# The GMO experience in North & South America – where to from here?

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**Abstract**

In 2003 North and South America (NSAm) accounted fore more than 64 million ha, 94%, of total world area planted to genetically modified organisms (GMOs). Delivery has occurred almost entirely through the private sector and adoption has been rapid in areas where the crops addressed serious production constraints and where farmers had access to the new technologies. Four countries (USA, Argentina, Brazil and Canada), four crops (soybean, cotton, canola and maize) and two traits (insect resistance and herbicide tolerance) account for the vast majority of global transgenic area. Colombia, Mexico, Honduras, Uruguay and Paraguay have also planted GMOs. The economic benefits of the diffusion of GMOs have been widely shared among farmers, industry, and consumers despite the fact that the products are patented. The GMOs have had a favorable impact on the environment by facilitating reduced pesticide use and the adoption of conservation tillage. This paper surveys the level and distribution of the economic impacts of GMOs in NSAm to date.

**Media summary**

Ninety-four percent of world transgenic crop area is in the Americas. The economic benefits of GMOs have been widely shared among farmers, industry, and consumers.

**Key Words**

Biotechnology, Latin America, Impacts

## Introduction

More than 64 million ha were planted to genetically modified organisms (GMOs) in North and South America (NSAm) in 2003. The region includes the world's top four GMO growing countries (USA, Argentina, Canada, and Brazil) and accounts for 94% of the world's transgenic crop area[1] (James, 2003). This concentration of area in North and South America is largely explained by the focus of the transnational developers of GMOs on the huge US market and NSAm countries with similar climates and with existing business ties. This explains other countries in the region to the United States. Virtually 100% of world GMO area is planted to varieties of maize, soybeans, canola or cotton that is herbicide tolerant, that contains a Bt gene for insect resistance, or that contains both events. All GMOs were first introduced in the Americas before spreading to other areas of the world, and with the exception of Brazil, they have diffused with relatively little consumer resistance and have been readily accepted by farmers. Nonetheless, while the diffusion of GMO technology has been rapid when compared to nearly any previous agricultural innovation, many scientific and industry observers have been disappointed by the limited geographic reach and product line scope of biotechnology.

The US and Canada have led in the development, testing and regulatory approval of GMOs. Brazil and Mexico have significant public sector biotechnology research capacity as well, but face institutional obstacles to commercial success of transgenic crops. By 2003, the US had approved for commercialization 60 different events appearing in 13 different crops. Canada had a similar level of regulatory approvals (table 1). Fourteen NSAm countries had held GMO field trials and eight have commercialized GMO crops. Although Paraguay is planting about 644,000 ha of herbicide tolerant soybeans, no GMOs have been officially approved. The development of the successful GMOs has been financed by the private sector, but with significant public sector support in Canada, US, Mexico, Brazil and Argentina (Table 2). All GMOs grown commercially are products developed for US or Canadian markets and have spilled over for use in other countries.

[1] Approximately another 644,000 ha of GMO soybeans are grown in Paraguay without government approval, but are excluded from the James report.

This paper reviews the use of GMOs in the Americas. The focus will be on Bt cotton and RR soybeans Evidence on how economic benefits have been shared among industry, farmers, and consumers will be summarized. Some data on the effect of GMO adoption on pesticide use will also be presented. Finally, some of the key challenges for the expansion of biotechnology in the region will be discussed.

**Table 1. Number of GMO events receiving regulatory approval and GMO cropped area, by country, 2003**

| Country | Number of events approved | Number of different crops with approvals | GMO area (thousand ha) | Crops planted commercially |
|---|---|---|---|---|
| United States | 60 | 13 | 42,800 | cotton, soy, maize, canola |
| Canada | 57 | 14 | 4,400 | soy, maize, canola |
| Argentina | 9 | 3 | 13,900 | cotton, soy, maize, |
| Mexico | 3 | 3 | <50 | cotton, soy |
| Brazil | 1 | 1 | 3,000 | soy |
| Colombia | 1 | 1 | 5 | cotton |
| Uruguay | 1 | 1 | 60 | soy, maize |
| Honduras | 1 | 1 | 0.5 | maize |
| Paraguay | 0 | 0 | 644 | soy |

**Sources: James, 2003; National biosafety committees.**

**Table 2: GMO Field Trials by Type of Institution, through 2000.**

| | Argentina | | Brazil | | Mexico | | USA | |
|---|---|---|---|---|---|---|---|---|
| | No. | % | No. | % | No. | % | No. | % |
| Multinational Firms. | 247 | 78 | 77 | 52 | 193 | 87 | 4,836 | 73% |
| Smaller Firms | 55 | 17 | 41 | 28 | 9 | 4 | 1,117 | 17% |
| Public Sector | 14 | 4 | 29 | 20 | 20 | 9 | 648 | 10% |

**Source: Biosafety committees. From: Trigo, et al.**

## GMO use in the Americas

*2.1 Insect resistant cotton in the US, Mexico and Argentina*

Transgenic Bt cotton was first grown in the United States and Mexico in 1996 and has subsequently been introduced in Argentina, Australia, South Africa, China, Indonesia, Colombia and India. The first cotton varieties containing a Bt gene were introduced commercially through a licensing agreement between the gene discoverer, Monsanto, and the leading cotton germplasm firm in the United States, Delta and Pine Land Company (D&PL). Some of the same US varieties were subsequently introduced in other countries. Herbicide tolerant (HT) varieties were also introduced in the US in 1996, and “stacked” containing both the Bt and the HT events, appeared in 1998. Herbicide tolerant and stacked cotton varieties have not been adopted in significant areas in any other NSAm country. In the first year of commercial availability in the United States, Bollgard™ cotton was planted on 850,000 hectares or 15 percent of the total cotton area. By 2003, approximately 3.8 million hectares or 73 percent of US cotton area was planted to GMO cotton varieties (USDA). This is distributed as 730,000 ha of Bt cotton, 1.7 million ha of RoundupReady (RR) cotton, and 1.4 million ha of stacked (Bt + RR) cotton varieties.

Bt cotton is not a solution for all pest control problems, so adoption has varied greatly across growing regions in the United States, Mexico, and other countries, depending on the availability of suitable varieties and most importantly, depending on the particular combination of pest control problems. In both the US and Mexico, Bollgard™ cotton varieties have been rapidly accepted by farmers in areas where BBWC is the primary pest problem, particularly when resistance to chemical pesticides is high. When boll weevils or other pest populations are high, farmers achieve coincidental control of the BBWC with the use of broad-spectrum chemicals, or pesticide mixtures, reducing the value of Bt control. In the United States, adoption has been slowest in California and Texas where suitable Bt varieties have not been available and most rapid in states where chemical pesticide resistance has been most pronounced. Patterns of infestation levels and economic losses also vary widely across the main growing regions in Mexico and have been important determinants of adoption of Bt cotton there (Table 3). Bt cotton adoption has been low and restricted to large-scale farmers in Argentina due to the large price premium charged for transgenic seeds (Qaim, Cap and deJanvry).

(a) Farm and aggregate economic impacts of Bt cotton

There is great annual and geographic fluctuation in estimates of the actual yield performance difference between Bt and conventional cotton. Insect infestations vary widely across time and space, and the relative performance of Bt cotton is highest when pest pressure is heaviest.

**Table 3: Adoption of Bt cotton and geographic distribution of pest problems in Mexico's major cotton areas.**

| *Pest* | *Bt effectiveness* | *Alternate plant hosts* | *Seriousness of problem[a]* *Comarca Lagunera* | *Tamaulipas* | *North Chihuahua* | *South Chihuahua* | *Sonora* | *Baja Calif* |
|---|---|---|---|---|---|---|---|---|
| Pink bollworm | 100% | none | Highest | none | minor | medium | medium | medium |
| Cotton bollworm | High | maize, tomato | High | high | medium | medium | minor | minor |
| Tobacco budworm | Partial | maize, tomato | Medium | high | medium | medium | medium | minor |
| Army worm | Partial | many | Minor | high | medium | medium | minor | minor |
| Boll weevil | None | none | Eradicated | highest | minor | highest | minor | none |
| White fly | None | many | Minor | none | none | none | highest | highest |
| *2000 Bt adoption* | -- | -- | *96%* | *37%* | *38%* | *33%* | *6%* | *1%* |

Source: Traxler, et al.

[a] Highest: requires multiple applications annually, potentially heavy crop damage; High: 2-3 applications required most years, some crop damage; Medium: 1-2 applications required most years, minor crop damage; Minor: not necessary to spray most years, some crop damage

Field level studies of the performance of Bt cotton have been completed in the US (Falck-Zepeda, Traxler and Nelson), Mexico (Traxler et al., 2003), Argentina (Qaim and deJanvry, 2003), Australia (Fitt, 2001), South Africa (Ismail et al., 2001), China (Pray et al., 2001), and India (Qaim and Zilberman, 2003). In all three NSAm countries, Bt cotton varieties had higher yields, were more profitable, and saved on pesticide expenditures. Several studies have estimated the aggregate impact and the functional distribution of benefits from the introduction of transgenic varieties on benefits to producers, consumers and industry. These studies use estimates of the farm level cost savings and model world cotton supply and demand within an economic framework to calculate benefits. This framework takes account of the fact that, as the new technology reduces the cost of production, farmers may expand supply and that as prices drop, consumers may demand slightly more cotton. These price changes affect the level of calculated benefits. Part of the motivation for these studies has been that, except for a few varieties in China, the Bt cotton transgenics have all been patented private sector innovations. Patent holders may hold some monopoly power over pricing of their innovation. Certainly, the price of transgenic seed has been higher than that of seed of conventional varieties, and technology fees are charged on top of such high prices for GM seeds. Does this mean that the marketing firms are extracting all of the benefits generated by the innovation? This is an unlikely outcome because farmers must be receiving some benefits, or they would not choose to adopt. It will generally be true that an innovator will only be able to extract part of the economic benefits created through their research effort. There will always be benefit "spillovers" to be enjoyed by other members of society. The empirical studies that have been completed find that the benefits from biotechnology innovations have been widely shared among consumers, producers and industry.

Falck-Zepeda et al. (2000a, 2000b, 2000c) calculate the annual distribution of benefits among cotton producers, consumers and germplasm suppliers from the introduction of Bt cotton in the US for the 1996-98 period using a standard economic surplus model (Alston et al., 1995). The estimated amount and distribution of benefits from the introduction of Bt cotton fluctuates from year to year, but total annual benefits created averaged approximately $215 million (Figure 1). The average benefit shares were 45 percent to US farmers, 36 percent to germplasm suppliers and 19 percent to cotton consumers. Frisvold et al. (2000) use a different modeling approach to calculate aggregate welfare changes from the introduction of Bt cotton in the same period. They estimate a smaller amount of average total benefits ($181 million), and a smaller share of benefits to US farmers (20 percent) and more to US consumers (27 percent). The share of benefits to industry is estimated at 38 percent.

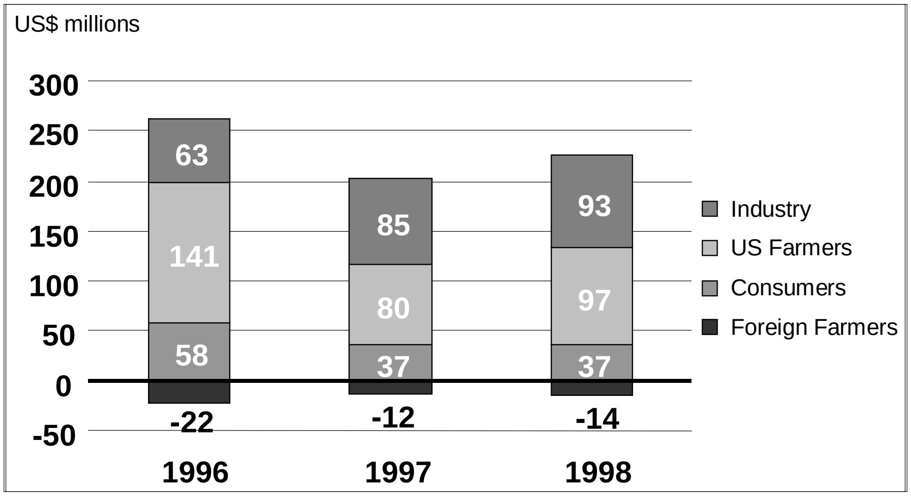


**Figure 1. Benefits from introduction of Bt cotton in the US**

The average benefit shares from the introduction of Bt cotton in the Comarca Lagunera region of Mexico[2] were 16 percent for germplasm suppliers and 84 percent for farmers (Traxler, et al.). The per hectares change in variable profit accruing to farmers varied widely between the two years, with an average figure of $ 335.45. Therefore, for the two years, we estimate that a total of more than $ 6 million in benefits was produced. In this calculation as in the welfare calculations for the United States, not the entire amount attributed to Monsanto is truly a net benefit, because costs such as seed distributor compensation, administrative and marketing costs were not accounted for. The $1.5 million revenue from seed sales is not a large sum for a company such as Monsanto with $5.49 billion in annual revenue. The large annual fluctuations are largely caused by variability in pest infestation levels – in years of heavy pest pressure, Bt cotton produces a large advantage over conventional cotton varieties. Because Mexico grows a small share of the world's cotton, there was no effect on consumers' benefits.

Bt cotton impacts have been studied more than RR cotton, even though the RR gene is grown over a larger area. The studies that have appeared support the conclusion that RR cotton varieties reduce pesticide costs and lead to higher per acre profit. (Marra, Pardey, and Alston; Fernandez-Cornejo, et al.).

(b) Effect of Bt cotton on use of chemical pesticides

Bt cotton is totally or highly effective in controlling several lepidoptera species known as the budworm-bollworm complex (BBWC) – the pink bollworm (Pectinophora gossypiella), cotton bollworm (Helicoverpa zea) – and is partially effective in controlling tobacco budworm (Heliothis virescens) and fall armyworm (Spodoptera frugiperda). In many major cotton-growing areas, BBWC is a major or the major pest control problem, but pesticide use is also conditioned by the presence of other cotton pests such at boll weevil (see James, 2002b). As a result, the effect of the introduction of Bt cotton on pesticide usage varies from region to region. In areas where BBWC is a major pest Bt varieties have contributed to a dramatic reduction in pesticide use.

In the United States, the number of pesticide applications used against BBWC has fallen from 4.6 in 1992-95 to 0.8 applications in 1999-2001 (Figure 2). Carpenter and Ginanessi (2001) estimate that the average annual reduction in use of pesticides on cotton in the United States has been approximately 1,000 tons of active ingredient. Pesticide use also declined in Mexico as Bt cotton use grew from 0 in 1995 to 96 percent in 2000 (table 8). A 50% reduction in insecticide use and a substitution away from highly toxic chemicals was also reported in Argentina (Qaim, Cap and deJanvry).

[2] Surplus calculations were done only for the Comarca Lagunera region, rather than all of Mexico because of data availability.

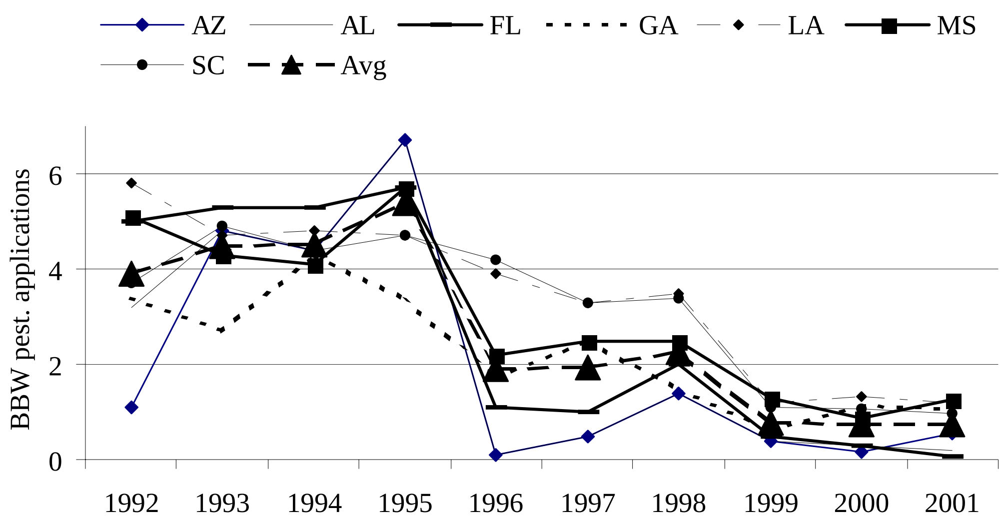


**Figure 2. The number of pesticide applications for budworm-bollworm complex, selected US states, 1992-2001**

Table 4: Average number of insecticide applications targeted to principal cotton pests in the Comarca Lagunera, 1995-2000

| Year | Pink Bollworm | Tobacco Budworm | Conchuela | Fall Army worm | White Fly | Total[a] |
|---|---|---|---|---|---|---|
| 1995 | 3 | 2 | 0 | 1 | 1 | 6 |
| 1996 | 7 | 2 | 0.3 | 2 | 2 | 7.35 |
| 1997 | 1.5 | 2.5 | 2 | 1.5 | 0.4 | 5.1 |
| 1998 | 2.5 | 1.3 | 1 | 2.1 | 0.2 | 4.5 |
| 1999 | 0 | 0 | 2 | 1 | 1 | 3.5 |
| 2000 | 0 | 1 | 1.5 | 0.2 | 0 | 2 |

Source: Sánchez-Arellano, 2000. Data from Plant Health Authority insecticide use records.
[a] Totals do not equal row sums because multiple pests are targeted in some applications.

*2.2 Herbicide tolerant soybeans in the US, Argentina and Paraguay*

(c) Adoption

RR soybeans were commercially released in the Argentina and the United States in 1996. The sale and use of RR technology is protected in the US through patents and sales contract with farmers, but neither form of intellectual property protection is used in Argentina. Thus in Argentina, RR soybeans are widely available from sources other than Monsanto, and Argentine farmers pay a relatively small price markup. Argentine farmers are legally allowed to use farm-saved seeds. The sale of pirated seed, including sales in Brazil and Paraguay is widespread. Adoption proceeded rapidly in both countries. By 2003, more than 95 percent of Argentine soybean area, and 80 percent of US area was cultivated with RR seeds. In addition, soybean area in Argentina has nearly doubled since the introduction of RR technology.

The first company to commercially release RR soybean varieties in Argentina was Nidera, the largest seed company in Argentina. Because Monsanto failed to obtain a patent for the RR technology in Argentina, Nidera obtained royalty-free access to Monsanto's RR technology in the late 1980s (Qaim and Traxler). Nidera channeled the technology through the Argentine biosafety process and received commercial approval for several RR soybean varieties in 1996. Monsanto itself and other companies only followed in subsequent years. By 2001, there were seven companies providing over 50 different RR varieties in Argentina. Except for Nidera, these companies pay license fees to Monsanto. Thus, both Nidera and Monsanto capture some revenue from RR technology.

(d) Farm and aggregate economic impacts of herbicide tolerant soybeans

Argentine farmers are not required to sign special purchase contracts, as used by Monsanto in the United States. This means that farmers are allowed to retain seeds from their harvest for future plantings. The national seed institute in Argentina, INASE, estimated that in 2001 farm-saved seeds accounted for 30 percent of all soybeans planted. Although sales of farm-saved and other uncertified materials are prohibited under national law, unauthorized sales are estimated to account for another 35 percent of total seed consumption. The remaining 35 percent are certified seeds sold by authorized seed companies. Weak intellectual property protection and the widespread use of farm-saved and black market seeds have placed downward price pressure in formal seed markets in Argentina. As a result, RR soybean seed can be purchased at a very small markup over the price of conventional seed. In January 2004 Monsanto announced that they were ceasing seed operations in the country due to the widespread sale of black market seed (Burke). If farmers in Argentina, Brazil and Paraguay were paying the same per ha royalty as US farmers, industry would be collecting nearly $200 million annually in technology fees from RR soybean technology.

Yields of RR soybeans are not significantly different from yields of conventional soybeans in either the United States or Argentina. The farm level benefits of RR soybeans are generated primarily through reduced herbicide, tillage and management costs. Many farmers switched to low-till or even no-till cultivation practices after adoption of RR soybeans and machinery and labor costs are also lower due to the reduced time needed for harvesting (Doanes 2001; Qaim and Traxler, 2003). Due to the lower incidence of green weeds in RR plots, the combine harvester can be operated at higher speed without the danger of clogging.

In Argentina total variable cost of production is about eight percent ($21 per hectare) lower for RR soybeans than for a conventional crop. In the United States for 1996, Hubbell et al. (2000) reported cost savings between $17 and $30 per hectare for the US as a whole. Moschini et al. (2000) estimated a cost advantage of $20 per hectare for 2000. Duffy (2001) carried out farm surveys in Iowa in 1998 and 2000, and found that cost savings are actually negligible there. But, by simulating different weed control scenarios, Gianessi et al., (2002) calculated RR cost advantages of $40 per hectare for many US states, in some cases even higher than this. The different results do not suggest a clear pattern over time. Taking an average over all sources, it appears that cost savings in the United States are similar to those in Argentina, even though the prices for RR seeds and glyphosate are lower in Argentina than in the United States.

Welfare effects of the spread of RR soybeans in the United States have been analyzed in a few studies (Price et al., 2001; Moschini et al., 2000; Falck-Zepeda et al., 2000c) but only Qaim and Traxler (2003) has explicitly modeled the diffusion of the technology in Argentina. In 2001, RR soybeans created more than $1.2 billion, or about 4 percent of the value of the world soybean crop, in economic benefits at the global level. The largest share of these overall benefits went to soybean consumers, who gained $652 million due to lower prices. Soybean producers received net benefits of $158 million, and biotechnology and seed firms received $421 million as technology revenue[3]. Soybean producers in countries where RR technology is not available faced losses of $291 million in 2001 due to the induced decline of about 2 percent ($4.06/ mt) in world market prices. This underlines that national restrictions to GM technology access can bring about considerable taxation of the domestic farm sector. A case in point is Brazil, the second largest soybean producer in the world. RR soybeans have now received official approval for commercialization in Brazil[4]. According to industry estimates, farm level benefits in Brazil could be similar to those in Argentina (Paarlberg, 2001).

Farmers in Argentina and the United States had large welfare gains that increased as RR adoption increased. Argentine farmers were receiving surplus of more than $300 million by 2001 and US farmers received surplus of $145 million in 2001. Although the RR area in the United States is larger than in Argentina, net producer surplus has been larger in Argentina since 1999 because the share of adopting farmers in Argentina exceeds the share in the United States. For example, in 2001, more than 9.6 million hectares were still planted to conventional soybeans in the US, compared to only about 1 million hectares in Argentina. This example clearly shows that, because of technology spillovers, producer benefits are not confined to the

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[3] As in the cotton studies, gross technology revenues are used as a measure of monopoly rent. No research, marketing, or administration costs are deducted. If we assume, for example, that these costs amount to 33% of technology fee revenues, the monopoly rent would fall to around $280 million (26% of total surplus).

[4] Moschini et al. (2000) show comparatively small producer surplus effects for South America in 2000. In their regional approach the gains for farmers in Argentina are offset by losses to Brazilian producers.

innovating country. Farmers in developing countries have much to gain when they are given access to suitable foreign technologies.

The average share of surplus going to producers over the 1996-2000 period was 14 percent (table 5). About half the benefits went to consumers of soybeans, and about one third went to industry. These shares were stable through time, but the surplus distribution across countries shifted as diffusion accelerated in Argentina. The US has clearly been the big winner from GMO soy, but its share of total surplus has fallen from 89% to 56%, as Argentina's total share increased from a net loss in 1996 to 27% of total world benefits in 2001.

Monopoly rents for private firms in the United States are sizable. On the other hand, because of weak intellectual property protection in Argentina, technology revenues there are much smaller, accounting for just 8 percent of the total Argentine surplus (2% of total world surplus). Falling prices for RR seeds and a growing informal market will further reduce this revenue stream over time[5]. However, these results also show that private firms will gain something from their innovations even without effective patent protection. Given the big market size, Argentina will remain interesting for foreign seed companies, even though intellectual property protection is weaker than in the United States.

**Table 5. Shares of total world surplus by area and functional group, 1996-2001.**

| Argentina | Producer | Consumer | Industry | Share world total |
|---|---|---|---|---|
| 1996 | (1%) | 0% | 0% | (4%) |
| 1997 | 5% | 0% | 1% | 6% |
| 1998 | 11% | 0% | 2% | 13% |
| 1999 | 17% | 0% | 2% | 20% |
| 2000 | 21% | 1% | 2% | 24% |
| 2001 | 25% | 0% | 2% | 27% |
| Avg | 16% | 0% | 2% | 18% |
| US | | | | |
| 1996 | 40% | 12% | 37% | 89% |
| 1997 | 34% | 12% | 34% | 80% |
| 1998 | 27% | 11% | 34% | 73% |
| 1999 | 16% | 12% | 32% | 60% |
| 2000 | 12% | 13% | 32% | 57% |
| 2001 | 12% | 12% | 32% | 56% |
| Avg | 24% | 12% | 34% | 69% |
| Rest of World | | | | |
| 1996 | -5 | 9 | -- | 15% |
| 1997 | -46 | 75 | -- | 14% |
| 1998 | -13 | 229 | -- | 15% |
| 1999 | -187 | 354 | -- | 20% |
| 2000 | -215 | 388 | -- | 18% |
| 2001 | -291 | 498 | | 17% |
| Average world total | | | | 16% |
| 1996 | 16% | 47% | 37% | 100% |
| 1997 | 16% | 49% | 35% | 100% |
| 1998 | 15% | 49% | 36% | 100% |
| 1999 | 11% | 54% | 34% | 100% |
| 2000 | 11% | 54% | 35% | 100% |
| 2001 | 13% | 53% | 34% | 100% |
| Avg | 14% | 51% | 35% | 100% |

**Source: Qaim and Traxler, 2003**

[5] For insect-resistant cotton in China, Pray et al. (2001) also reported relatively low and decreasing private-sector returns due to weak IP protection.

(e) RR Soybeans: Environmental Effects

RR soybeans change the use patterns of tillage and chemical herbicide use. Glyphosate substitutes for a number of other products, with the result that per hectare herbicide expenditures decline. Table 6 shows that in Argentina the average number of herbicide applications slightly increases, while herbicide amounts used per hectare even more than double. In the United States, the use of RR soybeans has been reported to lead to a decrease in the number of applications, with aggregate herbicide amounts more or less unaffected (Fernandez-Cornejo and McBride, 2000; Doanes, 2001).

**Table 6: Herbicide use effects of RR soybean adoption in Argentina**

| | Conventional soybeans ($n$ = 59) | RR soybeans ($n$ = 59) | Percent change |
|---|---|---|---|
| Number of herbicide applications | 1.97 | 2.30 | 16.8 |
| Total amount of herbicides (l/ha) | 2.68 | 5.57 | 107.8 |
| Herbicides in toxicity class II (l/ha) | 0.42 | 0.07 | -83.3 |
| Herbicides in toxicity class III (l/ha) | 0.68 | 0.00 | -100.0 |
| Herbicides in toxicity class U (l/ha) | 1.58 | 5.50 | 248.1 |
| Share of farmers using no-till practices | 0.42 | 0.80 | 90.5 |
| Number of tillage passes per plot | 1.66 | 0.69 | -58.4 |
| Machinery time (h/ha) | 2.52 | 2.02 | -19.8 |
| Fuel (l/ha) | 53.03 | 43.70 | -17.6 |

**Source: Qaim and Traxler, 2003**

Herbicides differ in their mode of action, duration of residual activity, and toxicity, so an increase in total herbicide amounts does not inevitably entail negative environmental effects. Glyphosate essentially has no residual activity and is rapidly decomposed to organic components by microorganisms in the soil. According to the international classification of pesticides, glyphosate belongs to toxicity class U, “active ingredients unlikely to present acute hazard in normal use” (WHO, 1988). As Table 6 shows, adoption of RR soybeans led to an almost complete abandonment of herbicides belonging to toxicity classes II and III. There are no other herbicides used in soybeans which belong to toxicity class I. Consequently, RR technology has led to an increase in the use of a relatively harmless herbicide and a significant reduction in the use of more hazardous herbicides.

The major reason for the rise in the number of herbicide applications is the farmers’ conversion to no-till practices that require pre-seeding chemical weed control. Although RR soybeans were not the only factor for the rapid adoption of no-till practices in the second half of the 1990s, Table 6 suggests that they played an important role. Whereas only 42 percent of the farmers in our sample used no-till for conventional soybeans, 80 percent of them use this practice on their RR plots[6]. No-till helps to preserve the soil texture and reduces the risk of wind and water erosion, with concomitant positive environmental effects. RR farmers who did not completely switch to no-till usually pursue a reduced-tillage system for soybeans. On average, the technology reduced the number of tillage operations by one passage per field. Overall, the number of machinery hours is reduced by 20 percent, and fuel savings are almost 10 liters per hectare.

A survey of 452 farmers conducted in 2001 for the American Soybean Association (Doanes) found that the use of conservation tillage methods increased from 60% of farmers to 83% since the introduction of Roundup Ready® soybean varieties in 1996. When farmers in the survey were asked what factor had the greatest impact toward the adoption of reduced tillage or no-tillage in soybeans during the past 5 years, 54% responded that it was the introduction of Roundup Ready® soybeans (p.15). The next most important factor was mentioned by just 15% of respondents.

*Transgenic maize and canola*

[6] RR technology has similarly increased adoption of reduced tillage and no-till in the US (Doanes, 2001).

Transgenic maize is grown in the US (11.4 million ha), Canada (0.7 million ha), Argentina (1.1 million ha) and Honduras (500 ha). In the US, 40% of maize area is in transgenics with 25% in Bt, 11% in RR and the remaining 4% in stacked varieties. It is difficult to calculate the benefits from Bt maize because of the extreme geographic variability in incidence of the European Corn Borer, and few farmers use chemical control. Carpenter and Gianessi estimate an aggregate net economic gain to US farmers of $28 million. In and ex-ante analysis for the year 2000 Alston, et al. estimate a total gain of 86 million for US farmers and 51 million to industry.

Approximately 3.2 million ha of RR canola was grown in Canada in 2003, and another 0.4 million ha were grown in the US (James). Philips estimates that the total benefits generated in 2000 were about $47 million accruing to producers, $93 million to industry, and $21 million to consumers. The shares to producers, industry and consumers are 29%, 57%, and 14%.

## 4. Conclusion

This paper has reviewed the experience with the use of transgenic crop varieties in North and South America. One of the most striking aspects of the experience has been the concentration of GMO use to two events in a few countries and a few major commercial crops. The transgenic crop introductions that have been evaluated have delivered large economic benefits to farmers, consumers and industry. The per hectare savings, particularly from Bt cotton, have been very large when compared with nearly any technological innovation introduced over the past few decades. But even within those countries, such as Mexico and the United States where transgenic products have been available, adoption rates have varied greatly across production environments.

Even though the transgenic crops have been delivered through the private, rather than the public sector, the benefits have been widely distributed among industry, farmers and final consumers. This suggests that the monopoly position engendered by intellectual property protection does not automatically lead to excessive industry profits. Evidence from Argentina (Qaim and deJanvry) and Mexico (Traxler et al.) suggest that small farmers have had no more difficulty than larger farmers in adopting the new technologies.

The environmental effects of transgenic crops have been strongly positive to date. In virtually all instances insecticide use on Bt cotton is significantly lower than on conventional varieties and glyphosate has been substituted for more toxic and persistent herbicides in RR soybeans, canola, cotton and maize. Furthermore, an increase in the use of reduced tillage has accompanied RR soybeans and cotton. Negative environmental consequences, while meriting continued monitoring, have not been documented in any setting where transgenic crops have been deployed to date.

The deployment of biotechnology resembles nearly all other agricultural technologies – for adoption to occur there must be a convergence of technology attributes, infrastructure for delivering the technology, and farmer conditions. Biotechnology's potential has been most notably unfulfilled with regards to farmers in small countries, and for tropical agriculture. Biotechnology holds great promise as a new tool in the scientific toolkit for generating applied agricultural technologies for these groups. The challenge at present is to design an innovation system that focuses this potential on the problems of developing countries (Pingali and Traxler).

It seems unlikely that transgenic products will have a major impact in most NSAm countries in the next decade. This expectation exists along side recognition of the immense potential for biotechnology to address many of the most difficult production problems that plague the region's farmers. The challenge is to devise and fund institutions that will be able to target the tools of biotechnology on the problems of tropical agriculture. While the science is advancing rapidly, the institutional capacity to deliver biotechnology faces huge challenges. No existing institution currently has the financial and scientific resources, and adequate incentive to lead the delivery of biotechnology innovations to developing countries.

The private sector has been responsible for the delivery of all GMOs in use in NSAm. Yet the incentives for private sector investment in small tropical countries are limited. At least three major obstacles face private sector entry into small countries. First, transaction costs are very large for market entry in each country. In most countries obtaining biosafety clearances is either impossible or so uncertain and expensive that the private sector does not consider market entry to be a good business risk. The list of countries with functioning biosafety committees is increasing, but until there is some type of regional harmonization and sharing of biosafety information, the regulatory transaction costs are entry barriers for a substantial number of countries. A second obstacle is the difficulty of protecting IPR. The experience to date with IPR enforcement on soybean, maize and cotton GMOs worldwide is mixed – protection has been good in some countries, difficult in others, and uncertain in most. The third, and possibly the most difficult to remedy obstacle is the absence of functioning seed markets in most countries for most crops. With the exception of maize, cotton and vegetables in a few countries, seed markets are very thin, making it difficult to deliver GMOs to farmers. The combined effect of these obstacles is an environment of very weak incentives for private sector biotechnology investment in developing countries – certainly nothing like the market potential that fueled the discovery of existing GMOs. At present then, the developing world suffers from the absence of profitable GMO markets with secure access.

Because of the very long lead times required to take GMOs through biosafety protocols and to develop and distribute adapted transgenic varieties, it is likely that the next decade will see only a few new transgenic products approach the level of acceptance that the four crops discussed here have achieved. In the longer run, it seems certain that advances in biotechnology will affect the supply of many food crops. Research is underway to improve food maize, wheat, rice, tubers and many vegetable crops, and there seems little doubt that these efforts will be successful in developing plant varieties that assist farmers in overcoming many of their current production constraints. However it must be realized that it has been eight years since the first transgenic crops appeared, and there are still only two novel traits (Bt insect resistance and herbicide tolerance) that have had important effects on world food production, and the effect on developing country agriculture has been minor.

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