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Economic and herbicide use impacts of glyphosate-resistant crops†

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Abstract: More than 95% of United States maize, cotton, soybean and sugarbeet acres are treated with herbicides for weed control. These products are used to improve the economic profitability of crop production for farmers. Since their introduction in 1996, over 75 million acres of genetically engineered glyphosate-resistant crops have been planted, making up 80% of soybean acres and 70% of cotton acres in the USA. These genetically engineered crops have been adopted by farmers because they are perceived to offer greater economic benefits than conventional crop and herbicide programs. The adoption of glyphosate-resistant crops has saved US farmers $1.2 billion associated with the costs of conventional herbicide purchases, application, tillage and hand weeding. With the adoption of glyphosate-resistant sugarbeets on currently planted sugarbeet acres, US growers could potentially save an additional $93 million. The adoption of glyphosate-resistant crops by US agriculture has reduced herbicide use by 37.5 million lbs, although the adoption of glyphosate-resistant sugarbeets would dampen this reduction by 1 million lbs.

Keywords: herbicides; biotechnology; glyphosate; economic benefits; soybeans; canola; cotton; sugarbeets; maize

1 INTRODUCTION

The United States herbicide market for most field crops is well established. More than 95% of the nation's acres of maize, cotton, soybeans and sugarbeets are treated with herbicides annually and have been for the past 30 years. Currently, growers have a choice of numerous effective herbicides for almost all of their weed problems. Economic considerations determine the specific herbicides a grower will include in a weed-control program. Likewise, adoption of a new weed-control program is dependent upon its ability to displace previously used programs on the basis of economic considerations, such as saving the farmer money, improving yield or reducing inputs. Other factors that are important in weed-control decisions are perceived simplicity, manufacturer programs and the potential for crop injury.

Since 1996, genetically engineered crops have been commercially grown by US farmers. US commercial agriculture currently plants over 75 million acres with crops engineered to be resistant to the herbicide glyphosate.[1] Glyphosate-resistant crops that have been introduced in the USA include soybeans, maize canola, cotton and sugarbeets. Like any new weed-control technology, crops that have been genetically engineered to resist particular herbicides will only be planted if the resulting weed-control systems improve farmers' profits. In some cases, the reasons for adoption are not measured in profit margins but rather in reductions in management time. This paper estimates the current and potential farm-level economic benefits of planting glyphosate-resistant crops, as well as estimating the changes in herbicide use associated with these crops.

2 METHODOLOGY

The economic gains generated by the use of glyphosate-resistant technology for weed control have been quantified by estimating the economic cost and benefit differences between glyphosate-resistant and conventional weed control programs on a per acre basis. Cost and benefit differences result from the differences in the cost per acre of herbicides, herbicide application, technology fees, hand weeding, tillage and yield associated with conventional and glyphosate-resistant weed-control programs. Aggregate impacts have been calculated based on the application of average per acre differences to all acreage planted with the glyphosate-resistant crops. This same assessment technique has been used to estimate the changes in

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amounts of herbicide used that result from adoption of glyphosate-resistant crops for weed control. By comparing the average amount of herbicide active ingredient used in the glyphosate-resistant crop system with that of alternative systems, aggregate estimates of change in pounds of herbicides applied have been calculated for the country for 2001. The estimates of per acre cost and herbicide use differences were collected from available surveys of farmers, research experiments, and from surveys of extension service specialists. The estimates are based on the 2001 levels of adoption of glyphosate-resistant cultivars. Prices of alternative herbicide programs were calculated based on university weed-control guides. In all cases, no yield differences were noted between the glyphosate-resistant and conventional programs.

3 RESULTS AND DISCUSSION

3.1 Soybeans

United States soybean growers have traditionally had the most herbicide choices of any crop producer in the world. A recent weed-control guide rates the effectiveness of 182 herbicide options for soybean growers, including single active ingredients and mixes of two to five herbicide active ingredients.[2] The use of glyphosate with glyphosate-resistant soybeans received 'excellent' or 'good' control ratings for 23 of the 24 weed species evaluated in the guide. In addition, the glyphosate treatment on glyphosate-resistant soybeans is assigned a rating of 'minimal' crop injury potential. The next most highly rated alternative herbicide program was a combination of three herbicide active ingredients that received an 'excellent' or 'good' control rating for eighteen weed species and a crop-response rating of 'serious crop injury can occur.' Most alternative herbicides will control only certain types of weeds: annual grasses, broadleaves or perennials, while glyphosate is active on all of these. Because of gaps in the spectrum of weed species that are controlled, many alternative herbicide programs often have to be supplemented with tillage. Thus, one of the main advantages of a glyphosate program is the simplification of weed control from the perspective that one herbicide can be sprayed whenever the grower wants at whatever rate the grower can pay for. One herbicide with no need for tillage substitutes for three or four herbicides, often applied separately, with the potential need for supplemental tillage. Alternative herbicides also have severe limits on their effectiveness against weeds that have grown beyond a certain height. The effectiveness of some herbicides in soybeans is limited to control of weeds less than one inch tall. Glyphosate is typically effective against taller weeds. The rate of application can be adjusted to kill weeds that are four inches tall, increasing farmer flexibility. Crop safety is also a concern for the farmer. The use of glyphosate with glyphosate-resistant soybeans receives the highest crop safety rating in the weed control guides. Of the 182 alternative herbicide-treatment programs available for use on soybeans, only 47 received the highest crop safety rating.[2]

The adoption of glyphosate-resistant soybeans has been rapid and widespread. Following their introduction in 1996, the acreage of US soybeans planted with glyphosate-resistant varieties has steadily increased and accounted for 80% of total US soybean acreage in 2003.[3] State-by-state adoption ranges from 70 to 91% with adoption in Midwestern states ranging from 77 to 84%.[1] Some of the highest adoption rates have been outside the Midwest; New York, South Dakota, and Kansas soybean growers have planted 90% of their acres with glyphosate-resistant varieties. Growers in these three states increased soybean acres planted by 50–100% since the introduction of the glyphosate-resistant technology, due to the ability to control weed species that were previously very difficult and expensive to control.[4] Another documented economic effect of the introduction of the glyphosate-resistant technology has been a significant reduction in the price of all major herbicides in soybeans.[5] It has been estimated that these price reductions have saved soybean growers $216–307 million per year in weed control costs.[6,7] A recent survey by the American Soybean Association indicated that 53% of US soybean growers reported making fewer tillage passes through their fields since 1995 with the average reduction reported as 1.8 tillages per acre.[8] Glyphosate-resistant soybeans have enabled growers to eliminate $385 million per year worth of tillage in their fields.[1]

In order to determine the value placed on the glyphosate-resistant soybean program by growers, a replacement simulation was undertaken in a recent study.[1] University weed scientists were asked to define a one- or two-trip herbicide weed-control program for soybeans that was as effective on the major weed species as the glyphosate program with no need for tillage. Cost was not taken into account, as the efficacy and simplicity (defined as a one- or two-trip program with no tillage) of the program were the replacement criteria. These alternative programs were defined for each soybean-producing state. The replacement programs generally, required three or four active ingredients and two applications. A typical replacement scenario was a combination of acifluorfen, bentazone, imazaquin, pendimethalin and clethodim which was estimated to cost $40 per acre for 1.8 lb AI per acre in comparison with the glyphosate program (including the technology fee) of $16 per acre for 1.0 lb AI per acre. The replacement programs were rated as effective in university weed-control guides as the glyphosate program on the major weed species in each state. The average cost difference between the replacement programs and glyphosate-resistant programs was $20 per acre. In 2001, there were 50 million glyphosate-resistant soybean acres in the USA, which implies an aggregate value of $1 billion for the glyphosate-resistant technology. Another finding

in the comparison was that an effective alternative program required 0.5 lb more active ingredient per acre than the glyphosate program. US soybean growers would have to use 25 million lbs more of alternative herbicide active ingredients for weed control benefits equivalent to that of the glyphosate-resistant program.[1]

Several studies by Benbrook suggest that the glyphosate program represents an increase in herbicide use. In one study, Benbrook suggests that soybean farmers could 'easily' reduce herbicide use by 0.5 lb per acre by using low rate post-emergence herbicides as an alternative.[9] Benbrook provides no analysis of the effectiveness ratings of these low-rate herbicide programs. Low-rate post-emergence herbicides cannot be relied on by themselves to match glyphosate's effectiveness. To achieve efficacy comparable to glyphosate, low-rate post-emergence herbicides typically must be used in combination with soil-applied pre-emergence herbicides or other post-emergence herbicides, increasing the overall herbicide use rate. The use of low-rate post-emergence herbicides is further complicated by widespread herbicide-resistant weed populations that exist throughout US soybean production regions. For example, over 900 000 acres of soybeans in Missouri and Kansas are infested with common waterhemp resistant to the sulfonylurea and imidazolinone herbicide chemistries.[10]

In a recent paper, Benbrook claims a 'trend' of increasing glyphosate use rates by looking at USDA survey data for 2001 and 2002. He attributes this increase in use rates to glyphosate's 'slipping' efficacy and the spread of glyphosate-resistant weeds.[11] Although USDA data do show national US average glyphosate use-rates in soybeans of 0.87 lb per acre in 2001 and 1.07 lbs per acre in 2002, year-to-year differences such as these do not qualify as a 'trend.'[12‡] Furthermore, there is only a limited acreage with documented glyphosate-resistant weed problems. Increases in glyphosate use-rate to control weeds on this acreage are not enough to increase the national average. Alternative explanations for the higher rate in 2002 cannot be dismissed: wet weather may have resulted in more and greater weed flushes; more no-till soybean acres were planted which may have received extra glyphosate applications; and the lower cost of branded and generic glyphosate may have resulted in growers increasing the rate of use to improve control of perennial weeds.

3.2 Maize

Glyphosate-resistant maize varieties account for about 10% of the US maize acreage.[3] There are several reasons why glyphosate-resistant maize adoption has been so much lower than soybean adoption. The glyphosate-resistance trait has not been available in many of the most popular hybrids. This has changed recently as glyphosate-resistant technology was licensed to Pioneer Hybrid. Glyphosate-resistant maize varieties have not been approved for import into Europe so that growers in states with significant export of maize have been unwilling to plant the varieties because of complications in storage. Adoption has been highest in states such as Kansas (17%), Nebraska (13%) and South Dakota (33%), for which exports are of less concern.[3]

Another potential reason for the slower adoption of glyphosate resistance technology in maize is that low-cost broad-spectrum alternatives have been used for many years by corn growers. Atrazine in combination with other pre-emergence herbicides, such as *s*-metolachlor or acetochlor, provide season-long weed control in most situations for a low cost ($19 per acre).[13] Close examination of farms that have planted glyphosate-resistant maize varieties reveals that they generally have difficult-to-control weed problems that require more costly programs. A standard program for maize farmers with hard-to-control weed species is defined as atrazine plus acetochlor pre-emergence followed by atrazine/rimsulfuron/nicosulfuron. University research has demonstrated that glyphosate use with herbicide-tolerant maize provided effective control of several weed species which had not been effectively controlled with traditional herbicides: field bindweed, wirestem muhly, wild proso millet, burcucumber, sandbur, hemp dogbane, bermudagrass, and perennials in general, which normally require post-emergent applications of several active ingredients in addition to a pre-emergence herbicide application for acceptable control.[14–17] For growers with these weed problems, a conventional weed-control program costs about $38 per acre, which means that the glyphosate program, including the reduced pre-emergence application, which costs $28 per acre, saves them $10 per acre. In 2001, it was estimated that 5.8 million maize acres were planted with the glyphosate-resistant varieties, implying an aggregate savings of $58 million for farmers who have adopted this technology to control difficult weed problems.

The glyphosate-resistant program including a reduced-rate pre-emergence application is estimated to use 2.37 lb active ingredient per acre in comparison with 3.37 lb per acre for a conventional program to control difficult weed species.[1] This 1 lb per acre difference implies a reduction of 5.8 million pounds of herbicide use on maize acres planted with the glyphosate-resistant varieties to control difficult weeds.

Benbrook has suggested that the glyphosate-resistant maize is treated with about 30% more active ingredient than the average of conventional corn.[18,19] The difficulty with Benbrook's analysis is that the current adopters of glyphosate-resistant maize technology are not average growers: they are growers with difficult-to-control weed species which require higher-than-average herbicide rates. For these

‡ Unfortunately, USDA did not collect herbicide use estimates from soybean farmers in 2003.

growers, the glyphosate-resistant program represents a reduction in overall herbicide use rates.

3.3 Canola

Canola is an edible type of rapeseed that was developed in Canada in the 1970s. Canola production began in earnest in the USA in the early 1990s. North Dakota is the number one canola producing state in the USA. North Dakota canola planting increased from 16 000 acres in 1992 to 800 000 acres in 1998. Since it is a new crop, there were not many herbicides approved for use on canola in the early 1990s. Weed problems (particularly Canada thistle) worsened in North Dakota in the 1990s due to a succession of years with high rainfall. In 1999, North Dakota canola growers petitioned EPA for the emergency registration of glyphosate for use with glyphosate-resistant canola varieties.[20] The emergency registration was followed by a full registration and it is estimated that 75% of US canola acreage is currently planted with glyphosate-resistant varieties. Glyphosate provides excellent control of all weeds, including wild oat and ALS-resistant kochia in canola.[21] In addition, glyphosate-resistant canola fits well in the Canada thistle management program, as it provides a more economical option when multiple hard-to-control weeds are present in the field. Canola growers typically make only one glyphosate application.[22,23] Currently, alternative herbicides are registered for canola growers that provide effective control of all troublesome weed species; however, the average cost of the conventional program is $13 per acre greater than the glyphosate-resistant program. An effective herbicide treatment program for conventional canola consists of trifluralin and quizalofop, and either clopyralid or ethametsulfuron at $35 per acre.[24] This implies an aggregate savings of $11 million per year in North Dakota alone.[1] The average herbicide use rate in the conventional weed-control program is 0.61 lb AI per acre greater than in the glyphosate program, which implies an aggregate reduction of 531 000 pounds of active ingredient on glyphosate-resistant acres.

3.4 Cotton

United States cotton acreage planted with glyphosate-resistant varieties increased steadily following their introduction in 1997, reaching 70% of planted acreage in 2001.[25] There are two USDA reference sources for estimates of glyphosate-resistant cotton acreage. USDA's National Agricultural Statistics Service surveys farmers while the Agricultural Marketing Service surveys cotton ginners, seed distributors and extension agents.[3,25] Research has shown that two applications of glyphosate with the glyphosate-resistant cotton provides equivalent weed control and total yield to four applications of alternative herbicides.[26] Numerous press articles have reported that cotton growers have adopted the glyphosate-resistant varieties as a way to significantly reduce their production costs. Savings of $8–20 per acre have been reported in the Mississippi Delta and savings in hand weeding costs of as high as $150 per acre have been reported in California.[27–29] Growers have reported making fewer cultivation and herbicide application trips across fields. A comparison of herbicides used in cotton production prior to the introduction of the glyphosate-resistant system with those used in 2000 indicates a reduced expenditure of $3 per acre, which implies an aggregate reduction in herbicide costs of $47 million per year.[1] Estimates have been made of the reductions in costs resulting from reduced tillage (−$53 million per year), fewer herbicide application trips (−$58 million per year), and less hand weeding (−$54 million per year). After subtracting the technology fees for the glyphosate-resistant cotton varieties, the total savings to cotton growers is estimated at $132 million per year.[1]

A comparison between the herbicide use amounts in the year before the introduction of glyphosate-resistant cotton varieties and in 2000 indicates a reduction of herbicide use of 6.2 million lbs.[1] Aggregate use amounts were lower in eleven out of fifteen cotton-producing states. Herbicide use amounts increased in four states (Arizona, California, Oklahoma and Texas) following the adoption of the glyphosate-resistant cotton. In these states, glyphosate applications were largely substituted for tillage and hand weeding, not for previously used herbicides.

3.5 Sugarbeets

Competition from uncontrolled annual weeds can suppress sugarbeets so severely that no salable crop is produced. Sugarbeet growers utilize cultivation, hand weeding and combinations of herbicides for weed control. On average, an acre of sugarbeets receives 11.7 herbicide treatments per acre each year. An acre treatment is defined as one treatment of one acre with a single herbicide active ingredient. Sugarbeet growers spend $74 per acre for herbicides, totaling $115 million per year. In addition, sugarbeet growers spend $22 million for cultivation (two trips per acre), $42 million for hand weeding and $33 million for herbicide application costs (two to four applications per acre).[1]

Approval for planting glyphosate-resistant sugarbeets in the USA was granted in the spring of 1999. Research showed that two applications of glyphosate (two acre treatments) would produce yields equivalent to current weed-control practices.[30–32] Current weed control costs on US sugarbeet acreage average approximately $136 per acre. Two applications of glyphosate and a technology fee for the glyphosate-resistant seed is estimated at $76 per acre, which is $60 per acre less than current practices. The aggregate savings to US sugarbeet growers would be $93 million per year, assuming 100% adoption. These economic benefits are currently being foregone by sugarbeet growers since not a single acre of glyphosate-resistant sugarbeets is commercially planted in the USA. The glyphosate-resistant sugarbeet has not been adopted

because no sugarbeet factories have listed a glyphosate-resistant variety as acceptable. Processing facilities will not approve glyphosate-resistant varieties because of concerns about marketing their sugar.

Current herbicide use on sugarbeets averages 0.89 lbs AI per acre. The substitution of two glyphosate applications totaling 1.5 lbs per acre implies an increase of 963 000 pounds a year assuming 100% adoption, but there would be a reduction of 10.6 million herbicide–acre treatments.

4 CONCLUSION

By comparing the economic costs for farmers associated with the use of glyphosate-resistant crops with those of conventional herbicide programs, an estimate of the current and potential economic impact of glyphosate-resistant crops can be developed. The adoption of glyphosate-resistant crops has yielded US farmers $1.2 billion worth of savings, reducing the costs associated with herbicide purchase and application, tillage and hand weeding. With the adoption of glyphosate-resistant sugarbeets, US growers could potentially save an additional $93 million. The adoption of glyphosate-resistant crops by US agriculture has reduced herbicide use by 37.5 million lbs, although the adoption of glyphosate-resistant sugarbeets has the potential to dampen this reduction by 1 million lbs.

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