ADOPTION, RESIDUAL HERBICIDE USE AND GROWER VALUES FOR ROUNDUP READY® COTTON

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Abstract

This study examines cotton grower adoption of the Roundup Ready® (RR) weed management program with and without a residual herbicide application using random survey data from 298 Southern and Southern Plains producers in 2007. The study examines how the use of weed resistance best management practices and grower attitudes affect adoption, plus it estimates the net benefit to growers of the RR weed management program. Growers in the survey planned to plant an average of 930 acres of cotton in 2008— 855 acres of RR cotton, with a residual herbicide applied to 588 of these RR acres. Growers who are more likely to scout fields before and after herbicide applications, control weeds early, and use recommended herbicide application rates planned to plant significantly more RR acres, as did those who are more concerned about having a clean field, their family's health, and water quality. Growers who are more likely to clean equipment between fields, use saved seed, and use supplemental tillage for weed control planned to plant significantly fewer RR acres, as did those who are more concerned with weed control costs, yield loss, and the public's health. Growers who are more likely to prevent weed escapes, use saved seed, and use multiple herbicides planned to plant significantly more RR acres with a residual herbicide application, as did those who are more concerned with yield loss, their family's health, and wildlife. Growers who are more likely to scout fields after an herbicide application and who are more concerned with crop safety planned to plant significantly fewer RR acres with a residual herbicide application. The estimated expected net benefit (consumer surplus) of the RR cotton weed management system in 2008 was $7.69 per acre— $6.39 per acre with a residual herbicide application and $11.68 per acre without.

Introduction

Herbicide tolerant and insect resistant crop varieties like Roundup Ready® (RR) soybean and Bt corn have now been in use for over a decade in the U.S. In 2008, the United States Department of Agriculture's National Agricultural Statistics Service reported that 80 percent of corn, 86 percent of cotton, and 92 percent of soybean acreage in the U.S. was planted with either herbicide tolerant, insect resistant, or a combination of herbicide tolerant and insect resistant varieties. Such rapid adoption of a new technology suggests that growers perceive significant benefits. Marra et al.'s (2002) review of the literature generally supports this hypothesis, though there are a few cases where benefit estimates do not appear to favor the new varieties over their conventional counterparts (see for example Duffy and Ernst, 1999; and Fernandez-Cornejo and McBride, 2002). Even though the weight of evidence suggests the new varieties currently provide substantial benefits to growers, critics contend that these benefits may be short-lived because adoption can lead to unsustainable production practices (e.g. Benbrook, 2001). Therefore, it seems prudent to regularly monitor the benefits provided by these new varieties and to explore how the adoption of production practices to promote sustainability may enhance these benefits.

RR crop varieties are the most widely adopted herbicide tolerant crop varieties in the U.S. These RR crop varieties allow growers to spray glyphosate, a broad spectrum herbicide, on their crop for weed control. However, some weed species have developed resistance to glyphosate. Figure 1 shows counties where glyphosate resistant weeds have been confirmed. Weed resistance to glyphosate poses a challenge to sustainability that could reduce the benefits growers expect from planting RR crops. Therefore, there is increasing interest in identifying production practices that maintain these benefits while reducing the risk of weed resistance.

This study evaluates the benefits of RR cotton weed management programs and ascertains how these benefits are affected by the adoption of production practices to promote sustainability. Because a residual herbicide to control glyphosate resistant weeds can also mitigate glyphosate resistance, of particular interest is how a grower's incorporation of a residual herbicide application into the RR program affects its benefits. The paper also explores how glyphosate resistance and grower concerns regarding weed resistance influence the benefits of the RR program.

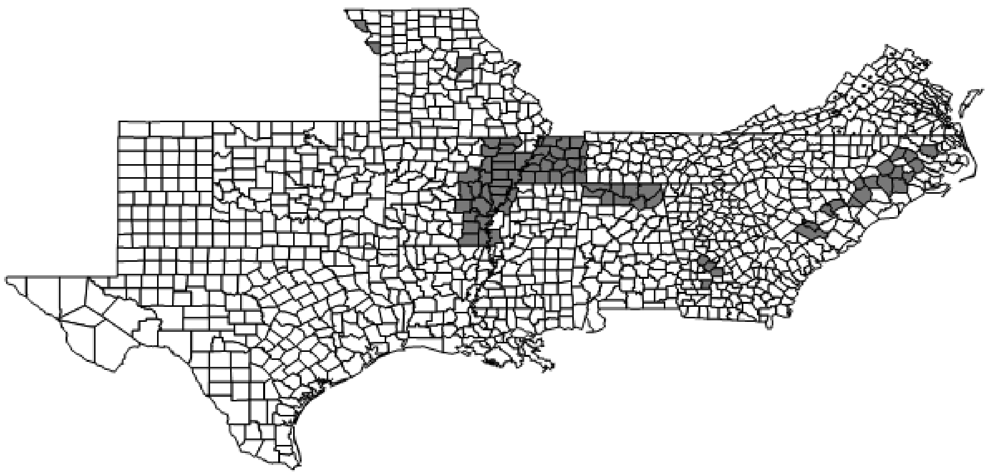

Figure 1: Counties with confirmed weed resistance to glyphosate (Derived from public and published sources).

A key challenge to assessing the benefits of the RR program is that not all of the benefits are pecuniary (i.e. measured in terms of grower profit). Past studies (e.g. Carpenter and Gianessi, 1999; and Marra et al., 2004) have found that growers derive substantial non-pecuniary benefits (e.g. increased flexibility and safety) from the adoption of RR programs. To capture the non-pecuniary benefits as well as the pecuniary benefits from planting herbicide tolerant and insect resistant crop varieties, Alston et al. 2002 and Marra et al. 2004 use a survey methodology that asks growers direct questions regarding these benefits: What value, if any, would you place on the flexibility the RR weed management program provides? A potential weakness of this methodology is that it requires growers to assign dollar denominated values in an unfamiliar context.

The methodology employed in this study also relies on grower surveys, but uses a different approach. A strength of the approach is that it asks growers to respond to questions in a more familiar context: How many acres of Roundup Ready® cotton would you plant next year if the price of RR cotton seed increased by $3.00 an acre? Responses to these and similar questions can be used to estimate grower demand for RR cotton conditioned on several factors: how often the grower employs alternative weed best management practices (BMPs); the level of importance the grower assigns to alternative pecuniary and non-pecuniary factors; whether glyphosate resistance has been detected in the grower's county of operation; and whether the grower is concerned about weed resistance. The estimated grower demand for RR cotton is then used to evaluate the benefits of RR cotton using the economic concept of consumer surplus, which provides a dollar-denominated measure of all the pecuniary and non-pecuniary benefits enjoyed by growers.

The next section discusses the conceptual framework used to estimate grower demand for RR cotton and to evaluate grower benefits. It details the survey design and administration. It also outlines the information drawn from the survey that is used to estimate grower demand for RR cotton, and discusses how demand was estimated and benefits calculated. The results section provides summary statistics for the data used in the demand analysis. It then discusses the demand estimates and the implications of these estimates in terms of grower benefits. The final section summarizes some key findings and provides some interpretation and suggestions for future research.

Materials & Methods

A standard method in economics for measuring the benefits accruing to an individual from participating in a particular activity is to look at how sensitive the individual's participation in the activity is to the cost of participation. The relationship between participation and participation costs is referred to as demand. This demand can be used to calculate what is referred to as consumer surplus. Consumer surplus provides a dollar denominated measure of the total net benefit from engaging in a particular activity.

In the context of the objectives of this study, the activity of interest is a grower's choice of RR cotton acres. Figure 2 provides a simple illustration of a grower's RR cotton demand. This demand characterizes the relationship between RR planting costs per acre and the number of RR acres planted by a grower. If the cost of planting an acre of RR cotton is C^0, this demand implies the grower will plant A^0 acres of RR cotton. Alternatively, if the cost of planting an acre of RR cotton is C^1, this demand implies the grower will plant A^1 acres of RR cotton. Notice that as planting costs increase the number of acres planted declines, which is a common characteristic of demand and reflects the notion that growers will plant their most productive cotton acres first.

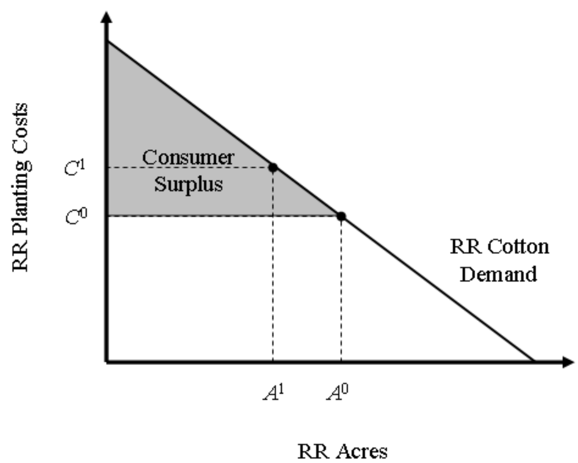

Figure 2: Example of grower demand and consumer surplus.

Intuitively, demand measures the added benefit to the grower of planting another acre of RR cotton exclusive of planting costs. Adding this benefit up for each acre planted yields the gross benefit to the grower exclusive of planting cost. This gross benefit can be illustrated graphically as the area under the demand in Figure 2. To get the net benefit, per acre planting cost must be subtracted, which leaves the consumer surplus. This consumer surplus when a grower plants A^0 acres of RR cotton at a cost of C^0 per acre is the gray area in Figure 2 and can be interpreted as the total net benefit to the grower of planting Roundup Ready cotton.

The primary purpose of this study was to calculate the benefit to growers from planting RR cotton. To accomplish this objective, a demand relationship was estimated in order to calculate consumer surplus. The primary data used to estimate demand comes from a telephone survey of 401 randomly selected growers who produced more than 250 acres of cotton in 2007. The survey instrument was designed by Monsanto and Marketing Horizons in consultation with the authors. The survey was administered by Marketing Horizons in November and December of 2007.

The survey instrument consisted of seven sections:

1. General information about growers and their farming operation in 2007.
2. Detailed information on production practices in 2007.
3. How often growers employ the weed BMPs listed in Table 1.
4. How important the factors in Table 2 were in terms of herbicide choices.
5. Grower plans to plant cotton in 2008 including plans to plant RR cotton and to treat these RR cotton acres with a residual herbicide.
6. How grower plans might change if the price of RR cotton seed changed or the cost of a residual herbicide application decreased.

7. Growers' biggest concerns in terms of weed management.

Table 1: Weed best management practices.

Abbreviation	Practice
Scout Before:	Scout fields before a herbicide application
Scout After:	Scout fields after a 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 data was supplemented with county crop data acquired from the U.S. Department of Agriculture National Agricultural Statistics Service (USDA/NASS, http://www.nass.usda.gov) and with data on the spatial distribution of suspected and confirmed glyphosate resistant weeds from a variety of public and published sources (e.g., Figure 1). The county crop data included county average yields. The resistant weeds data included counties with confirmed glyphosate resistance for Palmer amaranth, waterhemp, common ragweed, giant ragweed, horseweed, hairy fleabane, rigid ryegrass, Italian ryegrass, and Johnsongrass.

Table 2. 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

The survey and supplemental data were used to construct a variety of variables for the demand and economic analysis of the RR program. To determine grower demand for planting RR acres and for treating those acres with a residual herbicide, the survey asked growers about their plans to plant cotton in 2008. Specifically, growers were asked how many acres of cotton they planned to plant, how many of these acres would be planted with RR varieties, and how many of these RR acres would be treated with a residual herbicide.

If growers indicated that they planned to plant RR acres, they were also asked how their plans would change if the price of RR seed increased. The proposed price increase varied randomly across surveys. The price increases used and proportion of growers asked each are reported in Table 3. If growers did not plan to plant any RR acres, they were asked how their plans would change if the price of RR seed decreased by a certain amount. The proposed price decrease varied randomly across surveys. Also, if growers indicated that they planned to plant RR acres, they were asked how their plans would change if the cost of a residual herbicide application decreased. The proposed decrease in cost varied randomly across surveys. Note that the order of the questions for a change in RR seed price and the cost of a residual herbicide application were varied randomly across surveys to control for any bias that may be introduced by the order of these questions.

Table 3. Price changes proposed to growers.

Price	% of Surveys
Roundup Ready Seed Price Increase Per Acre	
3.00	32.8
6.00	35.9
9.00	31.3
Residual Herbicide Price Per Acre	
1.00	26.7
2.00	25.6
3.00	24.7
4.00	23.0
Roundup Ready Seed Price Increase Per Acre	
3.00	20.0
6.00	26.7
9.00	53.3

To summarize, growers who planned to plant RR acres in 2008 provided information on the total acres of cotton, RR acres, and RR acres with a residual herbicide for three alternative scenarios. The first scenario reflected the grower's current expectations of crop revenues and production costs. The second scenario reflected the grower's current expectations of crop revenues and production cost with an increase in the cost of RR seed. The third scenario reflected the grower's current expectations of crop revenues and production cost with a decrease in the cost of a residual herbicide application. Growers who did not plan to plant a RR variety in 2008 provided the same information for two alternative scenarios. The first scenario again reflected the grower's current expectations of crop revenues and production costs. The second scenario reflected the grower's current expectations of crop revenues and production cost with a decrease in the cost of RR seed.

A variety of survey and supplemental information was used to explain the variation in growers' acreage plans. These explanatory variables fell into four categories: price change variables, control variables, weed resistance variables, and weed BMP and herbicide choice variables. Construction of these variables is explained below and Table 4 lists many of these variables with their means and standard deviations.

The price change variables make it possible to identify the sensitivity of RR acreage and RR acreage with a residual herbicide application to changes in expected production costs, which is the demand relationship needed to evaluate the benefits of the RR program to growers via consumer surplus.

Both the change in the RR seed price and residual herbicide cost were used to explain differences RR acreage plans. With downward sloping demand, an increase (decrease) in the price of RR seed makes planting RR acreage more (less) expensive and will reduce (increase) the amount of RR acreage a grower will choose to plant regardless of whether or not a residual herbicide is used. A decrease in the cost of a residual herbicide application makes planting RR acreage with a residual herbicide less expensive and also makes planting conventional acreage with a residual herbicide less expensive. Therefore, the demand for all RR acreage could increase or decrease depending on how a grower chooses to substitute between RR acreage with and without a residual herbicide, and conventional acreage with and without a residual herbicide.

The sum of the changes in the RR seed price and in the residual herbicide cost was used to explain the difference in the demand for RR acreage with a residual herbicide. Again, with downward sloping demand, an increase (decrease) in the price of RR seed plus the residual herbicide cost makes planting RR acreage with a residual herbicide more (less) expensive and will reduce (increase) the amount of RR acreage a grower treats with residual herbicides.

For the regression analysis, the control variables included state variables; a grower's years of education and experience farming; a Herfindahl Index of crop specialization (defined below); the percentage of the crop acreage owned by the grower; whether or not the grower raised livestock in 2007; whether or not the grower used a hired custom herbicide applicator in 2007; the difference in the grower's expected yield from the ten year county average; and the coefficient of variation for the ten year county average yield.

Growers from 12 states participated in the survey: Alabama, Arkansas, Georgia, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia. To control for differences in RR plans across states from unobservable geographic, social, and political differences, indicator variables were created, equal to 1 if the grower was from the state and 0 otherwise. Indicator variables were created for Alabama, Arkansas, Georgia, and Tennessee. Due to a limited number of responses in some states, a single indicator variable was created for Louisiana and Mississippi; North Carolina, South Carolina, and Virginia; and Texas and Oklahoma. Since an indicator variable was not constructed for Missouri, differences in acreage plans explained by these state indicator variables are differences relative to Missouri.

The survey included a question regarding the grower's 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). The number of years a grower had managed his operation was used to measure years of farming experience. Years of education and experience capture differences in acreage demands related to what economist refer to as human capital — specific skills acquired by individuals that typically make them more productive.

Information reported by growers on the total number of crop acres in 2007 and the distribution of these acres across corn, soybean, cotton, and other crops was used to construct a Herfindahl Index as a measure of crop specialization. If A, A_{corn}, $A_{soybean}$, and A_{cotton} are total crop, corn, soybean, and cotton acres in 2007, then

$$\text{Herfindahl Index} = \frac{A_{corn}{}^2 + A_{soybean}{}^2 + A_{\cot ton}{}^2 + \left(A - A_{corn} - A_{soybean} - A_{\cot ton}\right)^2}{A}.$$

For a grower planting only one crop (e.g. cotton), the Herfindahl Index would equal 1, its highest possible value. For a grower planting equal amounts of all crops, the Herfindahl Index would equal 0.25, its smallest possible value. High numbers represent more specialization, while low numbers represent less. Crop specialization can be an important explanation of differences in acreage plans because it influences factors like a grower's risk and ability to allocate labor.

Grower survey responses were used to calculate the percentage of crop acreage owned by the grower. The percentage of crop acreage ownership can be important in explaining differences in acreage demands because a grower has more at stake in cropland that is owned. For example, a grower may have a stronger incentive to use management practices that reduce soil erosion on cropland that is owned because eroded land can be less productive land and less valuable for sale. If the grower does not own the land, he may still suffer from productivity losses due to erosion, but he will not suffer from a loss in the sale value of the land.

An indicator variable was constructed for growers who raised livestock in 2007 — equal to 1 if livestock was raised and 0 otherwise. Growers with a livestock enterprise typically have less time to devote to other farming enterprises, which can significantly influence management decision regarding factors such as labor allocation and herbicide or insecticide choices.

An indicator variable was also constructed for growers who hired custom applicators for their RR or conventional crop herbicide applications in 2007 — equal to 1 if a grower hired custom applicators for his RR or conventional crop herbicide applications and 0 otherwise. Hiring custom applicators provides opportunities for a grower to reallocate labor and management time, and capital. It can also reduce health risk associated with handling agricultural chemicals.

The survey asked growers to report the average per acre yield they expected from their 2008 crop. The ten year average yield per acre in the grower's county obtained from USDA/NASS was used to construct the percentage difference in the grower's expect yield from the county average yield. Inherent differences in land productivity, climate, and farm management skills across counties are all factors that can influence the ten year county average yield. A grower's expected difference from this average captures advantages or disadvantages a grower faces in terms of land productivity, climate, and management skills.

The coefficient of variation for the ten year county average yield was calculated using USDA/NASS data. It is the standard deviation of the ten year county average yield divided by the ten year county average yield and provides a measure of how risky cotton production is in the grower's county. Risk is commonly found to affect grower decisions and the results of these decisions.

Three weed resistance variables were used in the analysis. The first was derived from responses to the open-ended question in the survey's final section: *What are your biggest concerns in regards to weed management?* Responses to this question were used to create an indicator variable equal to 1 if the grower mentioned weed resistance, and 0 otherwise. The second and third weed resistance variables were developed using public and published data on confirmed glyphosate resistance. For the second variable, an indicator variable was set equal to 1 if glyphosate resistance had been confirmed in the grower's county and 0 otherwise. For the third variable, the proportion of counties with confirmed glyphosate resistance was calculated for the grower's USDA/NASS crop reporting district. A grower's concerns regarding weed resistance can play an important role in determining weed management practices. The existence of glyphosate resistance in a county and proportion of counties with glyphosate resistance in a crop reporting district can provide validation of a grower's concerns or evidence of the widespread adoption of management practices that promote glyphosate resistance.

To better understand preferences for adopting various weed BMPs, growers were asked how often they used each of the practices listed in Table 1. The possible responses included: Always (1.0), Often (0.75), Sometimes (0.5), Rarely (0.25), and Never (0.0). It was hypothesized that the grower's inclination to use these various weed BMPs could have an important influence on acreage plans.

To better understand the pecuniary and non-pecuniary factors that influence a grower's choice of weed management programs, growers were asked how important each of the factors listed in Table 2 were in terms of their selection of herbicides. The possible responses included: Very Important (5), Somewhat Important (4), Neither Important Nor Unimportant (3), Not Too Important (2), and Not at all important (1). To account for idiosyncratic differences in how growers interpreted various categories of importance, responses were normalized so that factors the grower ranked lowest in terms of importance were assigned a value of 0, while factors ranked highest in terms of importance were assigned a value of 1. Factors ranked between the lowest and highest levels of importance were assigned values uniformly between 0 and 1 with higher values reflecting a higher level of importance. To accomplish this normalization, the highest and lowest rankings were identified for each grower, here they are defined as $x_i^{\max}$ and $x_i^{\min}$ where the subscript i refers to a particular grower. If x_i^k represents the answer to the k^{th} factor, then the normalized variable was calculated as $(x_i^k - x_i^{\min}) / (x_i^{\max} - x_i^{\min})$ when $x_i^{\max} \neq x_i^{\min}$ and 0.5 when $x_i^{\max} = x_i^{\min}$. It was hypothesized that the factors that lead a grower to choose one herbicide over another can have an important influence on acreage plans.

The 23 separate BMP and herbicide choice variables were significantly correlated. In order to mitigate the effects of multi-collinearity, a second set of 23 variables was created using a principal components transformation. The principal components transformation creates linear combinations of the original variables that are uncorrelated in such a way that it concentrates variability (Brown, 1991). In other words, the first linear combination created exhibits the greatest amount of variation, while last combination exhibits the least amount of variation.

An indicator variable was also created to capture differences between growers who did not respond to all of the weed BMP and herbicide choice statements. Growers who chose not respond to all the statements were assigned a value of 1, which was used in the analysis instead of their preference variables. Growers who chose to respond to all of the statements were assigned a value of 0 and their preference variables were included in the analysis. This variable was designed to mitigate any potential non-response bias for these statements.

The data described above provides an opportunity to estimate two demand relationships: (i) the demand for RR cotton acreage and (ii) the demand for RR cotton acreage with a residual herbicide. Estimation was accomplished by assuming planned acres were a linear function of several variables: the price change, various control variables, weed resistance variables, incomplete weed BMP and herbicide choice response, and the weed BMP and herbicide choice variables or their principal component transformations. Many growers planned to plant only RR cotton or no RR cotton. Also, many growers planned to treat all of their RR cotton acres with a residual herbicide or none of their RR cotton acres with a residual herbicide. That is, both demand relations were censored from above at 100% adoption and from below at 0% adoption so that linear demand estimates obtained using ordinary least squares regression will be biased. To avoid this bias, both demand relationships were estimated simultaneously allowing for censoring from above and below using SAS's QLIM maximum likelihood estimation procedure. Planned RR cotton acres were censored from above by total planned cotton acres and from below by 0. Planned RR cotton acres with a residual herbicide were censored from above by planned RR cotton acres and from below by 0. Four separate models were estimated. The first two models included all the variables. One used the weed BMP and herbicide choice variables that were not transformed into principal components, while the other used the principal component transformations. The second two models were the same as the first two except insignificant (at 10%) weed BMP and herbicide choice variables were eliminated. Of these four models, the one that used the principal component transformation of the weed BMP and herbicide choice variables and eliminated the principal components that were not significant fit the best based on likelihood dominance (Pollack and Wales, 1991), so all the paper's reported results are based on the estimates obtained from this model.

Coefficient estimates and their covariance matrix obtained from SAS's QLIM procedure were used with Palisade @RISK and Microsoft Excel to derive the effects of the weed BMP and herbicide choice variables in terms of their original values rather than their principal component transformations. Since RR cotton acres without a residual herbicide are just the difference in total RR acres and RR acres with a residual herbicide, demand estimates for RR cotton acres without a residual herbicide can also be easily obtained. Finally, @RISK and Microsoft Excel was used to calculate the distribution of grower benefits for all RR acres, and RR acres with and without a residual herbicide.

Table 4: Summary statistics for planned acres, control variables, and resistance variables.

	Mean	Standard Deviation
Cotton Acres Planned for 2008	930.4	754.9
RR Cotton Acres Planned for 2008	855.0	744.3
RR Cotton Acres with Residual Herbicide Planned for 2008	588.4	725.3
Alabama	0.050	0.219
Arkansas	0.060	0.239
Georgia	0.087	0.283
Louisiana/Mississippi	0.054	0.226
North Carolina/South Carolina/Virginia	0.084	0.278
Tennessee	0.054	0.226
Texas/Oklahoma	0.550	0.498
Education (Years)	14.6	1.9
Experience Farming (Years)	28.9	13.3
Herfindahl Index	0.596	0.208
Percent Owned Crop Acres	37.0	32.4
Raise Livestock	0.282	0.451
Uses Custom Hire Applications	0.248	0.433
Percent Yield Difference from County Average	52.6	56.0
County Yield Coefficient of Variation	0.265	0.087
Resistance Concerns	0.550	0.498
Resistance in County	0.161	0.368
Percent Counties in Crop Reporting District with Resistance	11.8	25.6
Incomplete Responses to BMPs & Herbicide Choice Questions	0.017	0.129
Observations	298	

Results

This section begins with a summary review of the data used to estimate grower demand for RR acres and then discusses the demand estimates. It concludes by exploring the implications of these demand estimates in terms of the benefits growers derive from planting RR cotton.

Of the 401 survey respondents, 298 provided complete enough information for the demand analysis. On average, these growers planned to plant just under 1,000 acres of cotton (see Table 4), with about 92 percent of these acres planted with RR varieties. Residual herbicide treatments were planned for about 70 percent of these RR cotton acres. Just over half of the growers had operations in Texas and Oklahoma. The rest of the growers were fairly uniformly distributed across the other 10 states. Average education was just under 15 years, while average experience was just under 30 years. The Herfindahl index suggests growers do not plant a diverse range of crops. Growers owned about two out of every five acres they operated. About a quarter raised livestock and used custom hire applicators. Growers expected yields 50 percent higher than the ten year county average. The yield coefficient of variation is high relative to crops like corn and soybean, which suggests growers are subject to substantial production risk. Over half were concerned about weed resistance (see Figure 3 for the spatial distribution of these concerns) and 16 percent operated in counties where glyphosate resistance had been confirmed. On average, about one in ten counties in a grower's crop reporting district had confirmed glyphosate resistance. Less than two percent of growers failed to complete the BMP and herbicide choice questions.

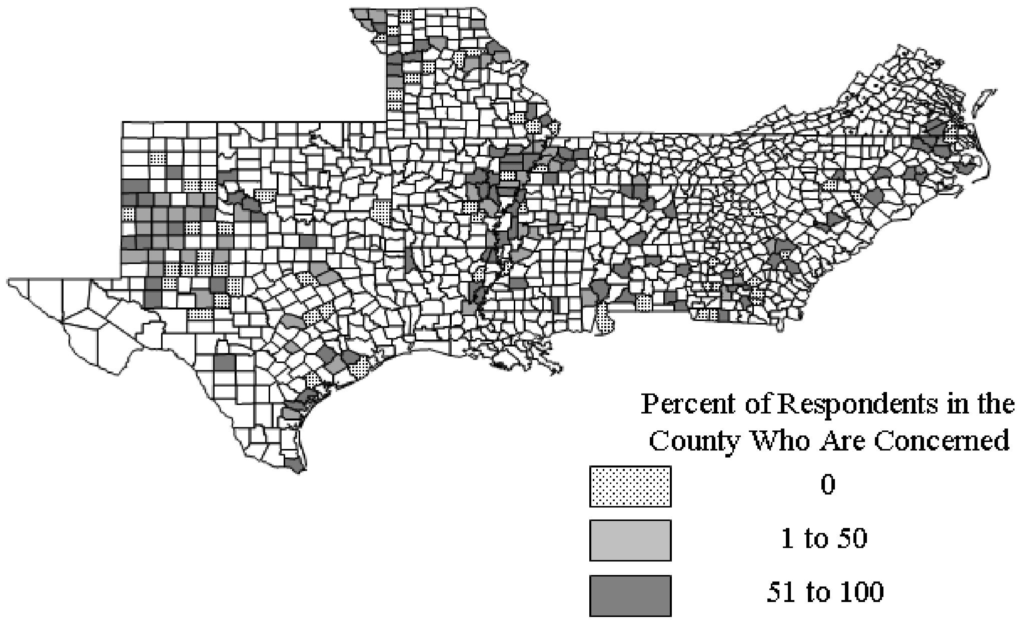

Figure 3: Spatial distribution of weed resistance concerns (white counties not surveyed).

Figure 4 shows the average responses for the weed BMP and herbicide choice responses. Scouting before and after herbicide applications; starting with a clean field; controlling weeds early; preventing weed escapes; buying new seed; and using the recommended application rate are all commonly used BMPs. Cleaning equipment, multiple herbicides, and supplemental tillage are less commonly used BMPs. Growers rated yield loss, consistency, family health, and crop safety as the most important factors used to choose herbicides. The least important factors were wildlife quality, erosion control, and application timing.

Table 5 reports regression results and, since the regression model is linear, coefficients can be directly interpreted in terms of changes in planned acreage. As expected for a downward sloping demand, increased production costs due to an increase in the price of RR seed or the cost of a residual herbicide application reduced the number of acres growers planned to plant with RR cotton and RR cotton with a residual herbicide. Interestingly, decreases in RR cotton acres due to increases in production costs tend to result from decreases in RR cotton acres that are planned to be treated with residual herbicides.

In terms of the control variables, there were significant differences ($\chi^2(14) = 74$) across states for plans to plant RR cotton and to treat RR cotton with a residual herbicide. Interestingly, in Arkansas, Alabama, and Tennessee where glyphosate resistant weeds are more widespread, growers planned to plant significantly more RR acres without a residual herbicide and significantly fewer RR acres with a residual herbicide. In North and South Carolina where glyphosate resistant weeds are also more widespread, growers planned to plant significantly fewer RR acres with a residual herbicide. Growers with less diversified crop production and who rely more on custom hire herbicide applications planned to plant significantly more RR acres. Growers who raise livestock and operated in counties with a high yield coefficient of variation planned to plant significantly more RR acres without a residual herbicide and significantly fewer RR acres with a residual herbicide.

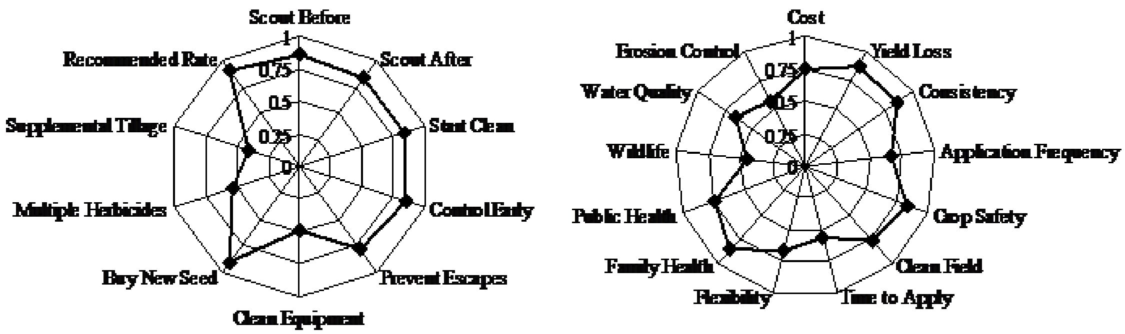

Figure 4: Average weed BMP and herbicide choice responses.

Growers in counties with glyphosate resistant weeds planned to plant significantly more RR acres. Those with a higher proportion of counties with glyphosate resistance in their crop reporting district planned to plant significantly fewer acres of RR acres without a residual herbicide and significantly more RR acres with a residual herbicide.

In terms of weed BMPs, growers who scout before herbicide applications more often planned to plant significantly more RR acres and RR acres without a residual herbicide. Those who scout after herbicide applications more often planned to plant significantly more RR acres and RR acres without a residual herbicide, but significantly fewer RR acres with a residual herbicide. Those who control weeds early and use the recommended application rate more often planned to plant significantly more RR acres, while those who clean their equipment and use supplemental tillage for weed control more often planned to plant significantly fewer RR acres. Those who prevent weed escapes and use multiple herbicides more often planned to plant significantly fewer RR acres without a residual herbicide, but significantly more RR acres with a residual herbicide. Those who use saved seed more often planned to plant significantly fewer RR acres and RR acres without a residual herbicide, and significantly more RR acres with a residual herbicide.

Growers who were more concerned with weed control costs, yield loss, and public health planned to plant significantly fewer RR acres. These results suggest that pecuniary factors that directly influence grower profit (e.g. costs and revenues from yield) are not as important to RR cotton growers. They also suggest non-pecuniary concerns with RR cotton in terms of public health. Growers who are more concerned about having a clean field and family health planned to plant significantly more RR acres, which suggest that these non-pecuniary factors are an important source of benefits derived from planting RR cotton. Those who thought yield loss and wildlife quality are more of a concern planned to plant significantly fewer RR acres without a residual herbicide and significantly more RR acres with a residual herbicide. Those relatively more concerned about the time it take to apply herbicides and crop safety planned to plant significantly more RR acres without a residual herbicide and significantly fewer RR acres with a residual herbicide. Those who thought cost was of greater importance planned to plant significantly fewer RR acres without a residual herbicide, while those who thought family health was of greater importance planned to plant significantly more RR acres with a residual herbicide.

The median benefit of planting RR cotton implied by these demand estimates was $7.69 per acre, with a 90 percent confidence interval of [$6.92, $8.71]. The benefit estimate for RR cotton without a residual herbicide was $11.68 per acre with a 90 percent confidence interval of [$7.39, $16.60], while the benefit estimate with a residual herbicide treatment was $6.39 per acre with a 90 percent confidence interval of [$5.35, $7.83].

Table 5: Demand estimates for RR cotton acres and RR cotton acres with and without a residual herbicide.

Variable	Roundup Ready®	Roundup Ready® Without Residual	Roundup Ready® With Residual
Change in RR Seed Price	-297.5***	77.7	
Change in Residual Herbicide Application Cost	-278.2***	97.1	
Change in RR Seed Price & Residual Herbicide Application Cost			-375.2***
Intercept (Missouri)	2930.5***	-749.9	3680.5**
Alabama	-1960.2***	1360.3	-3320.5***
Arkansas	-1389.2	4066.4**	-5455.6***
Georgia	-50	-1073.9	1023.9
Louisiana/Mississippi	-237.4	3186.9***	-3424.4***
North Carolina/South Carolina/Virginia	-1085.3**	692.1	-1777.4**
Tennessee	-1496.4*	3358.3*	-4854.6***
Texas/Oklahoma	-710.7*	-1706.4**	995.7
Education (Years)	-40.4	24.5	-64.9
Experience Farming (Years)	-3.90111	-1.71184	-2.19
Herfindahl Index	1177.2**	-231.9	1409.2
Percent Owned Crop Acres	0.395	5.54	-5.15
Raise Livestock	256.2	914.8**	-658.6*
Uses Custom Hire Applications	427.1**	54.3	372.8
Percent Yield Difference from County Average	2.31	-5.88*	8.18**
County Yield Coefficient of Variation	506.7	7524.7***	-7018.0***
Resistance Concerns	93.8	-38.1	131.8
Resistance in County	1680.4**	551.7	1128.7
Percent Counties in Crop Reporting District with Resistance	-3.71	-56.7**	53.0**
Incomplete Responses to Weed BMP & Herbicide Choice Questions	-2784.9***	-2784.9***	
Scout Before	585.0***	1036.5**	-451.5
Scout After	525.4***	1561.0***	-1035.6**
Start Clean	152.5	-498	650.5
Control Early	464.9*	717.2	-252.3
Prevent Escapes	-50.4	-1640.9**	1590.5**
Clean Equipment	-417.0*	-375.5	-41.5
Buy New Seed	604.4**	2007.7***	-1403.3*
Multiple Herbicides	-199.9	-3950.2***	3750.3***
Supplemental Tillage	-802.9***	-404	-398.8
Recommended Rate	1095.0***	438.6	656.4
Cost	-764.8***	-842.8**	78
Yield Loss	-428.2*	-1098.4***	670.2***
Consistency	-84.9	-287.6	202.7
Application Frequency	-69.7	129.6	-199.3
Crop Safety	129.9	671.7***	-541.8**
Clean Field	327.1**	522.4	-195.3
Time to Apply	196.4	679.3**	-482.9
Flexibility	-127.3	173.2	-300.6
Family Health	933.7**	476.4	457.3**
Public Health	-323.9**	-165.5	-158.5
Wildlife Quality	102.1	-1737.7***	1839.7***
Water Quality	495.9***	208.9	287
Soil Erosion	-39.1	-450.3	411.2
Maximized Value of Log-Likelihood Function		-2771.00	
Observations		898	

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

Conclusions

RR cotton provides substantial benefits to growers, which has resulted in widespread adoption. The widespread use of glyphosate has naturally accompanied the adoption of RR cotton. The increased use of glyphosate has been accompanied by an increase in the appearance of glyphosate resistant weeds. Glyphosate resistant weeds threaten the sustainability of the RR cotton weed management program, but the risk of weeds developing glyphosate resistance can be mitigated with the adoption of a variety of weed BMPs. The results of this paper suggest that many growers recognize the value of adopting a variety of weed BMPs including the incorporation of a residual herbicide into their RR program. The results however do raise some concerns. Growers in states with more widespread glyphosate resistance appear to have a strong preference for using the RR program without a residual herbicide and weed resistance concerns do not appear to be increasing grower interest in treating more of their RR acres with a residual herbicide. However, growers in crop reporting districts with more widespread resistance do express a preference for incorporating a residual herbicide into their RR program. Together, these results suggest that in the late Fall of 2007 growers were planning to be reactive in their response to glyphosate resistance rather than proactive (Mueller et al., 2005). The question this raises is whether it is possible to encourage growers to become more proactive and less reactive in order to stop glyphosate resistance before it gets started. Observations from agriculture professionals in 2008 suggest that growers may indeed be starting to act more proactively. Further research is needed to explore the strength of this trend and the factors driving it.

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