as very important more frequently than they rated cost.

Multivariate probit regression results found grower education and crop grown were the two factors most often significantly related to the importance growers placed on the herbicide and weed-management characteristics. For most characteristics, more educated growers were less likely to rate them as very important. Cotton growers were more likely to rate characteristics very important. While corn and soybean growers rated most factors similarly, soybean growers placed greater importance on flexibility.

Finally, factor analysis results suggest health and environmental concerns, yield concerns, and herbicide application concerns capture important unobservable preferences that influence grower decisions. Therefore, attempts to decompose the benefits of herbicide-tolerant crops by assigning unique values to specific characteristics that influence grower decisions can be confounded because of the difficulty in developing unique indirect measures of directly unobservable grower preferences.

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