Valuing the Roundup Ready® Soybean Weed Management Program

Authors
Stephen Aultman, University of Minnesota

Terrance M. Hurley, University of Minnesota
Department of Applied Economics
Room 231J Classroom-Office Building
1994 Buford Avenue
University of Minnesota
St. Paul, MN 55108-6040
Telephone: (612)-625-7028
Fax: (612)-625-6245
E-Mail: tmh@ umn.edu.

Paul D. Mitchell, University of Wisconsin

George Frisvold, University of Arizona

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ABSTRACT

This study examines soybean grower adoption of the Roundup Ready® (RR) weed management program with and without a residual herbicide application, and grower concerns regarding weed resistance to herbicides using telephone survey data from of 357 growers in 2007. It also estimates the pecuniary and non-pecuniary benefits enjoyed by growers from their RR program. The results indicate that soybean growers planned to treat 29 percent of their RR acres with a residual herbicide in 2008. More than half (53%) of the growers survey were concerned about weed resistance. The estimated expected benefit of the RR program in 2008 was $10.17 per acre, which translates into about $727 million with 75.7 million acres of soybean in the U.S. in 2008. The estimated value per acre of the RR program with and without a residual was $8.78 and $12.83. The estimates also suggest that if growers were not using residual herbicides with the RR program, their benefits would be 28.4% lower. Alternatively, if all growers were required to use residual herbicides on their RR acres, the value of the RR program would be 46% lower. Simply increasing grower weed resistance concerns could increase residual herbicide use on RR acres by up to 7%. The same increase in residual herbicide use could be accomplished by decreasing the cost of residual herbicide applications on RR acres by $0.81 per acre.

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 always 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 crop 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 on their crop for weed control. Glyphosate is an effective and relatively inexpensive broad spectrum herbicide. To be effective, it must be sprayed on actively growing plants, so it does not provide residual control for weeds that have not emerged. The evolution of weed resistance to glyphosate poses a challenge to the sustainability of RR crops that could reduce the benefits growers expect. Table 1 shows how the number and range of glyphosate resistant weeds has been increasing since the commercialization of RR crops. Therefore, there is increasing interest in identifying production practices to reduce the risk of weed resistance to glyphosate and to maintain the benefits of RR crops to growers. One practice that has been proposed is the incorporation of a residual herbicide into the RR weed management program. Using a residual herbicide in addition to glyphosate mitigates or reduces the risk of resistance because residual herbicides control weeds that escape glyphosate control.

The purpose of this study is to determine the extent to which soybean growers are using residual herbicides in their RR programs and to estimate the benefits of the RR program to growers with and without the incorporation of a residual herbicide. We also examine how weed resistance concerns are affecting the use of residual herbicides in the RR program and the benefits of the RR program to growers. The contribution of the study is threefold. First, it develops and employs a new methodology for estimating the benefits of RR crops that addresses some of the weakness found in previous studies. Second, it is the first study to explore how residual herbicide use and weed resistance concerns affect the value of the RR program to growers. Third, the results make it possible to explore how educational efforts that increase weed resistance concerns or price incentives might be used to promote the use of residual herbicides in the RR program.

The results of the study indicate that soybean growers planned to treat 29 percent of their RR acres with a residual herbicide in 2008. Over half (53%) were concerned about weed resistance. The estimated expected benefit of the RR program for the 2008 growing season was $10.17 per acre, which translates into about $727 million with 75.7 million acres of soybean planted in the U.S. in 2008. The estimated value per acre of the RR program with and without a residual was $8.78 and $12.83. The estimates suggest that if growers were not using residual herbicides with the RR program, their benefits would be 28.4% lower. Alternatively, if all growers were required to use residual herbicides on their RR acres, the value of the RR program would be 46% lower. Increasing grower weed resistance concerns could increase residual herbicide use on RR acres by up to 7%. The same increase in residual herbicide use could be accomplished by decreasing the cost of residual herbicide applications on RR acres by $0.81 per acre.

MATERIALS & METHODS

A key challenge to assessing the benefits of RR crops 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 planting RR crops. Therefore, studies that focus solely on profitability (e.g. Duffy and Ernst, 1999; and Fernandez-Cornejo and McBride, 2002) can provide misleading estimates. 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, and what value, if any, would you place on all the benefits the RR weed management program provides?[1] A potential weakness of this methodology is that it requires growers to assign dollar denominated values in an unfamiliar context.

Alternatively, Piggott and Marra (2008) propose a derived demand approach for better understanding how pecuniary and non-pecuniary benefits affect the adoption of crops like RR soybean. This approach appears well suited for also evaluating the pecuniary and non-pecuniary

[1] These questions are examples of the types of questions asked by other authors. They are not the exact questions used by other authors.

benefits of RR crops using common economic measures of welfare like consumer surplus. Calculating the consumer surplus generated by the adoption of RR crops requires estimates of a grower's marginal net benefit from planting RR crops. These marginal net benefit estimates can be obtained by eliciting quantity (e.g. acres of RR crops) and price information (e.g. the price of RR seed) from growers, which is more consistent with the context in which growers make production decisions.

Conceptual Model

The model proposed by Piggott and Marra (2008) can be extended to include the adoption of RR soybean with and without a residual herbicide treatment. Let $A > 0$ be the total acreage of land available to a grower for soybean production. The grower uses this acreage to plant conventional ($A^C \geq 0$) and RR ($A^B \geq 0$) crop varieties such that $A = A^C + A^B$. Some of this RR acreage is planted without a residual herbicide ($A^{B0} \geq 0$), while some is planted with a residual herbicide ($A^{B1} \geq 0$) such that $A^B = A^{B0} + A^{B1}$. Soybean yield ($y \geq 0$) depends on the distribution of conventional, RR without a residual, and RR with a residual acres: $y = f(A^{B0}, A^{B1}, A^C)$ where $\frac{\partial f\left(A^{B0}, A^{B1}, A^C\right)}{\partial A^k} > 0$ and $\frac{\partial f^2\left(A^{B0}, A^{B1}, A^C\right)}{\partial A^{k^2}} < 0$ for $k = B0, B1, C$. If the price a grower receives for soybeans is p^y, and the price per acre a grower pays to plant conventional, RR without a residual, and RR with a residual acres is r^C, r^{B0}, and r^{B1}, grower profit from soybean production can be written as

$$(1) \qquad p\left(A^{B0}, A^{B1}, A^C; p^y, r^{B0}, r^{B1}, r^C\right) = p^y f\left(A^{B0}, A^{B1}, A^C\right) - r^{B0}A^{B0} - r^{B1}A^{B1} - r^C A^C.$$

Equation (1) describes the pecuniary benefits of soybean production. To capture non-pecuniary benefits, Piggott and Marra (2008) assume that these profits are used to support the consumption of some composite good x with a price p^x and that planting RR acres provides other goods for growers to consume: $q(A^{B0}, A^{B1})$ where $\frac{\partial q\left(A^{B0}, A^{B1}\right)}{\partial A^k}$ > for $k = B0, B1$ if planting more of the kth RR acres provides non-pecuniary benefits.[2] With these assumptions, the benefit to a grower from soybean production can be written as $U(x, q(A^{B0}, A^{B1}))$ where $\frac{\partial U\left(x, q\left(A^{B0}, A^{B1}\right)\right)}{\partial x} > 0$, $\frac{\partial U\left(x, q\left(A^{B0}, A^{B1}\right)\right)}{\partial q\left(A^{B0}, A^{B1}\right)} > 0$, $\frac{\partial^2 U\left(x, q\left(A^{B0}, A^{B1}\right)\right)}{\partial x^2} < 0$, and $\frac{\partial^2 U\left(x, q\left(A^{B0}, A^{B1}\right)\right)}{\partial q\left(A^{B0}, A^{B1}\right)^2} < 0$, which simply says that the benefits of consumption increase at a decreasing rate.

The grower's decision problem is

$$(2) \qquad \max_{x \geq 0,\, A^{B0} \geq 0,\, A^{B1} \geq 0} U\left(x, q\left(A^{B0}, A^{B1}\right)\right) \text{ subject to } \qquad A = A^C + A^{B0} + A^{B1} \text{ and}$$

$$p^x x = p\left(A^{B0}, A^{B1}, A^C; p^y, r^{B0}, r^{B1}, r^C\right),$$

or, incorporating the constraints, equation (2) implies $U(A^{B0}, A^{B1}; A, p^y, p^x, r^{B0}, r^{B1}, r^C) = U\left(\frac{p\left(A^{B0}, A^{B1}, A - A^{B0} - A^{B1}; p^y, r^{B0}, r^{B1}, r^C\right)}{p^x}, q\left(A^{B0}, A^{B1}\right)\right)$, and can be rewritten as

$$(2') \qquad \max_{A^{B0} \geq 0,\, A^{B1} \geq 0} U\left(A^{B0}, A^{B1}; A, p^y, r^{B0}, r^{B1}, r^C\right) \qquad \text{subject to} \qquad A \geq A^{B0} + A^{B1}.$$

[2] An example of a possible non-pecuniary benefit for planting RR acres without a residual herbicide is the increased flexibility in timing herbicide applications. An example of a possible non-pecuniary benefit for planting RR acres with a residual herbicide is the decreased risk glyphosate resistance.

The Lagrangian for this problem is

(3) $$L = U\left(A^{B0}, A^{B1}; A, p^y, r^{B0}, r^{B1}, r^C\right) + l\left(A - A^{B0} - A^{B1}\right),$$

which has the first-order conditions

(4) $$\frac{\partial L}{\partial A^{Bk}} = \frac{\partial U}{\partial x}\left(\frac{p^y}{p^x}\frac{\partial f}{\partial A^{Bk}} - r^{Bk} - \left(\frac{p^y}{p^x}\frac{\partial f}{\partial A^C} - r^C\right)\right) + \frac{\partial U}{\partial q}\frac{\partial q}{\partial A^{Bk}} - l \le 0,$$

$\frac{\partial L}{\partial A^{Bk}} A^{Bk^*} = 0$, $A^{Bk^*} \ge 0$, $\frac{\partial L}{\partial l} = A - A^{B0} - A^{B1} \ge 0$, $\frac{\partial L}{\partial l} l^* = 0$, and $l^* \ge 0$.

Assuming a solution exists, if it is optimal for a grower to plant conventional, RR without a residual, and RR with a residual, these first-order conditions imply

(5) $$\frac{p^y}{p^x}\frac{\partial f}{\partial A^{B0}} + \frac{\frac{\partial U}{\partial q}}{\frac{\partial U}{\partial x}}\frac{\partial q}{\partial A^{B0}} - r^{B0} = \frac{p^y}{p^x}\frac{\partial f}{\partial A^{B1}} + \frac{\frac{\partial U}{\partial q}}{\frac{\partial U}{\partial x}}\frac{\partial q}{\partial A^{B1}} - r^{B1}$$ and

(6) $$r^{Bk} = \frac{p^y}{p^x}\frac{\partial f}{\partial A^{Bk}} + \frac{\frac{\partial U}{\partial q}}{\frac{\partial U}{\partial x}}\frac{\partial q}{\partial A^{Bk}} - \left(\frac{p^y}{p^x}\frac{\partial f}{\partial A^C} - r^C\right)$$ for k = 0, 1.

The left-hand-side of equation (5) is the marginal net benefit of planting an additional RR acre without a residual, while the right-hand-side is the marginal net benefit of planting an additional RR acre with a residual. The first term on both sides of the equation reflect the marginal pecuniary benefits, while the second term captures the marginal non-pecuniary benefits. Equation (6) says that a grower should set the price of an acre of RR soybeans equal to the gross marginal benefit of RR soybeans minus the marginal net benefit from planting an addition acre of conventional soybeans. If a grower plants conventional and RR without a residual or conventional and RR with a residual, equation (5) is no longer applicable, but equation (6) still is for the relevant RR crop acres. If a grower only plants RR with and without a residual, then equation (5) and $A = A^{B0} + A^{B1}$ are relevant, but equation (6) is not. If the grower only plants RR with a residual or RR without a residual, equation (4) implies

$$(7) \qquad r^{Bk} + l = \frac{p^y}{p^x}\frac{\partial f}{\partial A^{Bk}} + \frac{\frac{\partial U}{\partial q}}{\frac{\partial U}{\partial x}}\frac{\partial q}{\partial A^{Bk}} - \left(\frac{p^y}{p^x}\frac{\partial f}{\partial A^C} - r^C\right)$$

for the relevant RR crop acres. Equation (7) says that the gross marginal benefit of the RR crop acres minus the marginal net benefit of conventional crop acres must be greater than the price of the RR crop. The final scenario that is possible is if it is optimal for the grower to plant only conventional soybeans. If this is the case,

$$(8) \qquad r^{Bk} \geq \frac{p^y}{p^x}\frac{\partial f}{\partial A^{Bk}} + \frac{\frac{\partial U}{\partial q}}{\frac{\partial U}{\partial x}}\frac{\partial q}{\partial A^{Bk}} - \left(\frac{p^y}{p^x}\frac{\partial f}{\partial A^C} - r^C\right) \text{ for } k = 0, 1,$$

which implies the gross marginal benefit for each RR crop acre minus the net marginal benefit of the conventional crop must be less than the price of the RR crop.

The solution to equation (2'), A^{B0*} and A^{B1*}, are demands for RR acres without and with a residual herbicide: $A^{B0*} = A^{B0}(A, p^x, p^y, r^{B0}, r^{B1}, r^C)$ and $A^{B1*} = A^{B1}(A, p^x, p^y, r^{B0}, r^{B1}, r^C)$. These demands can be used to calculate consumer surplus in order to measure the benefits of the RR acres to growers. These benefits are net of what the grower would have earned from planting conventional acres and include the non-pecuniary, as well as pecuniary, benefits enjoyed by the grower. For example, if $\frac{\partial A^k\left(A, p^x, r^{B0}, r^{B1}, r^C\right)}{\partial r^k} < 0$ for k = B0, B1, these demands can be inverted:

$$(9) \qquad r^{B0} = A^{B0^{-1}}\left(A, A^{B0^*}, p^x, p^y, r^{B1}, r^C\right) = \frac{p^y}{p^x}\frac{\partial f}{\partial A^{B0}} + \frac{\frac{\partial U}{\partial q}}{\frac{\partial U}{\partial x}}\frac{\partial q}{\partial A^{B0}} - \left(\frac{p^y}{p^x}\frac{\partial f}{\partial A^C} - r^C\right) \text{ and}$$

$$(10) \qquad r^{B1} = A^{B1^{-1}}\left(A, A^{B1^*}, p^x, p^y, r^{B0}, r^C\right) = \frac{p^y}{p^x}\frac{\partial f}{\partial A^{B1}} + \frac{\frac{\partial U}{\partial q}}{\frac{\partial U}{\partial x}}\frac{\partial q}{\partial A^{B1}} - \left(\frac{p^y}{p^x}\frac{\partial f}{\partial A^C} - r^C\right).$$

Letting acreage vary from the optimum yields the marginal benefit functions:

$$(11) \qquad MB^{B0}\left(A^{B0}; A, p^x, p^y, r^{B1}, r^C\right) = A^{B0^{-1}}\left(A, A^{B0}, p^x, p^y, r^{B1}, r^C\right) \text{ and}$$

(12) $$MB^{B1}\left(A^{B1}; A, p^x, p^y, r^{B0}, r^C\right) = A^{B1^{-1}}\left(A, A^{B1}, p^x, p^y, r^{B0}, r^C\right).$$

Subtracting the price of RR acreage and integrating to the optimal RR acreage produces the consumer surplus for each crop: CS^{B0} = $\int_0^{A^{B0*}}\left(MB^{B0}\left(A^{B0}; A, p^x, p^y, r^{B1}, r^C\right) - r^{B0}\right)dA^{B0}$ and CS^{B1} = $\int_0^{A^{B1*}}\left(MB^{B1}\left(A^{B1}; A, p^x, p^y, r^{B0}, r^C\right) - r^{B1}\right)dA^{B1}$. Summing yields the total consumer surplus from the RR crop: $CS^B = CS^{B0} + CS^{B1}$. Figure 1 illustrates this consumer surplus when conventional, RR without a residual, and RR with a residual acres are planted. Figure 2 illustrates when only RR without a residual and RR with a residual acres are planted.

Data

Calculating grower consumer surplus for RR crop production requires estimates of the marginal net benefit for RR acres without and with a residual: $MB^{B0}(A^{B0}; A, p^y, p^x, r^{B1}, r^C) - r^{B0}$ and $MB^{B1}(A^{B1}; A, p^y, p^x, r^{B0}, r^C) - r^{B1}$. The data needed to estimate these marginal net benefits was collected by a telephone survey of 402 growers (357 or 89% useable for this analysis) from 10 states (Arkansas, Illinois, Indiana, Iowa, Minnesota, Missouri, Nebraska, North Dakota, Ohio, and South Dakota) with more than 250 acres of soybean 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 a grower and his farming operation in 2007.
2. Detailed information on the grower's 2007 production practices.

3. Information on how often the grower used various weed best management practices.
4. Information on how important various factors were to the grower in terms of his herbicide choices.
5. A grower's plans to plant soybean in 2008 including plans to plant RR soybean without and with a residual herbicide.
6. Information on how a grower's plans would change if the price of RR soybean seed changed or the cost of a residual herbicide application on RR acres decreased.
7. Open ended information on a grower's biggest concerns in terms of weed management.

The survey data was supplemented with county crop data for average soybean yields over the past ten years acquired from the U.S. Department of Agriculture National Agricultural Statistics Service (USDA/NASS, http://www.nass.usda.gov).

The information from the survey used for the analysis included:

1. How many acres of soybean the grower planned to plant in 2008.
2. How many of these soybean acres would be conventional varieties, RR varieties, and RR varieties with a residual herbicide treatment.
3. If the grower planned to plant RR acres in 2008, how many of these soybean acres would be conventional varieties, RR varieties, and RR varieties with a residual herbicide application assuming the price of RR seed increased (see Table 2 for the proposed price increases).[3]
4. If the grower did not plan to plant RR acres in 2008, how many of these soybean acres would be conventional varieties, RR varieties, and RR varieties with a residual herbicide application assuming the price of RR seed decreased (see Table 2 for the proposed price decreases).[2]

[3] Proposed price changes were randomly assigned across surveys.

5. If the grower planned to plant RR acres in 2008, how many of these soybean acres would be conventional varieties, RR varieties, and RR varieties with a residual herbicide application assuming the price of a residual herbicide application decreased (see Table 2 for the proposed price decreases).[2,4]
6. Whether or not the grower was concerned about weed resistance (1 if the grower mentioned weed resistance as one of his biggest weed management concerns and 0 otherwise).
7. The grower's years of formal education (12 if the grower completed high school; 14 if the grower completed some college or vocational/technical training; 16 if the grower completed college; and 18 if the grower had an advanced degree).
8. The number of years the grower had been farming.
9. The number of crop acres the grower operated in 2007.
10. A Herfindahl index for crop diversity (constructed using the grower's total crop acres reported in 2007 and the number of those acres planted with corn, cotton, soybean, and some other crop).
11. Whether or not the grower raised livestock in 2007 (1 if the grower raised livestock and 0 otherwise).
12. The percentage of crop acreage operated that the grower owned in 2007.
13. Whether or not the grower used custom hired herbicide applicator services in 2007 (1 if custom hired herbicide applicator services were used and 0 otherwise).
14. The percentage difference in the grower's expected average soybean yield for 2008 and the ten-year county average yield.

[4] The order in which growers were asked to respond to a change in the RR seed price and a decrease in the residual herbicide application cost was randomized across surveys to avoid order effects.

15. The coefficient of variation for the ten-year county average yield.
16. The state in which the grower operated (1 if the grower operated in a particular state and 0 otherwise).

Total planned RR acres and RR acres with a residual herbicide application under the three alternative price scenarios served as our dependent variables. The independent variables included the proposed change in the price of RR seed and proposed decrease in the cost of a residual herbicide application. They also included the grower's education level, years of experience, and weed resistance concerns to control for individual differences in human capital and weed management concerns; crop acres to control for the size of the farming operation; a Herfindahl index, livestock indicator variable, and custom applicator use indicator variable to control for differences in diversification and labor utilization across operations; the percentage difference in the expected yield and ten-year county average, and the ten-year county average yield coefficient of variation to control for idiosyncratic spatial differences in land productivity and production risks; and state indicators to control geopolitical and cultural differences faced by growers.

Econometric Methods

Assume that grower demand for RR acreage without and with a residual are linear functions of own and cross-price effects:

(13) $A^{B0} = q^{B0} + Xb^{B0} - a^{B0}r^{B0} + j^{B0}r^{B1}$ and

(14) $A^{B1} = q^{B1} + Xb^{B1} - a^{B1}r^{B1} + j^{B1}r^{B0}$

where q^{B0} and q^{B1} are intercept parameters; X is a row vector of control variables; b^{B0} and b^{B1} are column vectors of control variable parameters; a^{B0} and a^{B1} are parameters that capture own-price effects; and j^{B0} and j^{B1} are parameters that capture cross-price effects. To estimate the parameters in equations (13) and (14) with the available data, they can be rewritten as

(13') $A_{it}^{B0} = q^{B0} + X_i b^{B0} - a^{B0}\left(r_i^{B0} + \Delta r_{it}^{B0}\right) + j^{B0}\left(r_i^{B1} + \Delta r_{it}^{B1}\right) + e_{it}^{B0}$ and

(14') $A_{it}^{B1} = q^{B1} + X_i b^{B1} - a^{B1}\left(r_i^{B1} + \Delta r_{it}^{B1}\right) + j^{B1}\left(r_i^{B0} + \Delta r_{it}^{B0}\right) + e_{it}^{B1}$

where A_{it}^{B0} and A_{it}^{B1} are the RR acreage without and with a residual herbicide reported by the *i*th grower under price scenario *t* (*t* = 0 for no change in the RR seed price or residual herbicide application cost, *t* = 1 for a change in the RR seed price, and *t* = 2 for a decrease in the residual herbicide application cost); X_i is a vector of the *i*th grower's control variables; Δr_{it}^{B0} and Δr_{it}^{B1} are the change in RR acreage production cost without and with a residual herbicide under price scenario *t*; and e_{it}^{B0} and e_{it}^{B0} are independent, mean 0, normally distributed random errors.

The first complication in estimating equations (13') and (14') is the fact that r_i^{B0} and r_i^{B1} are unobserved. This complication can be dealt with by defining $\bar{r}^{B0}$ and $\bar{r}^{B1}$ as the average prices faced by growers, such that equation (13') and (14') can be rewritten as

(13'') $A_{it}^{B0} = \Theta^{B0} + X_i b^{B0} - a^{B0}\Delta r_{it}^{B0} + j^{B0}\Delta r_{it}^{B1} + y_i^{B0} + e_{it}^{B0}$ and

(14'') $A_{it}^{B1} = \Theta^{B1} + X_i b^{B1} - a^{B1}\Delta r_{it}^{B1} + j^{B1}\Delta r_{it}^{B0} + y_i^{B1} + e_{it}^{B1}$

where $\Theta^{B0} = q^{B0} - a^{B0}\bar{r}^{B0} + j^{B0}\bar{r}^{B1}$, $y_i^{B0} = j^{B0}\left(r_i^{B1} - \bar{r}^{B1}\right) - a^{B0}\left(r_i^{B0} - \bar{r}^{B0}\right)$, $\Theta^{B1} = q^{B1} - a^{B1}\bar{r}^{B1} + j^{B1}\bar{r}^{B0}$, and $y_i^{B1} = j^{B1}\left(r_i^{B0} - \bar{r}^{B0}\right) - a^{B1}\left(r_i^{B1} - \bar{r}^{B1}\right)$. Therefore, dealing with this complication requires incorporating random grower effects into the error specification.

The second complication that emerges is that total RR acres ($A_{it}^{B} = A_{it}^{B0} + A_{it}^{B1}$) cannot exceed total soybean acres (A_i), and RR acres without and with a residual herbicide application cannot exceed total RR acres. To deal with this complication, note that

(15) $$A_{it}^{B} = \begin{cases} A_{it}^{B0}, & \text{for } A_{it}^{B0} > 0 \text{ and } A_{it}^{B1} = 0 \\ A_{it}^{B1}, & \text{for } A_{it}^{B0} = 0 \text{ and } A_{it}^{B1} > 0 \\ A_{it}^{B0} + A_{it}^{B1}, & \text{for } A_{it}^{B0} > 0 \text{ and } A_{it}^{B1} > 0 \end{cases},$$

which provides an equation for all RR acres that can be constraint by total crop acres.

Estimation was accomplished by setting Δr_{it}^{B0} equal to the change in the RR seed price if any and Δr_{it}^{B1} equal to the change in the RR seed price plus the decrease in the residual herbicide application cost if any. The row vectors

(16) $$X_{it}^{B} = \begin{cases} [1, X_i, \Delta r_{it}^{B0}, \Delta r_{it}^{B1}, 0,0,0,0], & \text{for } A_{it}^{B0} > 0 \text{ and } A_{it}^{B1} = 0 \\ [0,0,0,0,1, X_i, \Delta r_{it}^{B1}, \Delta r_{it}^{B0}], & \text{for } A_{it}^{B0} = 0 \text{ and } A_{it}^{B1} > 0 \\ [1, X_i, \Delta r_{it}^{B0}, \Delta r_{it}^{B1}, 1, X_i, \Delta r_{it}^{B1}, \Delta r_{it}^{B0}], & \text{for } A_{it}^{B0} > 0 \text{ and } A_{it}^{B1} > 0 \end{cases}, \text{ and}$$

(17) $X_{it}^{B1} = [0,0,0,0,1, X_i, \Delta r_{it}^{B1}, \Delta r_{it}^{B0}]$

were created for each grower and treatment. The row vectors from equation (16) were stacked to create a matrix $\mathbf{X^B}$, while the row vectors for equation (17) were stacked to create a matrix $\mathbf{X^{B1}}$. Total RR acres reported by a grower for each treatment were stacked corresponding to equation (16) to form the column vector $\mathbf{A^B}$, while RR acres with a residual were stacked corresponding to equation (17) to form the column vector $\mathbf{A^{B1}}$. Finally, the column vector

(18) $\mathrm{B} = \left[\Theta^{B0}, b^{B0}, a^{B0}, j^{B0}, \Theta^{B1}, b^{B1}, a^{B1}, j^{B1}\right]^T$

was defined. The final model that was estimated was

(19) $\begin{bmatrix} \mathbf{A^B} \\ \mathbf{A^{B1}} \end{bmatrix} = \begin{bmatrix} \mathbf{X^B} \\ \mathbf{X^{B1}} \end{bmatrix} \mathbf{B} + \Psi + \mathrm{E}$

where Y is a column vector of grower and crop (either total RR acres or RR acres with a residual) specific random errors, and crop E is a column vector of random errors. Equation (19) was estimated using STATA's xttobit command. The xttobit command permits upper and lower constraints for each observation. The lower constraint was set to 0 for all observations, while the upper constraint was set to a grower's total soybean acres for the total RR acres observations and RR soybean acres for the RR acres with a residual observations. The xttobit command also permits estimation with random effects within groups of observations for the y errors. For these random effects, observations were grouped based on the grower and whether the observation was for total RR acres or RR acres with a residual.

With estimates for equation (19) in hand, the expected marginal net benefit can be found by realizing equations (13) and (14) imply the marginal net benefits:

$$
\begin{aligned}
MNB_i^{B0} &= \frac{q^{B0} + X_i b^{B0} - A_{it}^{B0} + j^{B0} r_i^{B1}}{a^{B0}} - r_i^{B0} \\
&= \frac{\Theta^{B0} + X_i b^{B0} - A_{it}^{B0} + y_i^{B0}}{a^{B0}}
\end{aligned}
\qquad (20)
$$

and

$$
\begin{aligned}
MNB_i^{B1} &= \frac{q^{B1} + X_i b^{B1} - A_{it}^{B1} + j^{B1} r_i^{B0}}{a^{B1}} - r_i^{B1} \\
&= \frac{\Theta^{B1} + X_i b^{B1} - A_{it}^{B1} + y_i^{B1}}{a^{B1}}
\end{aligned}
\qquad (21)
$$

.

The challenge to using equations (20) and (21) for calculating consumer surplus given estimates form equation (19) is that y_i^{B0} and y_i^{B1} are random. Therefore, Palisade @Risk and Monte-Carlo simulation was used to calculate the average consumer surplus where y_i^{B0} and y_i^{B1} are drawn randomly for each grower in each iteration assuming a normal distribution with mean 0 and a variance equal to the estimated variance for the random grower effects from the xttobit results.

RESULTS

Table 3 reports descriptive statistics for the dependent and control variables, and the results of running the stacked regression. On average, growers in the sample planned to plant 587 acres of soybean in 2008. Almost all these acres (97%) were expected to be planted with RR varieties. Just under a third (29%) of these RR acres were expected to be treated with a residual herbicide. Just over half (53%) of these growers were concerned about weed resistance. The average education was about two years of college and average farming experience was almost three decades. They operated more than 1,000 acres of cropland in 2007, which was split fairly equally between corn and soybean (e.g. Herfindahl index of 0.49). One-third had livestock operations. They owned about 40% of the cropland they operated, while 45% relied on custom herbicide applicator services. They expected their 2008 yields to exceed the ten-year county average by 23% (e.g. Yield Difference). The majority of respondents (60%) operated in Illinois, Indiana, Iowa, Minnesota, the primary soybean growing states in the U.S.

Own price effects are negative and significant as expected. Cross-price effects are positive indicating substitution between RR without and with a residual, but only significant for RR acres with a residual. Resistance concerns increase RR acres with a residual significantly as does a grower's years farming, and size of operation. The percentage of operated acreage owned by the grower significantly decreases RR acreage treated with a residual. There are also significant differences across states in the amount of RR acreage planted. Fewer RR acres without a residual are planted in Indiana and Ohio, while fewer RR acres with a residual are planted in North Dakota.

Using these regression results, the average per-acre benefit of the RR weed management program was calculated resulting in $10.17 per acre, which translates into about $727 million with 75.7 million acres of soybean planted in the U.S. in 2008 assuming the sample of growers was reasonably representative. RR acres without a residual resulted in a benefit of $8.78 per acre, while RR acres with a residual resulted in a benefit of $12.83 per acre. This result suggests growers using a residual on their RR acres perceive an added benefit, possibly attributable to the reduced risk of glyphosate resistant weeds emerging. Note that for this base case analysis the model predicted growers would plant 94.5% of their soybean acreage with RR varieties and treat 34.1% of these varieties with a residual, so the model under predicts RR acreage by 2.7 percentage points or 3% and over predicts RR acres with a residual by 4.7 percentage points or 16%.

To better understand how the availability of a residual herbicide affects the benefits of the RR program, total benefits were recalculated under the assumption that no residual herbicide was available, which resulted in a 28.4% decline. To see what might happen to grower benefits if a residual application was made compulsory in order to reduce the risk of resistant, net benefits were recalculated assuming RR acres without a residual were no longer an option for growers, which resulted in a 46% decline in total benefits. To understand how weed resistance concerns were affecting the average benefit of RR acres without and with a residual, average benefits were recalculated assuming no growers were concerned. This resulted in a decrease in the average benefit for RR acres without a residual to $8.45 per acre or 4%. For RR acres with a residual, the average benefit decreased to $12.09 or 6%. These results also indicate that more RR acres are being planted due to weed resistance concerns, which could be an indication that weed resistance concerns extend beyond glyphosate resistance.

As a final exercise to explore options for increasing the rate of residual herbicide use on RR acres, the results above were recalculated assuming all growers were concerned about weed resistance, which increased the use of a residual herbicide on RR acres by 7%. This result suggests that education programs designed to increase grower awareness of weed resistance may have relatively little impact on residual herbicide use in the RR program. It was also found that a decrease in the cost of a residual herbicide treatment of $0.81 per acre would have the same affect on the amount of RR acres planted with a residual.

CONCLUSIONS

This paper explored the benefits to soybean growers of using the Roundup Ready® (RR) weed management program using data collect from a telephone survey conducted in 2007. It also explored grower concerns regarding weed resistance, the extent to which these concerns were leading growers to incorporate residual herbicides into their RR program, and the effect of these concerns and residual herbicide use on RR program benefits. The results of the analysis suggest that the expected benefits to growers from the RR weed management program in 2008 were $727 million. Just over half of the growers surveyed were concerned about weed resistance. Growers expected to plant about a third of their RR acres with a residual herbicide, which was modestly more than what it would have been had growers not been concerned about weed resistance. Growers who planned to plant their RR acres with a residual herbicide expected higher benefits per acre than growers who did not plan to use residual herbicides, possibly due to the fact that using a residual in the RR program can help reduce the risk of glyphosate resistant weeds emerging. The results also suggest simply raising grower concerns about weed resistance may have only a modest impact on increasing the amount of RR acreage treated with a residual herbicide. Interestingly, weed resistance concerns seem to be increasing the total amount of soybean acreage planted with RR varieties, primarily through and increase in RR acreage with a residual, which suggest growers might be worried about resistance to other herbicides as well as glyphostate. Unfortunately, the current survey data is not detailed enough to determine how much of a grower's weed resistance concerns are attributable to glyposate resistance and how much are attributable to resistance to other herbicides.

Additional work needs to be done to further improve the estimates of RR benefits enjoyed by growers. The econometric model was estimated with a single random grower effect, while multiple grower random effects may indeed be present. Confidence bounds on the benefit estimates might be possible to obtain by taking into account the fact that the econometric model estimates are only estimates. It also may be possible to use the survey data to estimate demand equations with stronger links to theory such as an almost ideal demand system. With such estimates, welfare measures with stronger theoretical foundations like the equivalent and compensating variation might be used instead of consumer surplus.

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

States	Year First Discovered
Common Ragweed (*Amaranthus rudis*)	
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: Weed Science Society of America, http://www.weedscience.org/In.asp

Table 2. Price changes proposed to growers.

Price	% of Surveys
Roundup Ready® Seed Price Increase Per Acre	
Price	% of Surveys[a]
2.00	32.7
4.00	34.3
6.00	33.0
Residual Herbicide Cost Decrease Per Acre	
Price	% of Surveys
1.00	25.3
2.00	26.1
3.00	24.5
4.00	24.2
Roundup Ready Seed Price Decrease Per Acre	
Price	% of Surveys[b]
2.00	30.0
4.00	30.0
6.00	40.0

[a] Reflects percent of surveys where an increase in the price of Roundup Ready® seed was queried (i.e. surveys where growers indicated they planned to plant Roundup Ready® varieties in 2008).

[b] Reflects percent of surveys where a decrease in the price of Roundup Ready® seed was queried (i.e. surveys where growers indicated they did not plan to plant Roundup Ready® varieties in 2008).

Table 3. Regression coefficients (standard deviation).

	Descriptive Statistics	Coefficient Estimates RR Without Residual	RR With Residual
Planned Soybean Acres	587		
	(402.9)		
Planned RR Acres	571		
	(410.2)		
Planned RR Acres With Residual	168		
	(331.2)		
Own Price		-287.58***	-142.46***
		(62.87)	(23.19)
Cross-Price		27.31	62.9**
		(46.35)	(30.85)
Concerned about Resistance	0.53	161.03	378.53**
	(0.50)	(220.52	(156.56)
Years of Education	13.8	8.78	49.04
	(1.75)	(64.52)	(45.42)
Years Farming	29.3	-8.51	17.43**
	(10.46)	(11.86)	(8.30)
Crop Acres in 2007	1229	0.11	0.36***
	(767.6)	(0.15)	(0.11)
Herfindahl Index	0.49	-710.98	317.5
	(0.10)	(1131.49)	(825.83)
Livestock in 2007	0.34	277.61	205.82
	(0.48)	(242.31)	(165.04)
Percent of Acres Owned	40.7	2.15	-6.23**
	(30.86)	(3.82)	(2.67)
Use Custom Applicator	0.45	66.20	193.55
	(0.50)	(227.65)	(160.48)
Yield Difference	23.4	8.67	4.80
	(46.92)	(7.49)	(3.26)
Yield Coefficient of Variation	0.14	274.19	-1033.46
	(0.04)	(3113.92)	(2182.91)

Coefficient Significance: *, ** *** denote significance at the 10%, 5% and 1%.

Table 3. Regression coefficients (standard deviation) continued.

	Descriptive Statistics	Coefficient Estimates: RR Without Residual	RR With Residual
Arkansas	0.039	-159.82	-596.92
	(0.19)	(616.70)	(465.81)
Illinois	0.174	-250.77	-353.93
	(0.38)	(477.24)	(336.19)
Indiana	0.098	-1522.39***	416.37
	(0.30)	(508.36)	(355.32)
Iowa	0.185	-284.43	15.64
	(0.39)	(482.17)	(325.77)
Minnesota	0.140	-553.61	-512.27
	(0.35)	(465.82)	(332.34)
Missouri	0.087		
	(0.28)		
Nebraska	0.087	-2.21	705.41*
	(0.28)	(612.52)	(387.60)
North Dakota	0.053	664.96	-1394.37***
	(0.22)	(648.56)	(497.29)
Ohio	0.073	-1139.85**	517.94
	(0.26)	(559.98)	(385.79)
South Dakota	0.064	219.20	-543.74
	(0.25)	(680.10)	(426.19)
Constant		2311.91*	-1376.95
		(1296.18)	(920.09)
Standard Deviation of Grower Random Effects		1518.44***	
		(112.69)	
Standard Deviation of Regression Error		475.80***	
		(32.55)	
Correlation Coefficient		0.91**	
		(0.0137)	
Maximized Log-Likelihood		-2565.44	
Regression Significance ($\chi^2(44)$)		271.50***	
Joint Significance of States ($\chi^2(18)$)		61.29***	
Observations	357	2075	
Observations Left Censored		662	
Observations Right Censored		1188	

Coefficient Significance: *, ** *** denote significance at the 10%, 5% and 1%.

Figure 1: Illustration of consumer surplus when planting conventional acres, RR acres without a residual, and RR acres with a residual is optimal.

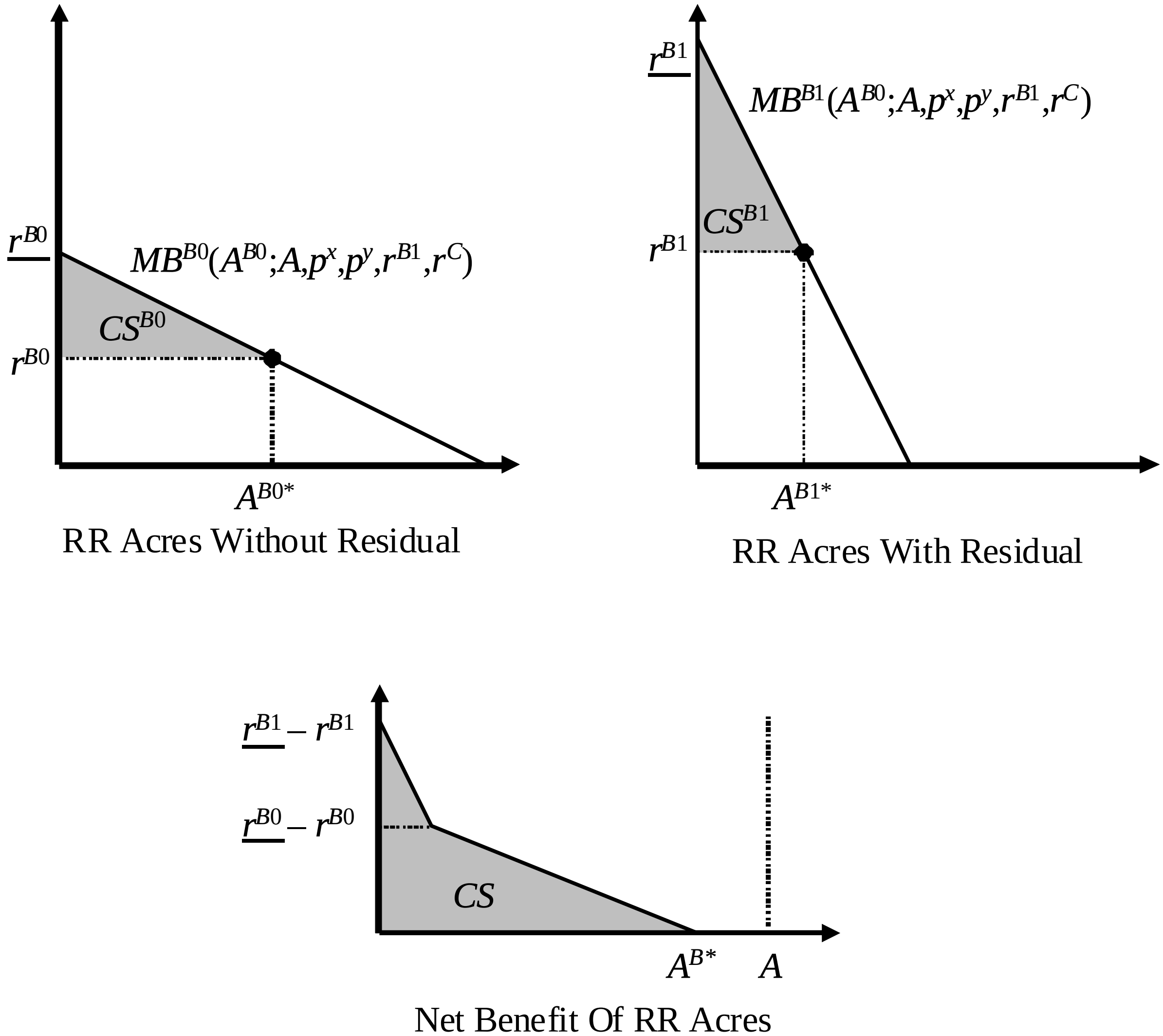

Figure 2: Illustration of consumer surplus when planting RR acre without a residual and with a residual is optimal.