THE NET BENEFITS, INCLUDING CONVENIENCE, OF ROUNDUP READY® SOYBEANS: RESULTS FROM A NATIONAL SURVEY

Michele C. Marra, Nicholas E. Piggott, and Gerald A. Carlson*

** Professor, Associate Professor, and Professor Emeritus in the Department of Agricultural and Resource Economics, North Carolina State University, Raleigh, NC 27695-8109.* *Thanks go to Olga Sydorovych for help with data and to the NSF Center for Integrated Pest Management, Raleigh, NC for funding the study through a member contribution by Monsanto Company.*

NSF Center for IPM Technical Bulletin 2004-3. 39pp
September, 2004. Raleigh, NC

EXECUTIVE SUMMARY

The reasons for choosing or not choosing to plant the Roundup Ready® soybean technology and the degree to which reduced tillage plays a role in the choice are investigated in this study. As part of this study, a national survey of soybean farmers in the United States was conducted in early 2003 by Doane's Market Research in which farmers were asked about their choice of technology type and a variety of factors that may influence their choice. These factors included both pecuniary (traded and priced in markets) and non-pecuniary (not traded in markets) characteristics of Roundup Ready soybean technology. Standard stated preference (willingness to pay) methodologies were used to elicit the values respondents placed on the non-pecuniary characteristics of the technology.

The role non-pecuniary factors play in the decision to plant Roundup Ready soybeans is clear. In particular, adopting farmers place significant value on operator and worker safety, environmental benefits, and convenience characteristics of Roundup Ready soybeans. Growers also consider costs of the new seed technology. They place a negative value on the additional market risk that may be associated with growing Roundup Ready soybeans and on the agreement not to save Roundup Ready seed for sale or planting. The value of the perceived market risk diminishes sharply as the percent of Roundup Ready soybean acres increases.

On average, non-adopters of Roundup Ready soybeans perceive a net loss of $7.55 per acre from Roundup Ready adoption. Partial adopters perceive a slightly positive net benefit of $1.36 per acre on average, and full adopters perceive a net benefit on average of $10.72 per acre.

The growers surveyed also place significant value on the environmental and convenience benefits of reduced tillage. The net benefit of Roundup Ready adoption *with* reduced tillage can be substantial, up to $37 per acre for some farmers.

The survey results also suggest that growing Roundup Ready soybeans is complementary to and associated with increased rates of reduced tillage. Roundup Ready growers make 25% fewer tillage passes over the field than growers of traditional soybean varieties. The proportion of farmers using reduced tillage on at least 50% of their soybean acres increases with Roundup Ready soybean adoption.

We find some growers' soybean acreage decisions (Roundup Ready soybean plus non-Roundup Ready soybean acres) are influenced by relative Loan Deficiency Payment rates and Agricultural Market Transition Assistance payments. In addition, some growers acreage decisions are influenced by relative soybean price and improvements in soybean seed technology.

We conclude that soybean farmers are rational in making their soybean seed decisions, taking into consideration both the relative profitability of Roundup Ready soybeans and their valuation of the relative non-pecuniary characteristics of the technology. They consider the full range of benefits and costs, both pecuniary and non-pecuniary, when choosing on which acres, if any, to plant Roundup Ready soybean technology.

INTRODUCTION

Roundup Ready® (RR) soybeans account for over 80% of U.S. soybean acreage (USDA, NASS, 2004). Many farmers are planting 100% of their soybean acreage to RR soybeans and plan to continue doing so. RR soybean adoption is still increasing even though prices of herbicides commonly used on conventional soybeans have fallen to the point that, when only monetary costs and returns are considered, conventional soybean systems are competitive with RR soybean systems.

Why then are the RR soybeans so widely used? What features of the technology cause farmers to rapidly adopt them? When asked why, many farmers answer that the RR soybean system is more "convenient," "simpler," or "safer" than a conventional system. These types of replies raise the question of whether non-traded, or non-pecuniary, aspects of the RR soybean production system impact farmers' choices. Accordingly, this study examines and quantifies these non-pecuniary aspects of the RR soybean production system.

Organization of the report is as follows. First is a general discussion of factors affecting farmers' adoption of new production technologies. Second, the evolution of soybean weed control and tillage systems over the past twenty years is described. Third is a discussion of the factors that might affect a farmer's decision about planting RR soybeans or using conservation tillage on his or her soybean acreage. Next is a brief discussion of study objectives and the methodology used, followed by survey data and final sections of the report containing the study results. Conclusions follow.

IMPORTANT FACTORS INFLUENCING PRODUCTION SYSTEM CHOICES AT THE FARM LEVEL

General Economic Issues

In his seminal work on adoption of hybrid corn in the U.S., Griliches (1960) was the first to use economic arguments to explain S-shaped adoption paths typical of new and revolutionary agricultural technologies. The adoption path for hybrid corn in the 1950s is similar in most areas to the path for RR soybeans in the late 1990s in some areas. Six years after the introduction of the first hybrid corn varieties, farmers in Iowa (Wisconsin) were planting them on about 90% (60%), of their corn acres. "The use of hybrid seed in an area also depends upon the rate at which hybrids are accepted by farmers. This rate, in turn, depends upon the profit farmers expect to realize from the shift to hybrids." (Griliches, 1960, p.280). Other studies of agricultural innovations conclude that the rate of adoption of a new innovation is the result of rational decision making on the part of farmers (see, for example, Rahm and Huffman, 1984; Marra and Carlson, 1990; or Marra, Hubbell and Carlson, 2001).

A farmer adopts a new production system or continues to use an old system based on his/her assessment of the incremental benefits of adoption compared to the incremental costs. If the expected future stream of additional benefits outweighs the expected future stream of additional costs, then the farmer will change production systems. Some of the benefits and costs may not be directly quantifiable but are important to farmers (and other decision makers).

Profitability

The new production system's relative profitability under a variety of circumstances is important to farmers. Relative profit is defined as the difference in revenue less the difference in costs for the old and new production systems. Revenue is determined by the product of price per unit and total units of production, where production is defined as crop yield times acres harvested. The price may be a factor of crop quality characteristics, government programs, and local as well as world supply and demand conditions.

Crop yield is determined by seed genetics and growing conditions. Pest management (e.g. weed control) preserves yield. When evaluating a weed management system, the relevant costs to consider are seed and herbicide costs, labor and equipment costs, any costs related to product handling, and required or voluntary herbicide safety precautions.

Convenience

Flexibility of a production system and its influence on other aspects of the farming operation can also influence technology choice. If a production system can be used successfully under a variety of circumstances, leaving farmers with more options concerning which crops to grow and inputs to use this crop year and in future years, then farmers will tend to favor it over other competing technologies. The RR soybean system has been recognized as affording outstanding flexibility because it presents no herbicide carryover problems and it is easy and convenient to use.

Farm Size and Scope. If a production system is labor- or management-saving relative to the competing technologies, it may allow more acres to be farmed with the same (or less) labor and equipment, thus providing an opportunity to earn more profit. Farm size has been increasing over time. Moreover, rented land as a proportion of total land farmed has been rising since the 1950s and by 1997 approximately 42% of land in production was rented land (USDA-

ERS, 2004). Rented land generally comprises all or parts of other farms and it is usually not contiguous to the home farm. Today, many large farms consist of tracts of owned and rented land spread over a wide area. If a new production system requires less labor and management time per acre during the growing season, it will create value for farmers with dispersed acreage and adoption will occur.

Cropping Patterns. Growing several crops in the same year allows a farmer to diversify and thereby reduce the overall price and yield risk he or she faces. Furthermore, it is not uncommon for farmers to plant several varieties of the same crop in an effort to reduce overall yield risk. As supply and demand conditions change, some crop prices will increase while others decrease. Local weather conditions may favor some crops and varieties over others, as well. Southern farmers typically produce three to five different crops on their farm in one season and farmers in the Midwest typically plant at two to three. Most farmers have some fixed level of debt payments that must be made each year, so they are looking for ways to create stable income to meet those debt payments. Even relatively debt-free farmers will diversify their crop portfolio to reduce production risk. Crop diversification is a must in production risk management.

Crop rotation (planting a different crop on the same land in two or more consecutive years) reduces some types of diseases and pest infestations and can benefit soil. Growing a number of crops can be beneficial from an agronomic standpoint, as well. The benefits from multiple crops must be balanced against the additional management time needed and additional equipment costs, however.

Corn, soybeans and wheat are the most frequently grown row crops in the Midwestern states (USDA, NASS, 2003b). Cotton and peanuts are additional crops grown on Southeastern farms, with cotton acreage increasing more recently in the South due to improved cotton pest management.

Tables 1, 2, and 3 illustrate the many activities that may be going on during the time when soybean herbicide decisions are made in a typical Southeastern state (North Carolina), a typical Western Corn Belt state (Kansas) and a typical Eastern Corn Belt state (Ohio). In all areas, winter is the "downtime", which allows for information gathering, evaluation, planning, and decision making about production systems for the next crop year. During the growing season, a typical Mid-Atlantic or Southeastern crop farmer may be harvesting wheat, planting corn or soybeans, possibly planting peanuts, in addition to planting cotton, and may be transplanting tobacco plants into the field (a labor-intensive operation) during the time period when most soybean weed control decisions are made. If the farmer is double-cropping wheat and soybeans (more than 40% of the soybean acres in the Mid-Atlantic states[1] and more than 60% in the Southeast are double-cropped)[2] then the wheat harvest is also going on during this period. In Kansas, corn, sorghum, and soybeans are planted during this period and hay and winter wheat is harvested**.** During the time Ohio farmers are making their post emergence soybean weed control decisions they may also be planting late corn and oats, and harvesting hay.

Management time is precious during this phase of the crop year. Labor and management time savings can have major impacts on profits. For instance, the relative timing of weed and crop emergence has been shown to have a major effect on the degree of weed control (Kropff, 1988; Aldridge, 1987). If crop planting is delayed on those fields where traditional soybeans are

---

[1] Mid-Atlantic RESAC, Mid-Atlantic Regional Earth Science Applications Center, Department of Geography, University of Maryland, College Park.

[2] Personal communication with Dr. James Dunphy, Professor of Crop Science and Extension Soybean Specialist, North Carolina State University.

planted, then weeds can begin to compete significantly before the crop canopy has had a chance to close. This can result in lower yields and/or higher weed control costs. If the grower implements a time-saving soybean weed control regime on part of the farm, then he/she has more time during the planting period to ensure that other crops are planted in a timely manner. Any new production system that is cost-effective (maintains or increases profit levels), easy to implement (learning time is short), easy to use, and frees labor and management time during this crucial time in the growing season will be attractive to farmers.

Soybean farmers have been using Roundup® for years as a burndown herbicide in reduced tillage situations and to manage weeds around the farmstead. They have significant experience with the herbicide. When Roundup is used postemergence on RR soybeans, growers seldom make a mistake applying it. If a late weed flush appears, it can be corrected with a late application of Roundup.

<u>Farmer and farm worker health and safety</u>

Given a choice between two pest control technologies, both equally cost effective, risk-averse farmers will choose the one that is safest. In fact, most farmers are willing to sacrifice some profit for increased pesticide safety (Beach and Carlson, 1993; Lichtenberg, Spear, and Zilberman, 1993). Part of the reason for this is that less toxic pesticides are easier to use, with fewer safety precautions associated with them such as specialized safety clothing, breathing apparatus, handling restrictions and re-entry intervals. This saves time and expense. Product safety is important also because farmers (as do the rest of us) care about their own health, their family's health, and the health of their workers. Pesticides available to U.S. farmers today meet the minimum requirements set by the Environmental Protection Agency, but some are less toxic than others.

<u>Environmental quality</u>

As well as caring about their own and their workers' health and safety, it has been demonstrated repeatedly in economic research that many farmers care about the environment. Of concern to them are off-farm water quality and impacts of their decisions on wildlife (e.g. Beach and Carlson, 1993; Lichtenberg, Spear and Zilberman, 1993). Since some new agricultural technologies are more environmentally benign than others, this may be viewed as an additional benefit of these technologies from the farmer's, as well as from society's, perspective. Roundup is one of the most environmentally benign herbicides on the market today.

> "Glyphosate has a half-life in the environment of 47 days, compared with 60-90 days for the herbicides it commonly replaces. The herbicides that glyphosate replaces are 3.4 to 16.8 times more toxic, according to a chronic risk indicator based on the EPA reference dose for humans." (USDA, Economic Research Service, 2002, p. 17)

Reasons for Adopting RR Soybeans

Some reasons for adoption of RR soybeans other than soybean yields and weed control costs given by various authors are 1) they are easier to use (Benbrook, 2001), 2) they offer lower harvest costs (Duffy, 2001), 3) they have a longer herbicide application window, and are easier to use because only one herbicide material is involved (Gianessi and Carpenter, 2000), 4) they offer more convenience (Fernandez-Cornejo and McBride, 2002), and 5) they allow for more use of reduced and no-tillage systems (Faucett and Towery, 2002).

A more complete definition of profitability is needed to understand the reasons for RR soybean adoption. The studies mentioned above have only measured weed control costs and crop yields in comparing the profitability of RR and non-RR soybeans. Other studies of herbicide selection and adoption have shown the importance of relative worker safety and environmental benefits of various herbicide products (Beach and Carlson, 1993). Glyphosate is known to have a short half life in the soil, and it is relatively safe to workers, farm animals, and other environmental components.

The total net benefit of using RR soybeans may depend on the use of conservation tillage systems. Environmental and convenience benefits may be derived from the use of the conservation tillage systems. However, these cultural practices might require more management resources (Rahm and Huffman, 1984; Krause and Black, 1995), larger farms and different machinery inputs (Marra and Carlson, 1987) and more and higher quality information (Marra, Hubbell and Carlson, 2001).

Carpenter and Gianessi (2001) summarized economic benefits and costs of RR soybeans and concluded there were advantages relative to conventional soybeans, including some evidence of similar or increased yields. Harley (1998) found slightly higher yields in RR soybeans in North Carolina. However, a report by Benbrook (2001) highlights "yield drag". Yield comparisons by soybean specialists at several Land Grant Colleges have shown smaller yields from RR soybeans relative to conventional soybeans in small-plot studies (Elmor, et al. 2001, Oplinger, et al 1998). Surveys of growers in Iowa have also found slightly lower yields for RR soybean acres (Duffy, 2001).

Carpenter and Gianessi (2001) found lower herbicide use associated with RR soybeans. Benbrook (2003) argues that increased use of herbicides has resulted from adoption of RR soybeans, and that the benefits from planting RR soybeans are temporary in nature. Roundup came off patent in 2000. Since then the prices of Roundup and competing herbicides have decreased. This would result in increased pesticide use, as well, all else equal.

From an economic standpoint, yield comparisons are an incomplete picture of the desirability of the RR soybean technology. The total net benefit of RR soybeans relative to conventional soybeans and other crops is needed for farmers and others to assess this technology. The profitability studies of USDA (Fernandez-Cornejo and McBride, 2002), Duffy (2001) in Iowa and Bethour (2002) in Ontario, Canada have each found slightly lower or equal profits for RR soybeans.

It has also been reported that the RR soybean system (as well as other herbicide tolerant crop systems) fosters use of conservation tillage (ASA, 2001; Monsanto, 2003.). The evidence of this is, so far, mostly indirect; either from individual farmer testimonials in the popular press or from comparisons of means from aggregate data. We investigate this question further by empirically investigating the relationship between RR soybean use and the use of conservation tillage using a national survey of individual soybean farmers.

A motivating factor for the question of interest here is the lack of a good understanding of the convenience concept in the farm labor or agricultural economics literature. Convenience is related to labor time, management time, and equipment time for various farming operations. However, it is also related to the flexibility of the technology for multiple locations, soil types, weather conditions and size and types of weeds. A final dimension of convenience is the insurance or risk-reducing nature of some technologies. Herbicides that have longer duration of weed control can reduce the risk of weed escapes and the need for multiple applications (Marra and Carlson, 1983). In this study we ask farmers for their monetary estimates of the value of the relative labor and machinery time savings and other convenience factors from use of RR soybeans on their farm.

Another potential advantage of RR soybeans is improved soybean quality in the form of less foreign matter. This would result in less dockage at the elevator (Shaw, et al., 2003).

Economic disadvantages of RR soybeans relative to non-RR soybeans also must be included in an analysis of the net benefits. We have identified the uncertainty of extra marketing costs, potentially higher harvest costs, and higher seed costs for RR soybeans as potential disadvantages. In addition, we include the fact that farmers agree not to save seed from RR soybeans for replanting, whereas this is not a requirement for non-patented conventional soybean varieties.[3]

---

[3] Plant breeders are increasingly seeking patents for their best new soybean varieties. Therefore, not all conventional soybean varieties can be legally saved for replanting or for sale, either.

STUDY OBJECTIVES AND METHODS

Objectives

I. To assess the role of non-pecuniary factors in the use of RR soybeans and conservation tillage in the United States.

II. To test the hypothesis that RR soybean adoption has a positive influence on adoption of conservation tillage practices in the United States.

III. To obtain farmer-level information about factors affecting soybean acreage decisions.

Methods

A computer-aided, national telephone survey of soybean farmers growing at least 250 acres of soybeans was conducted during the early spring of 2003 by Doane's Market Research. A total of 610 farmers was surveyed in the major soybean-growing states. Respondents were asked in detail about their technology choices, the costs and returns of those systems, and their valuation of the non-pecuniary aspects of each technology (RR soybeans and conservation tillage).

STUDY BACKGROUND

An Overview of Soybean Weed Control and Tillage Systems Over the Past Twenty Years Weed Control

Weed control

In the early 1980's post emergence herbicides for soybeans were available commercially for the first time. These early post emergence herbicides included Basagran (bentazon), Blazer (acifluorfen), and Poast (sethoxydim) (Marra and Carlson, 1983; Gianessi and Carpenter, 2000). Although they each had their shortcomings (e.g. crop injury, carryover problems, or failure to control a broad spectrum of troublesome weed species), they were acceptable enough for growers in many areas to begin to use reduced tillage and rely more on post emergence treatments for weed control in full season soybeans. Growers, particularly in the southern United States, also could begin to adopt a system of double cropping whereby a small grain (usually wheat) was planted in the fall and harvested in late spring or early summer with soybeans planted directly after harvest of the first crop, often times using reduced tillage or no-till, (Marra and Carlson, 1990; ASA, 2001). Since the growing season for soybeans is shortened in this system, timely planting and effective post emergence weed control are critical to obtaining profitable soybean yields. As shorter-season soybean varieties were developed, double cropping small grains and soybeans moved north into the southern Corn Belt and full season soybean production moved into the Northern Great Plains.

One problem with these early post emergence herbicides was the inability to tank mix broadleaf and grass herbicides without producing significant antagonism (Gianessi and Carpenter, 2000). Tank mixing involves combining two or more chemical pesticides or formulations in the spray tank at the time of spray application. The next breakthrough in soybean weed control technology was the introduction in the mid-1980's to early 1990's of the imidazolinone and sulfonylurea herbicide classes [Pursuit (imazethapyr), Scepter (imazaquin), Pinnacle (thifensulfuron), and Classic (chlorimuron)] (*ibid*. p. 44). Throughout the period, as new classes of herbicides were introduced that were better economic performers, farmers began to adopt them.

The first transgenic field crop, BXN cotton, was introduced commercially in 1995. BXN cotton tolerates an over-the-top treatment of the broadleaf herbicide, Buctril. The introduction of RR corn, soybeans, and cotton, and Bt cotton and corn followed closely behind. Early this century, generic glyphosates began to play a small role in the RR soybean system, although the various formulations of Monsanto's Roundup are still the largest selling herbicides for the system.

Conservation tillage

Fernandez-Cornejo and McBride (2002), in an appendix to their report, examine the issue of whether RR soybeans and no-till are adopted simultaneously using the latent variable method and tests for simultaneity. They analyze the 1997 ARMS (single field) data and find that no-till adoption leads to higher probability of RR soybean adoption, but use of RR soybeans does not lead to higher probability of adopting no-till. They argue that inconsistent estimates resulting from estimating two separate single-equation probit models would lead to the conclusion that RR soybean use leads to a higher probability of no-till use. They further observe that the lack of effect of RR soybeans on no-till could be because this was in the second year of availability of RR soybean seeds.

The soybean growers' survey conducted by the American Soybean Association (ASA) indicates that 73% of growers are leaving more crop residue on the soil surface than they did in 1996, and 63% of the farmers surveyed said biotechnology was the "key factor" in their increased use of conservation tillage. The latter finding was from an unaided response to the question, "In the past five years, what changes in technology such as equipment, chemicals or seed have made it possible for you to reduce tillage or increase crop residue in soybeans?" (ASA, 2001).

Fawcett. and Towery (2002) examine the ASA survey and other data, and conclude that there is a positive relationship between sustainable tillage practices and the use of biotech crops. They report that the ASA survey indicates 58% of RR soybean growers make fewer tillage passes versus five years earlier, where only 20% of non-RR soybean growers report fewer tillage passes.

Bethour, et al. (2002) find that there is less use of moldboard plow and field cultivator trips for RR soybeans than on non-RR soybeans, but the distribution of no-till, reduced till, and conventional till is about the same in Ontario, Canada. Also, the Canadian growers listed "less time requirements," "improved tillage equipment," and "improved (or lower cost) post-emergent herbicides" as the main factors in the decision to adopt no-till or reduced tillage, whereas introduction of RR soybeans was a lower-ranked reason. These authors used simple means comparisons to evaluate their data, while the ASA study did not use statistical analysis.

Duffy (2001) in a survey of 172 Iowa farmers, found an average of 0.59 cultivations on RR soybean fields and 0.85 on non-RR soybean fields. He examines other field operations, but does report on other tillage practices. Duffy concludes that for both 1998 and 2000 crop years RR soybean and traditional soybean fields had about equal net returns.

THE SURVEY

Survey Procedure

During February, 2003, 610 growers (525 in the Midwest and 85 in the South) were interviewed by the computer-aided telephone method using a standardized questionnaire. The pool of potential respondents was restricted to those farmers growing at least 250 acres of soybeans in 2002.

The survey of whole farms provides information and a perspective not available from agronomic studies of weed control (Elmore et al., 2001) or from technology adoption studies (Fernandez and McBride, 2002). By examining both out of pocket costs such as seeds, herbicides and tillage costs, and obtaining farmer estimates of soybean yields and indirect costs and benefits, one can obtain a more complete view of the profitability (or net benefits) of the new, RR soybean technology relative to the traditional soybean enterprise.

The Questionnaire

The major objective of the survey is to compare farm management practices in terms of all measurable costs and revenue changes for the RR soybeans with fields containing traditional soybean varieties. The questionnaire was designed so that we might compile a "partial budget" on all additional costs and returns to RR soybean production. Many of the cost or benefit categories were asked in terms of "gains" or differences from traditional varieties. There is a block of questions dealing with weed control practices, tillage practices, another one attempting to assess yield comparisons, and a final one on marketing and seed saving costs from planting the RR soybeans.

SURVEY DEFINITIONS FOR MEASURING FARM LEVEL BENEFITS AND COSTS OF THE RR SOYBEAN TECHNOLOGY

Weed Control Costs

Weed control costs were assessed by asking farmers for their herbicide materials costs and application costs. The materials costs include surfactants and other herbicides used on RR soybean varieties, as well as Roundup costs. For the traditional varieties we also asked farmers to go through the season and give the types and amounts of herbicides applied. Average application costs for each technology system were also assembled by asking each grower directly for his/her estimate of per-acre application costs.

Seed Costs

Seed costs are expected to be different for the two technologies since technology fees are included in the Roundup Ready seed cost. Although individual seeding rates were not assessed, we asked farmers to estimate their seed costs per acre for the RR soybean varieties and traditional soybean varieties.

Convenience

Convenience is one of the components of benefits usually not measured when researchers attempt to compare the profitability of growing RR soybeans with traditional varieties. It may include savings in management time in herbicide selection, and less scouting for weed densities and species identification since the matching of herbicide with weed type is not as important as it is for conventional herbicides used on traditional varieties. More flexibility as to herbicide rates, time of application, and placement may be involved. There may be some time saving in handling herbicides, disposing of containers, and other weed control activities. After considering several methods to assess convenience benefits, we asked growers to identify time and or equipment savings, the amount of time in minutes saved per acre per season, and their estimate of the dollar value of the equipment and labor savings when the two seed types of soybeans are compared. We believe farmers can completely assess these changes for their farm (s) since they make these comparisons frequently over several fields and over several seasons.

Human and Environmental Safety

Both worker safety benefits and environmental benefits are difficult to measure for any technology. Objective measures of possible damage to humans from exposure to herbicides such as mammalian or dermal toxicity have commonly been available to farmers in weed control guides and on pesticide labels. Also, environmental traits of pesticides such as half-life, fish toxicity, and avian toxicity are available so that growers might compare the on-farm and off-farm environmental impacts of pesticide use practices. Farmers were first asked separate questions on whether they thought there were human and environmental safety benefits from switching to RR soybeans. Then, they were asked to place a value on these gains, if any, in dollars per acre ($/acre).

Tillage Benefits and Costs

Tillage practices can change when glyphosate is applied to RR soybeans. We asked our growers about tillage cost changes when they shift to reduced tillage, including no-till, from conventional tillage. Again, these assessments were made in terms of convenience (time savings) and in possible on-farm and off-farm environmental benefits. The terms "no-till," "reduced tillage," and "conventional tillage" were used. However, to determine how field treatments might change in moving from traditional soybean varieties to RR soybeans, we also asked growers to specify the number of field passes made with various tillage equipment—moldboard plow, chisel plow, disc, and cultivators. We also asked if there were environmental benefits from moving to reduced tillage (including no-till) and if so we asked the grower to place a dollar value on these benefits both on and off their specific farm. To assess the convenience values we asked growers to place a dollar per acre ($/acre) on the time savings from reduced tillage.

In order to shed light on the simultaneity issue, we asked respondents directly about how their soybean seed type and tillage practice decisions are made. Each respondent was asked to indicate which decision order applied to them, either making the seed type choice first, making the tillage type choice first, or making both simultaneously.

Other Costs

One part of the survey was designed to specifically find the magnitude of costs that are likely to increase with the RR soybean varieties. These include marketing uncertainty costs, saved seed costs, and harvest costs. Because farmers might spend more time and have other uncertainties in marketing RR soybeans, we asked the farmers' assessment of this marketing cost. This cost is usually omitted in production studies of soybeans. Also, there may be extra seed costs since Monsanto contracts specify that RR soybean seed must be purchased every year, whereas, with traditional varieties some farmers will replant saved seed. Some researchers contend that part of the advantage of RR soybeans is that they are easier to harvest since there would be fewer weeds in RR soybeans (Duffy, 2001; Shaw et al., 2003). Harvest costs per acre could be higher if RR soybeans produce greater yield. We asked farmers to report harvest costs per acre for each system.

Soybean Yield

Some farmers plant both traditional and RR soybean varieties, some plant only traditional varieties and some plant only RR soybean varieties. Yield comparisons are further complicated because of differences in weed densities, weed types, and soil types. A major cropping practice influencing yield is the comparison of full-season and double-cropped soybeans. To measure soybean yield we asked farmers their yield per acre in 2001 and 2002 for each of traditional varieties, RR soybean varieties, and for full-season and double cropped soybeans. We also asked farmers who grew only traditional or RR soybeans to give yields for the other technology in the last year it was grown. No grower who planted all of one soybean type reported an estimated yield for the other. This is probably because the technology is changing so rapidly that they did not feel they could provide an accurate estimate for 2001 based on past years' experience.

Demographic Variables

Characteristics of farmers collected include years of formal education, years of farming experience, percent of time spent in farming versus off-farm activities, and percent of farming time spent on crop production activities. In addition, farm characteristics are compiled such as total farm acres, total crop acres, acres in soybeans, and percent of the soybean acres using the RR soybean seeds.

GENERAL SURVEY RESULTS

The survey sample included 610 farms was compiled by telephone interview (525 from Mid-Western states and 85 from Southern states). The number of questionnaires completed per state for the two regions is shown in table 5. We report all results for the total U.S., instead of by region, since the low number of responses in the southern region by grower group makes independent results for that region unreliable.

Farm Characteristics

As mentioned above, table 4 shows average farm characteristics in the survey. In 2002, the average farm size for the farmers surveyed was 994 acres of cropland and 1,154 total acres. About 46% of the total land is owned, and about 48% of all crop acres are in soybeans. The proportion of soybean acres planted to RR soybean varieties in the survey is 72% in 2002 and 60% in 2001. These are very similar to the proportion of acres in RR soybeans found in USDA surveys.

General statistics on benefits of RR soybeans are given in Table 6. First, note that a majority of the farmers identify farm operator and worker safety (57%), environmental benefits (62%), and convenience benefits (56%) from using the RR soybean varieties relative to traditional ones. Typically, each of these benefit components are omitted from profitability studies. The relatively high number of farmers responding to these questions indicates that most farmers comprehend and can make estimates of the value of these benefits to them.

Table 7 gives the most frequently listed reasons why farmers did not plant all of their soybean acres to RR soybean varieties in 2002. Responses from all farmers answering the question, non-adopters in 2002, and partial adopters in 2002 are shown. No one reason is given by a majority of the farmers in any group. The most frequently reported reason given by all groups is the high cost of seed, although the highest percentage reporting this reason is 22% of the non-adopters (19% of all farmers and 17% of partial adopters). The next most frequent answer is that they are being paid a premium to grow traditional varieties (12% of all farmers, 14% of non-adopters, and 11% of partial adopters). Close behind, although very small, is the percentage that is getting higher yields with non-RR soybean varieties (11% of all farmers, 10% of non-adopters, and 11% of partial adopters). Another reason given somewhat frequently not to plant 100% RR soybean varieties is that there is too much market uncertainty (9% by all farmers, 13% of non-adopters, and 6% of partial adopters). These costs should be considered in a full accounting of the profitability of RR soybeans. They are assessed below.

Estimates of Convenience Values

There are very few estimates of convenience values for important farming practices. Convenience is often equated to less labor time, less management effort, or more flexibility in timing in field operations. Some recent advances in pest management have involved substituting *more* management to improve timing of applications and achieve more careful matching of pest type with narrow-spectrum pesticides. However, the improvements in pest management embodied in the adoption of the RR soybean technology involves substituting a new seed/herbicide program to replace more expensive weed management practices using traditional soybean varieties. The herbicide programs for traditional soybeans usually involve multiple herbicide materials applied multiple times in the season together with more tillage before and after planting.

In this section, we present farmer estimates of convenience benefits of using the Roundup Ready soybean technology relative to weed control using the traditional soybean varieties and the associated herbicide programs. Three different measures of convenience were solicited from the surveyed farmers, (a) degree of agreement with different definitions of convenience, (b) farmer estimates of time savings (in minutes) from use of the RR soybean system, and (c) farmer estimates of the dollar value of savings in time, equipment, and total convenience value. Each of these provides insights into convenience values.

Table 8 gives farmer agreement scores with four different definitions of convenience: longer herbicide application window, simplicity of use with only one herbicide, ease of controlling multiple weed species, and less difficulty with weather disruptions. Mean scores are reported by grower group (all farmers, those growing RR soybean varieties only [full adopters], farmers using both systems [partial adopters], and farmers with traditional varieties only [non-adopters]). The longer application window has a slightly higher mean agreement score, and the weather disruption factor has the lowest agreement score. The mean scores are between 4 and 5 for all definitions in the all farmer and full adopter groups, indicating strong agreement. All non-adopters' mean scores were between 3 and 4 for all definitions, indicating neutrality to somewhat agreement with each definition. Partial adopters strongly agree with the longer herbicide window, simplicity of using one herbicide, and the multiple species control definitions of convenience, but only somewhat agree with the lower weather risk definition. From this we might conclude that the RR soybean adopting farmers believe each of these four definitions has more validity relative to the farmers who only grow traditional varieties.

The farmers were asked to estimate time saved from using the RR soybean system rather than growing traditional varieties in minutes per acre. A wide range of estimates was given with a mean of 19.5 minutes per acre and a median of 4.5 minutes per acre (Table 9). Many of the responses (40.33%) were zero, but recall these are coming from non–adopters primarily. The estimates are grouped around typical summary numbers such as 5 (6% of respondents), 10 (10%), 15 (7%), 30 (9%), or 60 (8%) minutes per acre.

Finally, we asked the growers to assess the dollar value of time saved, equipment savings, and overall savings as measures of convenience to using the RR soybean technology. These estimates by various farmer groups are shown in Table 10. These mean values are for different groups of farmers. The numbers of farmers giving each of these three values are also shown since these are conditional means, that is, averages for those farmers willing to respond with positive values. The best estimates of convenience values for all the farmers in the sampled regions and in the four grower groups are the total convenience values (right column), since these means include the zero values given by the group of farmers that perceived no extra convenience value from using RR soybean technology. As expected, the total convenience value was highest for farmers growing RR soybeans only ($7.54 per acre) and lowest ($4.19 per acre) for the non-adopting farmers.

The mean estimate of about 19.5 minutes per acre evaluated at $20 per hour (a reasonable value of the opportunity cost for combined management and labor time) from table 9 gives a time saving value of $6.50. This time based estimate can be juxtaposed with the mean overall value of $6.23 obtained by directly asking farmers for convenience values of the technology (table 10).

Estimates of Human Safety and Environmental Benefits

Farmers were first asked a "yes or no" question about human safety benefits; "Are herbicides used for RR soybeans safer for you and your workers to handle than herbicides used for non-RR soybeans?" Most farmers were willing to answer this question, and the percent of farmers answering "yes" is shown in Table 11 for all farmers, non-adopters, partial adopters, and the full adopters. Clearly, there is a much lower percent "yes" response among the non-adopters (30%) than for the farmers selecting RR soybean varieties (with partial adopters at 58% and full adopters at 71%). The same type of question was asked about environmental safety of the herbicides used on RR soybeans versus those used on non-RR soybeans. As with human safety benefits, the percentage of the non-adopters who responded "yes" was about half the percentage of partial adopters and about 40% of the percentage of full adopters.

Tillage

Tillage trips decrease, percent of soybean acres in no-till systems increase, and value of time saved in tillage activities increases as farmers shift from traditional to RR soybeans. Table 12 shows that for our surveyed growers, there are 24-25 % fewer tillage passes on Roundup-Ready as on traditional soybeans. The average total number of tillage passes per season for non-RR soybeans was 1.73 per acre, while that for Roundup-Ready soybeans was 1.39 per acre on average for the 2001 and 2002 seasons. Moldboard plow trips fell by 50%, and all types of tillage passes added together decreased by 25%.

When farmers were asked to report tillage type used in RR soybeans and in traditional soybean varieties, no-till was 26% higher on the RR soybeans (see Table 13). Conventional tillage practices are used on about 37% on non-RR soybean acres compared with only 24% of RR soybean acres, a difference of 54%. In 2002, "reduced tillage" was higher on RR soybean fields, although for 2001 about the same percent of acres had "reduced tillage" on both soybean technologies. Self-reported tillage type may be a less accurate measure of tillage than is the number of tillage trips, because "reduced-tillage" and "no-till" may mean different things to different farmers. However, trips across the field by implement type and total number of trips are not ambiguous.

When asked about the order in which they chose their seed type and tillage practice, 66% of non-adopters reported they made the seed type decision before or at the same time as the tillage decision. Among the adopters, about half of the partial adopters made the seed type decision first or at the same time as the tillage decision, while 65% of full adopters made the seed type decision first or simultaneously with the tillage decision. If both adopter categories are combined, 61% chose the seed type before or at the same time as the tillage type. The data from this survey indicate that the tillage choice is made at the same time or subsequent to the seed type choice by slightly, but not substantially, more non-adopters than adopters. These results indicate that there is not a substantially different predilection among adopters and non-adopters to choose seed type first or at the same time as the tillage type. This comparison does not tell us anything about *which* tillage choice is made, however.

If we look at only those who grew half or more of their soybeans using reduced tillage, including no-till, we can see the increase in the percentage of farmers choosing reduced tillage as the percentage of RR soybean acres increases. Only five out of 95 (5%) of the non-adopters responding to this question used reduced tillage, including no-till, on 50% or more of their soybean acres. In the partial adopter category, 50% used reduced tillage, including no-till, on half or more of their soybean acres. The percentage of full adopters who planted 50% or more of their soybeans using reduced tillage, including no-till increased to 77%. Figure 1 depicts this relationship.

Other Costs

Seed and harvesting costs

Per acre seed costs for Roundup-Ready varieties include the price of seed and a technology fee. For traditional varieties of soybeans, the costs shown are for the purchased seed only, as those varieties do not have a technology fee. Since the cost of handling and planting the seed is approximately the same for both systems, we did not measure or add in these cost components for either technology.[4] Harvesting costs are primarily labor and equipment cost of the harvest operation. Since at least one study (Duffy, 2001) had indicated that these costs might differ for the two systems we asked farmers to estimate these costs on a per acre basis. The mean seed and harvesting costs for all groups of farmers are given in Table 14. For seed and harvesting costs we asked farmers directly for these costs and then calculated the difference in cost estimates. The "all farmers" estimates include both between-farm comparisons and within-farm differences and can be ambiguous for that reason. The number of farms giving estimates in the various categories is shown as well.

For seed costs, the "all farmer" estimates give a mean difference between RR soybean cost and non-RR soybean cost of -$9.88 per acre. As expected, this negative value reflects that growers pay more for the RR soybean seeds. The difference in seed cost is larger for partial adopters (-$11.56 per acre). Partial adopters pay more on average for RR soybean seed than do full adopters (-$9.02 per acre), indicating some volume discounts may be available for purchases of larger amounts of RR seed. All differences in mean seed costs are statistically significantly different from zero at the 95% level.

Harvesting costs are very similar when comparing RR soybean acres to non-RR soybean acres for both the all farm group and the within-farm comparisons on the partial adopters' farms. These differences of -$0.10 and $0.16 per acre are not statistically significantly different from zero at the 95% confidence level. Full adopters find statistically significantly higher harvest costs in the RR soybean system, although the difference is small, $0.47 per acre. Therefore, harvesting cost differences are not carried forward into the overall profitability comparisons for any grower group other than the full adopters.

Herbicide material and application costs

Table 15 gives the herbicide material and application costs for the RR soybean and non-RR soybean acres. These are farmer estimates of these components asked on the questionnaire after farmers had just gone through a detailed enumeration of each herbicide application through the growing season. Like the seed and harvesting costs we asked the farmers for their average costs per acre for each seed type and then computed mean differences for the four grower groups.

Herbicide material costs are lower on the RR soybean acres. This is true whether comparing this cost component on the same farms (between fields) or for the larger all farm sample (between farm and between fields). Average herbicide costs for the traditional varieties except for the non-adopters who perceive a $2.06 per acre advantage. The herbicide average material savings of $7.76 per acre for all farmers ($4.66 per acre for non-adopters, $7.54 per acre

---

[4] A possible exception to this is when the seed is saved from year to year. In this case, handling costs would include such items as seed cleaning and storage.

for partial adopters, and $8.68 per acre for full adopters) are statistically significantly different from zero at the 99% level of confidence.

Herbicide application costs are slightly higher on the non-RR soybean acres (a difference of $1.06 per acre across all farms), but the difference in application costs for non-adopters or partial adopters is not statistically significantly different from zero at the 95% level. Full adopters estimate herbicide application costs to be higher on non-RR soybeans, a difference of $1.40 per acre.

Yield effects

In our study, based on the 2001 and 2002 growing seasons, we find no significant yield difference between farmer-chosen RR soybean varieties versus non-RR soybean varieties under commercial growing conditions, comparing yields within the same farm, which holds constant such factors as management ability, field conditions, weather, etc. We also find that comparing yields across all farms results in a statistically in significant difference. As mentioned above, none of the non-adopters or full adopters report yield for the seed type they did not grow.

Demographic factors

The average age, education, experience, and farm income for the survey respondents, broken down by adoption category are reported in table 16. The average number of years as a farm operator was 33, and the average age of farm operators was 56 at the time of the survey. About 90% of all time is spent on farm activities versus off-farm activities, and farmers estimated that about 78% of their farming time is spent in crop production activities. The percent of farming time spent in crop production declines with increases in the proportion of soybean acres planted to RR soybeans. This may be further indication of farmers' time savings with RR soybeans.

No substantive conclusions can be drawn from comparisons of reported farm income, though, because the percent of the sample that reported farm income at all is quite small (only 57%), and the reported income levels indicate that those who did respond tended to under-report their farm income. The average years of formal education is about the same across all grower groups.

Potential Disadvantages

Even though RR soybeans have been approved for export into the EU and China, U.S. farmers still feel there is some uncertainty about producer and processor demand in the export markets. Farmers placed a value of this loss due to market uncertainty of $3.67 per acre. Non-adopters perceived the value to be $9.72 per acre; partial adopters, $4.37 per acre; and full adopters, $1.98 per acre. This difference by grower group is striking and may be one of the major influences on adoption decisions.

Farmers were not asked to place a separate value on their perception of the loss due to the inability to save RR seed. They were only asked about saving seed in a compound question about the total value of the loss to them from the market uncertainty *and* the inability to save RR seed. Therefore, it is not correct to report a separate range of values of their perceived loss from not saving seed.[5]

[5] In the valuation literature, a phenomenon arising from these types of compound questions has been called "part-whole bias," where the sum of the two separate valuations is larger than the value of the compound sum (Bateman, et al., 1997). So, a separate value inferred from the difference between the compound question and the separate

Net Benefits

In this section we present estimates of the benefits and costs of planting RR soybeans in the United States. We are attempting to make inferences about all soybean growers in a grower group by computing mean levels of seven different components of costs and benefits. Some of these are commonly presented in dollar terms such as seed, herbicide materials, application costs, harvesting costs, and revenues from estimated soybean yields. We also present farmer estimates of convenience, environmental and human safety benefits of the seed technology, as well as their valuation of the disadvantages of marketing uncertainty and the agreement not to save seed. In addition, we present environmental, time saving and convenience benefits of adopting reduce tillage on RR soybean varieties. These latter benefits and costs are non-pecuniary and reflected in opportunity costs of time and other resources.

To further define profitability of RR soybeans as estimated by various sets of farmers, we give results for all farmers, full-adopters, partial adopters, and non-adopters. We summarize the profitability results in a final section that aggregates all of the benefits and costs for each grower group.

We report the over all economic comparisons in Table 17 for all grower-respondents, for those who grew no RR soybeans in 2001, for those who grew both RR soybeans and non-soybeans, and for those who grew all RR soybeans in 2001. The grower group that planted both soybean types is the only one that reports the net benefits based on current comparisons of the two systems. This is the only comparison that assures management skill and growing conditions are held constant, but results in fewer observations to be included in the calculations. The other groups base their estimates of net benefits on their best estimates as to what the benefits and costs would be for the soybean type they did not grow in 2001. These can be based on recent past experience, from neighboring farmers' experience, or from what they have synthesized from any contact with literature, extension personnel, or chemical or seed company personnel.

Both the tillage trip and tillage type information reported previously strongly support the notion that there is less tillage on RR soybeans. Therefore, some of the environmental, convenience and time saving benefits associated with reduced tillage adoption might be credited to the introduction of the RR soybean technology for soybeans. Table 17 gives the estimates of changes in tillage costs, value of time saved, environmental benefits and other convenience benefits for all surveyed farms. The total net benefit, including reduced tillage benefits is in the $13 - 37 per acre range.

As can be seen in Table 17, the net benefits reported by the different groups follow a logical pattern. Those who did not plant any RR soybeans reported a negative net benefit from RR soybean production alone (-$7.55 per acre). Those who planted RR soybeans on some, but not all, of their soybeans acres report a higher net benefit than the first group ($1.31 for RR soybeans alone, $29.64 with 100% no-till), and those who fully adopted RR soybeans in 2002 reported the highest net benefit ($10.42 for RR soybeans alone, $37.05 with 100% no-till).

Figure 2 depicts the choices of the three groups of farmers within the framework of economic optimization. It shows, for the three different groups of farmers, non-adopters, partial adopters, and full adopters, that given the levels of their perceived costs and benefits from the system, they are all making rational choices. The non-adopters (Panel A) perceive the additional costs to be greater than the additional benefits for all acres on their farm. Therefore, they choose

---

market uncertainty question would not be a correct representation of the average perceived loss from not being able to save RR seed.

not to adopt the RR soybean system at all. The partial adopters (Panel B) plant RR soybeans on only some of their soybean acres – those acres for which the additional benefit is greater than the additional cost. They probably choose to plant RR soybeans on their weediest and/or most distant acreage from their main farm. The rest of their acreage is planted to non-RR soybeans because they perceive the costs to outweigh the benefits on those acres. The full adopters (Panel C) judge that the additional benefits are greater than the additional costs on all their soybean acres and, thus, choose to plant all of them to RR soybeans. These growers will tend to want to increase their soybean acreage, all else being equal, until the additional benefit on the last RR soybean acre equals the additional cost. All else is not equal, however, so the observed net change in soybean acres may be positive, negative, or zero, depending on other factors influencing the acreage decision as explained below.

SOYBEAN ACREAGE DECISIONS

Table 18 shows the soybean acreage choices for the groups of farmers in the survey. The long term trend in soybean acreage has been increasing for all groups. This can be the result of several things, including the commercialization of RR soybeans. The other major factor in explaining soybean acreage choice is the change in relative government support for soybeans ushered in by the 1996 Farm Bill. The Loan Deficiency Payments (LDP) and the Agricultural Market Transition Payments (AMTA) were favorable to soybean production relative to some other crops. Therefore there was an incentive to increase soybean acreage by switching some acreage out of the other crops. As the 2002 Farm Bill (which favored cotton production in the South and corn production in the Midwest), began to affect farmers' acreage choices, soybean acreage decreased for those whose choices were influenced more by the farm programs than by the technology improvements in soybean production.

The lower part of Table 18 shows the survey respondents' reported degree of influence on their soybean acreage choice of the farm program provisions, the technology improvements, and any changes in the relative price of soybeans. About 38-45%of farmers from each group reported some or strong influence of the provisions of the farm programs on their soybean acreage decisions. The influence of the LDP payment for soybeans had more influence than the AMTA payment for each groups of farmers. The percentage of farmers influenced somewhat or strongly by technology improvements in soybeans ranged from 44 to 52 percent. The full adopter group was the one with the highest proportion reporting some or strong influence of the technology improvements. The non-adopters reported the highest percentage (50%) of farmers reporting some or strong influence of the relative price of soybeans on their acreage decisions.

CONCLUSIONS

The role non-pecuniary factors play in the decision to plant RR soybeans is clear. In particular, adopting farmers place significant value on the operator and worker safety, environmental benefits, and convenience characteristics of RR soybeans. Growers also consider the costs of the new seed technology. They place a negative value on the additional market risk that may be associated with growing RR soybeans, as well as on the agreement not to save RR soybean seed for planting in future years or for sale.

On average, non-adopters of RR soybeans perceive a negative net benefit of $7.55 per acre from RR soybean adoption. Partial adopters perceive a slightly positive benefit of $1.31 per acre on average, and full adopters perceive a net benefit on average of $10.42 per acre. The growers we surveyed also place significant value on the environmental and convenience benefits of reduced tillage.

The net benefit of RR soybean adoption *with* reduced tillage can be fairly substantial, up to $37 per acre for some farmers. We also find evidence that growing RR soybeans is complimentary to practicing reduced tillage. On average, RR soybean growers make 25% fewer tillage passes each season compared to non-adopters. When growers switch to RR soybeans, they tend to switch from conventional tillage to no-till, with the amount of reduced tillage remaining fairly constant. More than 40% of RR soybean adopters used no-till in our survey, while about 30% of non-adopters used no-till. Five percent of non-adopters, 50% of partial adopters, and 77% of full adopters used reduced tillage on at least 50% of their soybean acreage.

We find further that growers' soybean acreage decisions (RR soybean plus non-RR soybean acres) are somewhat influenced by relative LDP rates and AMTA payments. Full adopters are slightly more influenced by changes in soybean technology and non-adopters soybean acreage choices are slightly more influence by changes in the relative soybean price

We can conclude that soybean farmers are rational in making their soybean seed type decisions, taking into consideration both the relative profitability of RR soybeans and their valuation of the non-pecuniary characteristics of the technology. They consider the full range of benefits and costs, both pecuniary and non-pecuniary, when choosing on which acres, if any, they choose to plant RR soybean technology.

REFERENCES

Aldridge, R.J. 1987. Predicting Crop Yield Reductions from Weeds. Weed Technology, 1(3): 199-206.

Alexander, C. 2000. Determination of GMO Use: A Survey of Iowa Corn-Soybean Farmers' Acreage Allocations. *in* Evenson, R. et al. International Conference on the Economics of Agricultural Biotechnology. Tor Vergata, Italy

American Soybean Association. Conservation Tillage Study. November, 2001. (http://www.soygrowers.com/?p=297). Accessed 6/1/03.

Bateman, I, A. Munro, B. Rhodes, C. Starmer, R. Sugden. 1997. Does Part-Whole Bias Exist? An Experimental Investigation. The Economic Journal, 207 (441):322-332.

Beach, E. and G. Carlson. 1993. A Hedonic Analysis of Herbicides: Do User Safety and Water Quality Matter? American Journal of Agricultural Economics, 75:612-623.

Benbrook, C. 2001. Troubled Times Amid Commercial Success for Roundup Ready Soybeans. AgBioTech InfoNet Technical Paper 4, Sandpoint Idaho.

Benbrook, C. 2003. Impacts of Gentically Engineered Crops on Pesticide Use in the United States: The First Eight Years. BioTech Infonet Technical Paper 6, Sandpoint Idaho.

Bethour, C. 2002. Agronomic, Economic and Environmental Impacts of the Commercial Cultivation of Glyphosate Tolerant Soybeans in Ontario. George Morris Centre, Guelph, Ontario. 51 pages.

Burrows, T. 1983. Pesticide Demand and Integrated Pest Management: A Limited Dependent Variable Analysis. American Journal of Agricultural Economics, 64(4):806-810.

Carpenter, J. and L. Gianessi. 1999. Herbicide Tolerant Soybeans: Why Growers are Adopting Roundup Ready Varieties. AgBioForum, 2 (2): 65-72.

Carpenter, J.E. and L.P. Gianessi. 2001. Agricultural Biotechnology: Updated Benefit Estimates. National Center for Food and Agricultural Policy, Washington, DC.

Duffy, M. 2001. Who Benefits from Biotechnology? American Seed Trade Association, Leopold Center. http://www.ag.iastate.edu/centers/leopold/pubinfo/paperspeeches/biotech.html. Accessed 9/3/02.

Elmore, R. 2001. Glyphosate-Resistant Soybean Cultivar Yields Compared with Sister Lines. Agronomy Journal 93:408-412.

Fawcett, R. and D. Towery. 2002. Conservation Tillage and Plant Biotechnology: How New Technologies Can Improve the Environment by Reducing the Need to Plow. Conservation Technology Information Center Report, Purdue University, W. Lafayette, In.

Fernandez-Cornejo, J. and W. McBride. 2002. Adoption of Bioengineered Crops. Agricultural Economic Report No. 810. Economic Research Service, USDA. Washington D.C.

Gianessi, L. and J. Carpenter. 2000. Benefits of Herbicide Resistant Soybeans. National Center for Food and Agricultural Policy, Washington, DC.

Griliches, Zvi. 1960. Hybrid Corn and the Economics of Innovation. Science, New Series, 132(4): 275-280.

Harley, K. 2000. Roundup Ready Soybeans: A Yield Analysis Using North Carolina Farms. Unpublished M. S. Thesis. Department of Agricultural and Resource Economics, North Carolina State University, Raleigh, N.C.

Just, R.E. and D. Zilberman. 1983. Stochastic Structure, Farm Size and Technology Adoption in Developing Countries. Oxford Economic Papers, 35: 307-328.

Krause, M. and R. Black. 1995. Optimal Adoption Strategies for No-Till Technology in Michigan. Review of Agricultural Economics. 17:299-310.

Kropff, M.J. 1988. Modelling the Effects of Weeds on Crop Production. Weed Research, 1988, 28: 465-471.

Lichtenberg, E., R. Spear, and D. Zilberman. 1993. The Economics of Reentry Regulation of Pesticides. American Journal of Agricultural Economics, 75: 946-958.

Marra, M. and G. Carlson. 1983. An Economic Threshold Model for Weeds in Soybeans. Weed Science. 31:604-609.

Marra, M. and G. Carlson. 1987. The Relationship Between Farm Size and Technology Adoption: Some Empirical Evidence on the Role of Risk. Western Journal of Agricultural Economics. 12(2): 109-118.

Marra, M.C., and G.A. Carlson. 1990. The Decision to Double Crop: An Application of Expected Utility Theory Using Stein's Theorem." American Journal of Agricultural Economics 72(2): 337-345.

Marra, M., B. Hubbell, and G. Carlson. 2001. Information Quality, Technology Depreciation, and Bt Cotton Adoption in the Southeast. Journal of Agricultural and Resource Economics 26 (1): 158-175.

Marra, M., P. Pardey, and J. Alston. 2002. The Payoffs to Transgenic Field Crops: An Assessment of the Evidence. AgBioForum: 5(2):43-50.

Monsanto, Inc. http://www.monsanto.com/monsanto/layout/products/default.asp Accessed 12/16/03.

Oplinger, E. 1998. Performance of Transgenic Soybeans. unpublished tables, Department of Agronomy, University of Wisconsin, Madison, Wis.

Rahm, M. and W. Huffman. 1984. The Adoption of Reduced Tillage: The Role of Human Capital and Other Variables. American Journal of Agricultural Economics, 66: 405-413.

Shaw, D and C.S. Bray. 2003. Foreign Material and Seed Moisture in Glyphosate-Resistant and Conventional Soybean Systems. Weed Technology, 17: 389-393.

USDA, Economic Research Service. 2002. Adoption of Bioengineered Crops. ERS Agricultural Economic Report No.AER810. http://www.ers.usda.gov/publications/aer810/. Accessed 4/13/04.

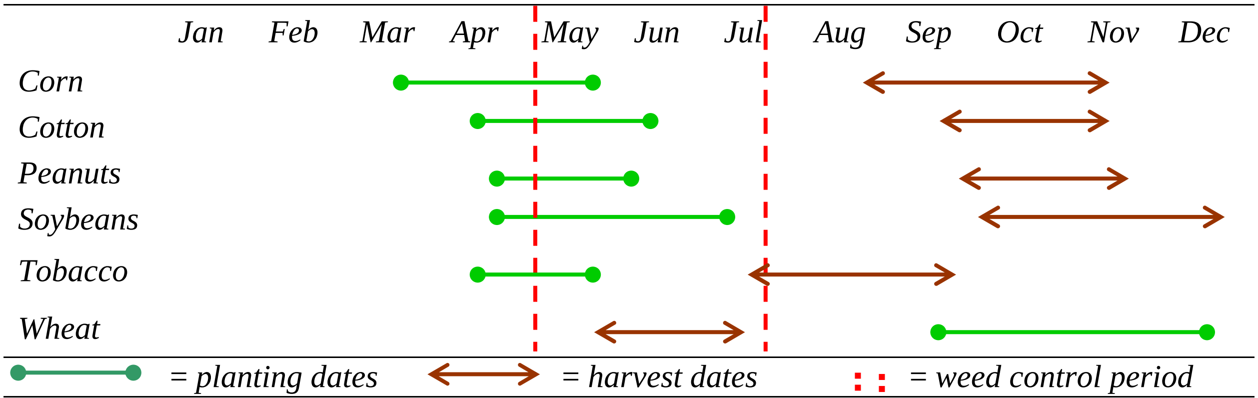
USDA, Economic Research Service. 2004. Farm Structure: Questions and Answers. http://www.ers.usda.gov/Briefing/FarmStructure/Questions. Accessed 4/8/04.

USDA, National Agricultural Statistics Service. 2003a.Agricultural Handbook. Washington: USGPO.

USDA, National Agricultural Statistics Service. 2003b. Acreage. Washington: USGPO.

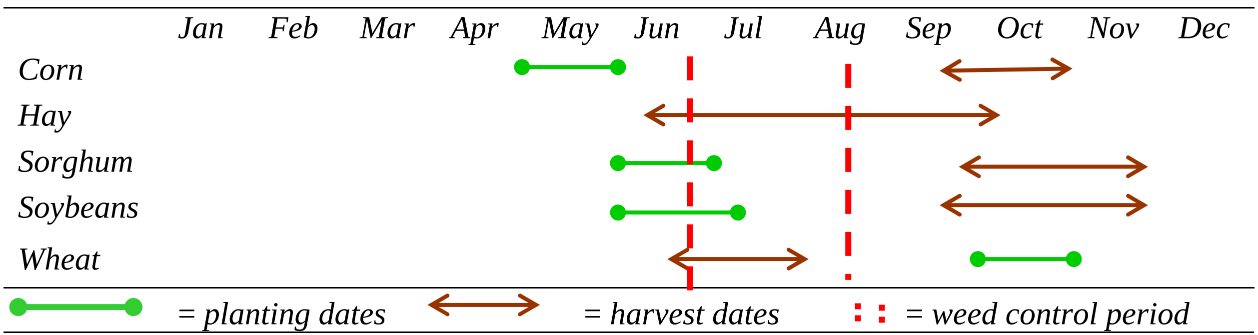
USDA, National Agricultural Statistics Service. 1999. Usual Planting and Harvesting Dates for U.S. Field Crops. Agricultural Handbook Number 628. Washington: USGPO.

Table 1. Typical crop planting, crop harvesting and soybean weed control periods in North Carolina



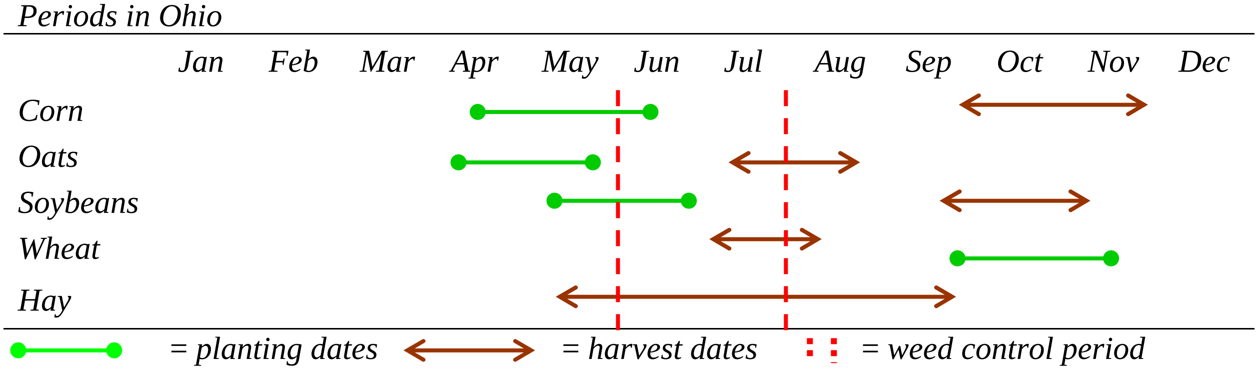
Source: USDA, NASS, Usual Planting and Harvest Dates, 1997

Table 2. Typical crop planting, crop harvesting and soybean weed control periods in Kansas



Source: USDA,NASS Usual Planting and Harvest Dates, 1997

Table 3. Typical crop planting, crop harvesting and postemergence soybean weed control Periods in Ohio



Source: USDA, NASS, Usual Planting and Harvest Dates, 1997

Table 4. Descriptive statistics of farms by adoption category

	All	*Non-Adopters*	*Partial Adopters*	*Full Adopters*
Farm Characteristics				
Soybean Acres in 1996	390.10	312.98	434.24	397.74
Total Crop Acres in 2001	954.57	871.45	1029.22	941.92
Total Soybean Acres in 2001	466.76	390.99	518.00	467.43
Percent Soybean Acres in 2001	53	54	50	53
Soybeans Acres RR in 2001	281.34	0.00	218.80	467.43
Percent Soybeans RR in 2001	59	00	35	100.0
Percent Soybeans Double-Cropped in 2001	7	3	10	6
Percent RR Soybeans Double-Cropped in 2001	7	0.00	11	8
Total Farm Acres in 2002	1153.56	967.72	1197.78	1214.37
Farm Acres Owned	534.03	482.28	524.78	566.64
Farm Acres Rented	619.53	485.45	673.00	647.74
Total Crop Acres in 2002	993.74	842.58	1095.61	995.32
Total Soybean Acres in 2002	476.15	375.30	538.09	481.59
Percent Soybean Acres in 2002	51	51	50	52
Percent Soybeans RR in 2002	72	22	70	97
Soybean Acres in 2003[a]	453.17	368.80	518.84	447.66
Percent Soybeans RR in 2003[b]	73	37	63	100

[a,b] Planned.

Table 5. Number of farms in the sample by state and region

Midwest Region		*Southern Region*	
State	*No. of Farms*	*State*	*No. of Farms*
Iowa	95	*Alabama*	2
Illinois	93	*Arkansas*	26
Indiana	50	*Kentucky*	12
Kansas	27	*Louisiana*	7
Michigan	19	*Mississippi*	12
Minnesota	62	*North Carolina*	12
Missouri	42	*South Carolina*	4
Nebraska	44	*Tennessee*	10
Ohio	41		
South Dakota	39		
Wisconsin	13		
Total	***525***		***85***

Table 6. Percent of all farmers reporting various types of benefits from RR soybeans

Type of Benefit	*Percent Reporting Benefits*	*No. of Farmers Responding*
Human Safety	57	458
Environmental Benefits	62	449
Convenience Benefits	56	437
Equipment Savings	49	528
Labor Savings	60	429

Table 7. Reasons given by growers for not planting all (100%) RR soybeans in 2002

	Grower Category		
Reason (Unaided)	*All Farmers (n=241)*	*Non-Adopters (n=98)*	*Partial Adopters (n=146)*
High cost of seed	19%	22%	17%
Premium paid to grow Non-RR soybeans	12%	14%	11%
Higher yields with Non-RR soybeans	11%	10%	11%
Lack of market acceptance	7%	11%	3%
Prefer to use saved seed	5%	5%	6%
Unsatisfactory tech fees	5%	8%	3%
Too much market uncertainty	9%	13%	6%
Other	32%	19%	43%

Table 8. Strength of grower agreement with differences in various components of convenience between RR soybeans and traditional weed control practices[a]

	Components of Convenience			
	Longer Herb. Appl. Window[b]	*Needs Only One Herbicide*	*Herbicide Controls Multiple Species*	*Less Weather Risk*
Grower Group	*Strength of Agreement*			
All Farmers	4.26	4.07	4.19	4.00
Non-Adopters	3.82	3.53	3.81	3.42
Partial Adopters	4.34	4.15	4.10	3.98
Full Adopters	4.42	4.29	4.45	4.29

[a] Mean scores using the following categories of agreement: 5 = strongly agree, 4 = somewhat agree, 3 = neither agree nor disagree, 2 = somewhat disagree, 1 = strongly disagree

[b] See survey questions 49-52 in appendix A for definitions of statements

Table 9. Estimates of average minutes saved per acre with the RR soybean system compared to the traditional soybean system

Grower Group	*Minutes Saved per Acre*	*No. Responding*
All Farmers	19.5	610
Non-Adopters	13.3	137
Partial Adopters	22.9	199
Full Adopters	19.9	274

Table 10. Grower valuations of components of RR soybean convenience

	Component		
Grower Group	*Time Savings*	*Equipment Savings*[a]	*Total Convenience Value*
	Dollars per Acre *(No. of Responses)*		
All Farmers	4.52	3.30	6.23
	(429)	*(528)*	*(437)*
Non-Adopters	2.97	3.53	4.19
	(98)	*(126)*	*(101)*
Partial Adopters	4.20	4.15	6.24
	(144)	*(175)*	*(148)*
Full Adopters	5.57	4.29	7.54
	(187)	*(227)*	*(188)*

[a] Mean valuations of farmers giving positive responses to the question of whether or not they experienced savings in that category.

Table 11. Percent of farmers indicating there are human safety or environmental benefits of herbicides used on RR soybeans versus non-RR soybeans

	Benefit Type	
Grower Group	*Operator and Worker Safety Benefits*	*Environmental Benefits*
	Percent Yes Responses	
	(No. of Respondents)	
All Farmers	57 *(610)*	62 *(610)*
Non-Adopters	30 *(137)*	31 *(137)*
Partial Adopters	58 *(199)*	64 *(199)*
Full Adopters	71 *(274)*	75 *(274)*

Table 12. Tillage passes per season on RR soybeans and non-RR soybeans

		Number of tillage passes per season			
Soybean Type	*Year*	*Moldboard Plow*	*Chisel Plow*	*Disc+Cultivate*	***Total***
Non-RR soybeans	*2001*	0.05	0.41	1.15	**1.61**
	2002	0.07	0.49	1.29	**1.85**
	Average	0.06	0.45	1.22	**1.73**
RR Soybeans	*2001*	0.04	0.34	1.00	**1.38**
	2002	0.04	0.36	1.00	**1.40**
	Average	0.04	0.35	1.00	**1.39**
Average Difference:	*(Non-RR soybeans - RR soybeans)*	0.02	0.10	0.22	**0.34**
Percent Difference:		50.0	29.0	10.0	**25.0**

Table 13. Relationship between tillage system and RR soybean acres

	Technology			
	RR soybeans		*Non-RR soybeans*	
	Year			
	2001	*2002*	*2001*	*2002*
Tillage System	*(Percent of all soybean acres)*			
No-till	41.60	41.40	29.30	32.20
Reduced till	33.90	35.00	33.90	30.90
Conventional till	24.40	23.50	36.90	36.90

Table 14. Seed and harvesting costs by technology and grower groups

	Technology		
	RR soybeans	*Non-RR soybeans*	
	Seed Costs		
Grower Group	*$/acre* *(No. of Respondents)*		*Within-farm Difference*
All Farmers	24.27	14.27	-9.88
	(507)	*(506)*	
Non-Adopters	22.31	13.38	-8.50
	(57)	*(126)*	
Partial Adopters	25.07	13.99	-11.56
	(187)	*(159)*	
Full Adopters	24.12	14.98	-9.02
	(263)	*(221)*	
	Harvesting Costs		
All Farmers	18.67	18.44	NS[a]
	(412)	*(423)*	
Non-Adopters	17.31	17.79	NS
	(51)	*(109)*	
Partial Adopters	18.3	18.29	NS
	(151)	*(132)*	
Full Adopters	19.26	18.99	-0.47
	(210)	*(182)*	

[a] NS means not significantly different from zero at the 90% confidence level.

Table 15. Herbicide materials and application costs by technology and adopter category

	Technology		
	RR soybeans	*Non-RR soybeans*	
	Herbicide Material Costs		
Grower Group	*(No. of Respondents)*		*Within-farm Difference*
	$/acre		
All Farmers	15.38	22.86	7.76
	(466)	*(458)*	
Non-Adopters	15.59	20.80	4.66
	(53)	*(111)*	
Partial Adopters	15.35	22.97	7.54
	(175)	*(149)*	
Full Adopters	15.36	23.94	8.68
	(238)	*(198)*	
	Herbicide Application Costs		
All Farmers	6.13	7.06	1.06
	(429)	*(425)*	
Non-Adopters	5.26	6.94	NS[a]
	(50)	*(102)*	
Partial Adopters	6.54	7.19	NS[a]
	(167)	*(146)*	
Full Adopters	6.01	7.02	1.40
	(212)	*(177)*	

[a] NS means not significantly different from zero at the 10% confidence level.

Table 16. Demographic characteristics of survey respondents

	All Farms	*Non-Adopters*	*Partial Adopters*	*Full Adopters*
Year Born	1946	1945	1948	1946
Years Experience	33.32	33.23	32.41	34.02
% Time Spent in Farming	90.13	88.38	90.92	90.27
% Farming Time Spent on Crops	78.53	81.07	80.35	77.15
Total Farm Income[a]	2.97	6.08	3.04	2.89
Years of Formal Education	13.43	13.21	13.70	13.34

[a] Farm Income Categories: 1 = <$2,500, 2 = $2,500-9,999, 3 = $10,000-19,999, 4 = $20,000-39,999, 5 = $40,000-99,999, 6 = $100,000-249,999, 7 = $250,000-499,999, 8 = $500,000-999,999, 9 = $1,000,000+

Table 17. Economic comparisons of Roundup Ready and traditional soybean systems in 2001

	All Farms	*Non Adopters*	*Partial Adopters*	*Full Adopters*
Difference in: [a]	*$ per Acre (No. of Observations)*			
1. Seed Cost	-9.88	-8.50	-11.56	-9.01
	(426)	*(56)*	*(156)*	*(214)*
2. Herbicide Product Cost	7.76	4.66	7.53	8.68
	(381)	*(46)*	*(145)*	*(190)*
3. Application Cost	1.06	0.82	0.72	1.40
	(356)	*(45)*	*(141)*	*(170)*
4. Harvest Cost	NS[b]	NS	NS	-0.47
	(33)	*(50)*	*(104)*	*(175)*
4. Operator and Worker Safety Benefit	2.17	0.65	2.15	3.16
	(458)	*(119)*	*(152)*	*(187)*
5. Environmental Benefit	2.45	0.96	2.73	3.19
	(449)	*(118)*	*(150)*	*(181)*
6. Total Convenience Benefit	6.32	4.18	6.24	7.54
	(437)	*(101)*	*(148)*	*(188)*
7. Saved Seed Restriction and Market Uncertainty of Biotech	-6.02	-10.32	-6.45	-3.77
	(501)	*(103)*	*(169)*	*(229)*
RR Soybeans Net Benefits Sub-Total Without Reduced Tillage Benefits	***$4.57***	***-$7.55***	***$1.36***	***$10.72***
8. Tillage Cost (Worker and Equipment Costs)	0.95	NS	NS	-0.72
	(509)	*(32)*	*(169)*	*(221)*
9. Reduced Tillage Time Saved	10.02	7.62	10.57	10.86
	(485)	*(111)*	*(163)*	*(211)*
10. Reduced Tillage Environmental Benefit	9.04	8.34	9.64	8.87
	(354)	*(23)*	*(127)*	*(154)*
11. Other Convenience Benefits of Reduced Tillage	6.72	4.69	6.89	7.64
	(497)	*(114)*	*(161)*	*(154)*
12. Yield Difference	NS	NR[c]	NS	NR
	(218)		*(96)*	
Net Benefit Including Reduced Tillage Benefits	***$30.94***	***$13.10***	***$28.46***	***$37.37***

[a] A positive number indicates a net benefit and a negative number indicates a net cost of RR soybeans compared to traditional soybean varieties

[b]NS indicates the mean difference was not statistically significantly different from zero at the 95% confidence level.

[c]NR indicates not reported.

Table 18. Soybean acreage changes and influence of factors by RR soybean adoption category

Time Period	*All Farmers*	*Non-adopters*	*Partial Adopters*	*Full Adopters*
	Percent Acreage Change			
1996 - 2001	75.63	77.03	87.90	66.15
1996 - 2002	83.80	60.38	104.94	80.60
1996 - 2003	65.27	59.39	89.02	51.30
2002 - 2003	-22.98	-6.50	-19.24	-33.93

Factor	*Degree of Influence*[a]			
Change in SB LDP Payment	1.28	1.34	1.22	1.30
Change in SB AMTA Payments	1.21	1.23	1.15	1.24
Technology Improvements in SB	1.45	1.37	1.33	1.57
Change in Relative SB Price	1.42	1.51	1.35	1.44

[a]Degree of Influence =1 if not influenced, 2 if somewhat influenced, and 3 if strongly influenced by the factor in the total soybean acreage decision.

Figure 1. Change in reduced tillage use as the proportion of RR soybean acres increases

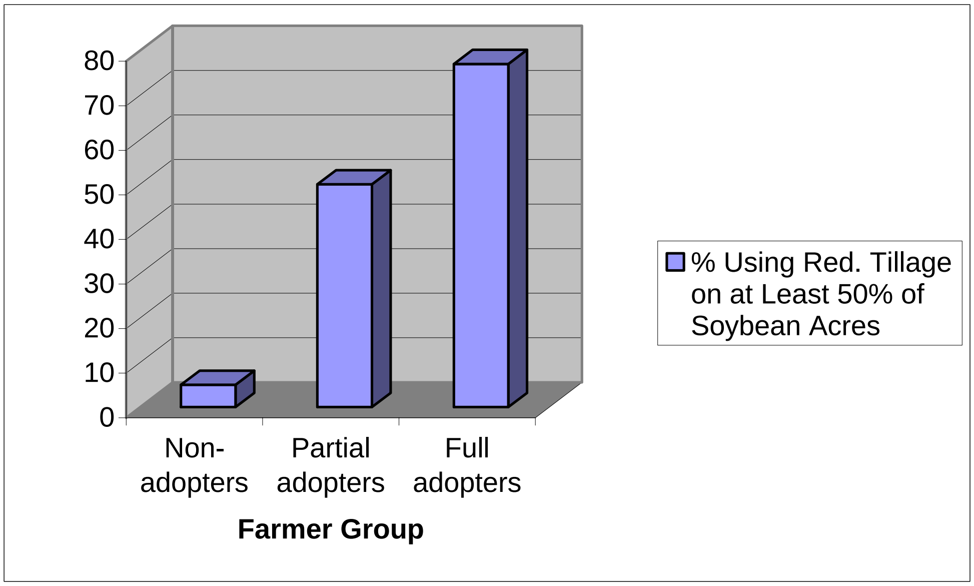


Figure 2. Optimal percent RR soybean adoption with different perceived costs and benefits