25 YEARS OF GENETICALLY-MODIFIED CROPS IN ARGENTINE AGRICULTURE

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EXECUTIVE SUMMARY

This paper studies the economic and environmental impact of the adoption of genetically modified (GM) seeds in Argentine agriculture in soybean, maize (corn) and cotton crops. The effects at the farmer and aggregate levels are analyzed here.

A first set of results shows that GM crops increased yields, reduced crop production costs and increased the profitability of primary production. In the period 1996-2020, GM crop production schemes outperformed conventional crop production schemes by an average of USD 29.1/ha for soybeans, USD 35/ha for maize, and USD 217/ha for cotton.

A second set of results shows that the adoption of GM crops has brought significant benefits to the country. Cumulative gross margins over 25 years are estimated at USD 159 billion. Out of this total, 92% (USD 146 MM) correspond to soybean cultivation, 7% (USD 10.9 MM) to maize, and the rest (USD 2.1 MM) to cotton. Considering the foreign exchange increase due to higher exports, the 25 years of GM represented an additional USD 153 billion. In the section of additional employment demanded by value chains when applying GM technology, an average of 93 thousand direct jobs were created per season.

A third group of results shows that, in environmental terms, GM crops have allowed to significantly mitigate the impact of primary production on the environment. Had it not been for the leap in the adoption of no-till farming witnessed after 1996, more than 18 billion kg of carbon equivalent to the annual consumption of 3.9 million private cars would have been dumped into the environment. On the other hand, technology made it possible to increase the organic carbon sequestered in the soil by 7.3 million tons for the 2020/2021 season and 121 million tons in the last 25 seasons.

Finally, a reflection is made on the importance of continuing to leverage the benefits of agricultural biotechnology, and the challenges existing today, as well as those that may arise in the future.

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Twenty-Five Years of GM Crops in Argentine Agriculture

I. Introduction

With more than 26 million hectares planted with soybean, maize and cotton crops, Argentina is one of the leading countries in the use of genetically modified (GM) crops. The GMO adoption process began in 1996 with the introduction of herbicide tolerant soybeans, and since then it has shown an unprecedented growth in other regions of the world: in just four seasons, the GM soybean area went from representing less than 5% of the area planted with soybeans to more than 80%, while in cotton and maize levels above 80% were reached only after 9 and 13 seasons, respectively.

There is extensive literature[1] that has shown that GM crops bring economic benefits, simplify processes and reduce the use of agrochemicals. In this sense, the purpose of this report is to estimate the main economic and environmental impacts of GM crops in Argentina. Some of the questions under analysis are the following: How much of the expansion of the area planted, the increase in yields and production can be attributed to the introduction of these technologies? What was the GM technology impact on production costs and farmers' benefits? How were these benefits distributed among the different value chain players? How much employment did it mean for the sector? How much for the country's economy? What was their impact on the environment? What was their contribution to the generation of greenhouse gases?

A diverse set of methodologies are used to examine these issues: simulation models, literature surveys, expert interviews and value chain models.

A first set of results shows that GM crops have improved farmer benefits. In the period 1996-2020, GM crop production schemes outperformed conventional crop schemes on average by USD 29.1/ha for soybeans, USD 35/ha for maize, and USD 217/ha for cotton. Depending on the crop, the margin increase was attributed to a combination of lower production costs and higher yields.

A second set of results shows that the adoption of GM crops has brought significant benefits to the country. Cumulative gross margins in the period under analysis are estimated at USD 158 billion. Out of the total benefits, 92% (USD 146 MM) correspond

[1] For instance, see Klumper and Qaim (2014), Finger *et al.* (2014), Nicolia *et al.* (2013), Kathage and Qaim (2012).

to soybean cultivation, 7% (USD 10.9 MM) to maize, and the rest (USD 2.1 MM) to cotton. Considering the increase in foreign exchange due to higher exports, the 25 years of GM represented an additional USD 153 billion. In terms of the additional employment demanded by value chains as a result of GM crops, an average of 93 thousand jobs were created per season.

A third group of results shows that in environmental terms, GM crops have made it possible to significantly mitigate the impact of primary production on the environment.

Environmental benefits were estimated on two fronts. On the one hand, benefits are identified due to the reduced use and toxicity of agrochemicals applied to the soil. In this regard, the case of GM soybeans stands out, with a 30% environmental impact reduction compared to conventional soybeans.

On the other hand, environmental benefits were estimated due to the enhanced adoption of no-till farming as a result of the use of GM crops. In this regard, benefits were identified from both the reduced use of fossil fuels and the increased rate of carbon sequestered in the soil that arises from applying this practice of conservation agriculture.

As regards the reduction in the use of fossil fuels, if the technological package that includes no-till farming and the use of GM seeds had not been adopted, today the carbon dioxide emissions would have been more than 1 billion kg per year higher, that is, emissions were reduced an equivalent to the annual consumption of 240 thousand cars (EPA, 2011). In the cumulative period 1996-2020, more than 18 billion kg of carbon equivalent to the annual consumption of 3.9 million private cars would have been released into the environment.

With respect to the increase of organic carbon sequestered in the soil, its amount results from the adoption of no-tillage. In particular, it is estimated that for the 2020/2021 season the volume increased by 7.3 million tons, or 121 million tons over the last 25 seasons.

The rest of the document is structured as follows: Section 1 contains an introduction; Section 2 provides a description of GM products approved for commercial use in Argentina; Section 3 describes the evolution of GMO technology adoption in the area planted with the main crops, and it identifies the principal factors accounting for the dynamics of technology adoption; Section 4 analyzes the economic impact at farmer and country level; Section 5 describes the current applied technology; Section 6 estimates environmental impacts; and finally, Section 7 presents several comments as a conclusion.

II. From Bench to Field

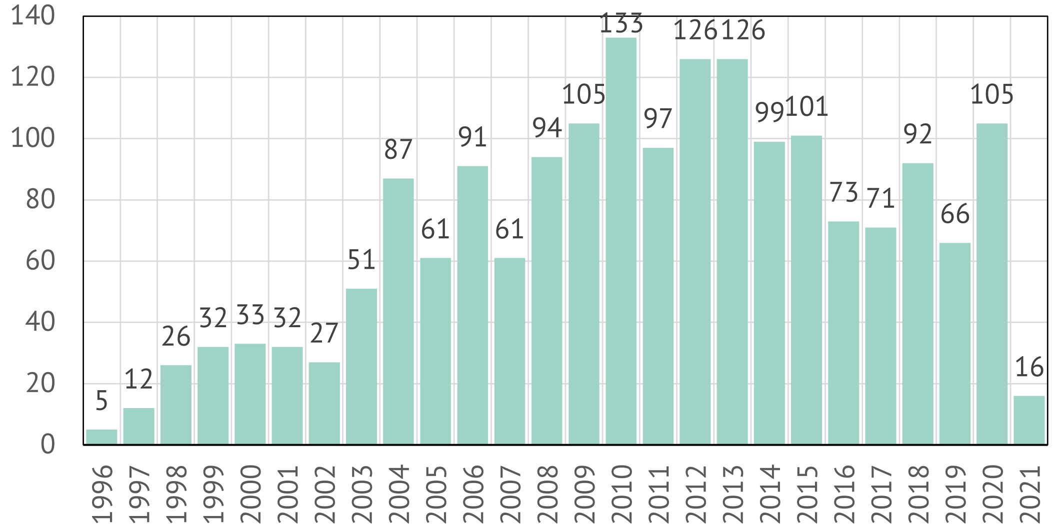
The first GM crop incorporated into Argentine agriculture was soybean tolerant to glyphosate herbicide, which was approved in 1996, nearly at the same time as in the United States.

The institutional framework then in force was one of the enabling factors for the rapid introduction of GMO technology in the country. In this regard, the creation of the National Advisory Commission for Agricultural Biosafety (CONABIA), the body responsible for the regulatory process for the experimental testing and commercial release of GM crops, played a central role (Trigo, 2011)

From that date onwards, more than two thousand GM varieties have been registered. Figure 1 shows the number of GM varieties that have been registered with the National Seed Institute (INASE) since 1996. The number of registered varieties grew from 5 in 1996 to 133 in 2010, and then averaged 88 per year. Out of the total number of GM varieties registered, 1,057 correspond to maize, 942 to soybean, 19 to cotton, and 2 to alfalfa (Figure 2).

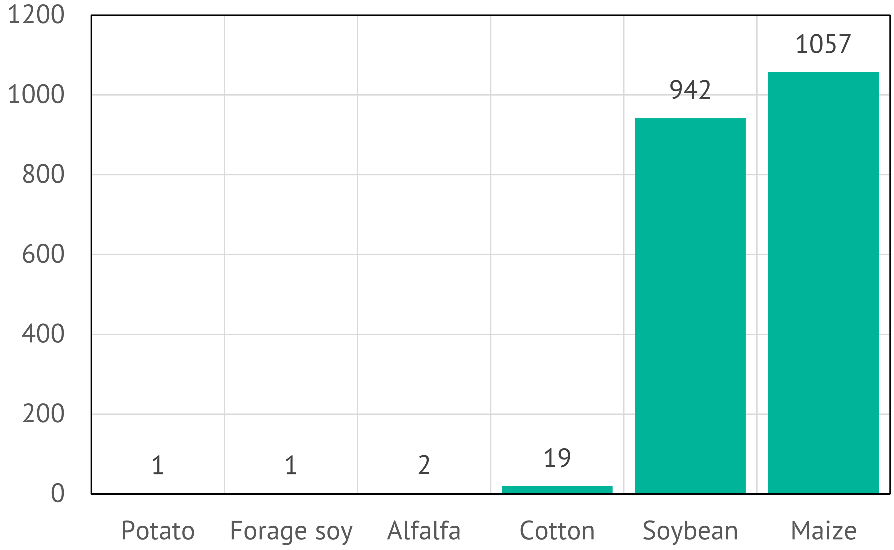
GM varieties registered within this period included the following introduced traits: herbicide tolerance (48.5%), insect resistance and herbicide tolerance (both together, 46.4%), and insect resistance (24.6%, Figure 3).

Figure 1. New GM Varieties on the National Register of Cultivars



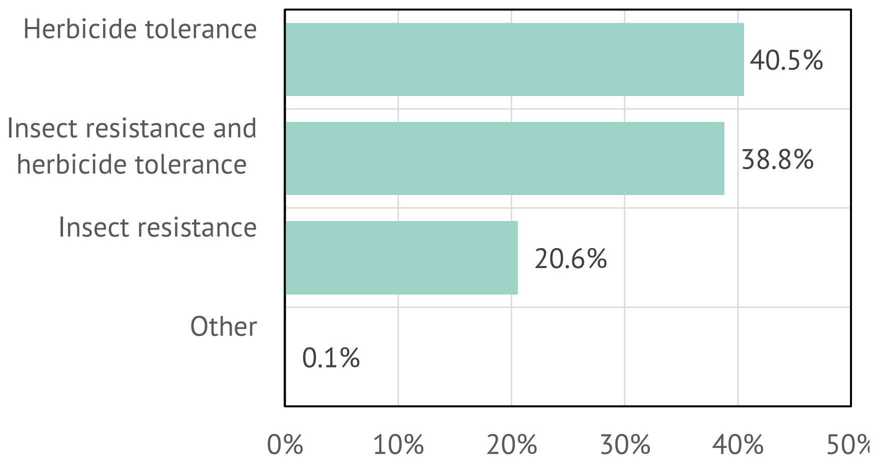
Source: National Register of Cultivars, INASE. Data as of April 30, 2021.

Figure 2. GM Varieties by Crop on the National Register of Cultivars



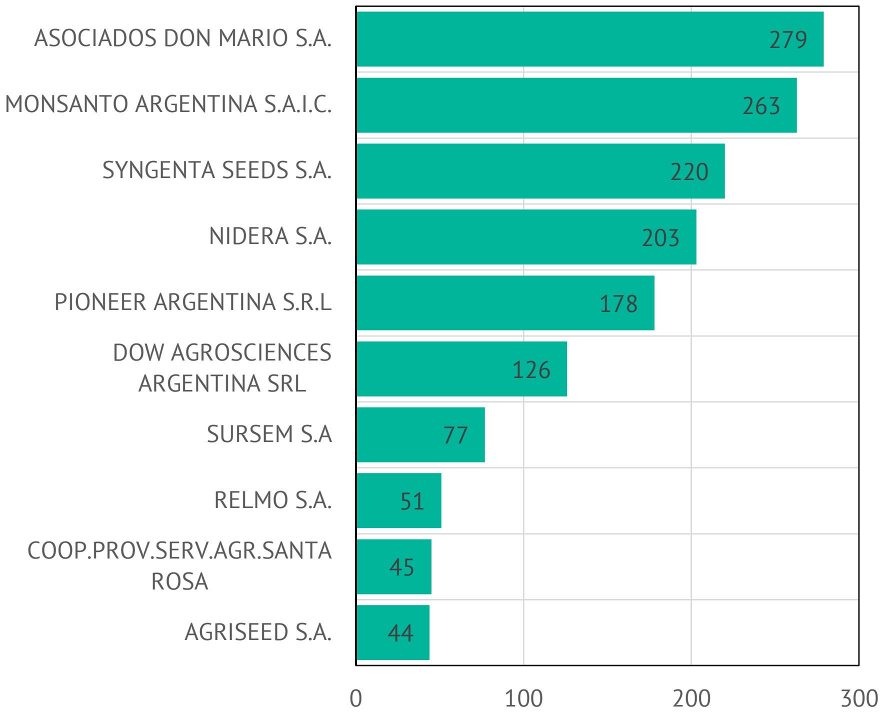
Source: National Register of Cultivars, INASE. Data as of April 30, 2021.

Figure 3. GM Varieties Registered by Introduced Trait*



Notes: *As of April 30, 2021. Source: National Seed Institute (INASE).

Figure 4. GM Varieties Registered by Applicant*. Top 10 Companies



Notes: *As of April 30, 2021. Source: National Seed Institute (INASE)

The top 3 companies in number of applications filed with INASE were Don Mario Associates (279), Monsanto (263) and Syngenta (220) (Figure 4).

In terms of the number of authorized commercial events (and combination of GE events), after the approval of herbicide tolerant soybean, 62 commercial approvals have been granted, including maize (34), soybean (16), cotton (7), alfalfa (1), safflower (1), potato (1), and wheat (1). Table A1 of Annex I contains a full list of approvals, including event names and introduced traits.

III. Adoption of GM Crops in Argentina

After the approval of glyphosate tolerant soybeans in 1996, the area planted with GM soybeans increased from less than 5% to more than 80% four seasons later (see Figure 5). This circumstance has positioned Argentina among the main producers of GM crops worldwide.

In 2019[2], 190.4 million hectares were planted with GM crops in 29 countries (ISAAA, 2019). Argentina accounted for about 12.6% of total hectarage planted with GM seeds, the United States 37.5%, Brazil 27.7%, Canada 6.6%, India 6.2%, Paraguay 2.1%, and China, South Africa and Pakistan about 1.5% each, respectively.

The widespread adoption of GM crops suggests that farmers have benefited from GMO technologies. When they adopt a new technology, they expect to increase their net profits, simplify processes, and reduce exposure to chemicals (Fernandez Cornejo, 2014). Net profits are a function of farm characteristics (size and soil quality), location, grain and input prices, existing production systems, and management capabilities.

In the 2019/2020 season, Argentine farmers planted 26.85 million hectares of GM maize, soybeans and cotton (Table A2), representing about two-thirds of the total crop area planted in the country[3].

The academic literature has examined the causes for the adoption of these technologies by farmers. Finger *et al*. (2009) identify, for the Argentine case, that development companies played a central role in the dissemination of herbicide tolerant soybeans through the provision of information. AAPRESID and INTA were also prominent institutions in playing such role. This improved farmers' perception of these new technologies. Penna and Lema (2002) find that the higher profitability and lower relative risk of GM soybeans over conventional soybeans are the main explanatory factors for the rapid technology adoption. This higher profitability would be the result of lower herbicide costs rather than higher yields.

The institutional framework was also relevant in order to explain the speed of adoption. Three central points stand out in this regard:

First, the creation of regulatory institutions such as the National Advisory Commission on Agricultural Biotechnology (CONABIA) and INASE in 1991, which laid the foundations for the experimental testing and commercial release of GM crops in the country.

Secondly, the particular conditions under which GM soybean was introduced into the country. Qaim and Traxler (2005) highlight this point in their paper:

> *"The first company to commercialize RR soybean varieties in Argentina was Nidera. Nidera received royalty-free access to Monsanto's technology in the late 1980s. A brief overview of the context accounts for the situation: In the mid-1980s, Asgrow International, which was then controlled by Upjohn, had an agreement in place with*

[2] Latest available data.
[3] Estimate based on the latest Applied Agricultural Technology Survey (ReTAA) for 2019/2020.

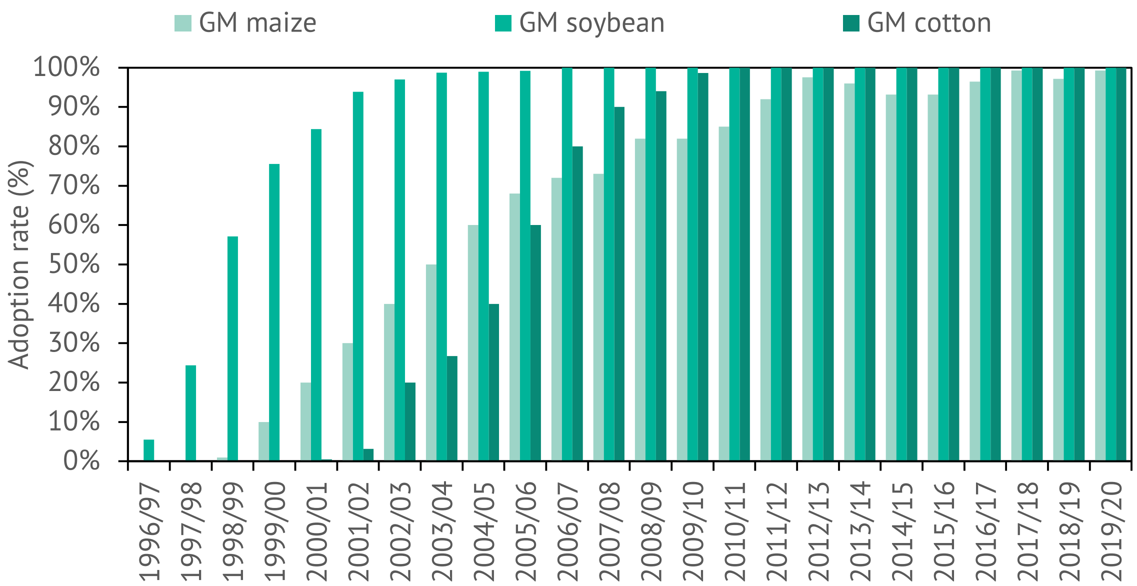
Monsanto to introduce RR technology into its seed line. Shortly after this, Upjohn decided to sell and/or close its subsidiaries in the southern hemisphere. Nidera bought Asgrow Argentina and, with such purchase, became entitled to use Asgrow International's germplasm. In the mid-1990s, Monsanto bought Asgrow International's grain and oilseed business and concluded an open access agreement with Nidera for new developments. The existing material, however, remained unchanged, including the lines with the RR event. Nidera applied to the Argentine biosafety framework for authorization of this technology and obtained approval for commercial use in 1996. Monsanto and other companies followed this process in subsequent years. By 2001, there were seven companies supplying more than 50 RR soybean varieties in Argentina. With the exception of Nidera, all companies paid royalties to Monsanto." Adapted from Qaim and Traxler (2005).

The third point refers to the operational aspects of the seed market. Under the principles of the International Union for the Protection of New Varieties of Plants (UPOV), to which Argentina adhered in 1995, farmers can legally save seeds for their own use. This factor significantly reduced GMO technology costs in the early stages of adoption, together with the existence of illegal transactions (so-called 'brown bag') for the sale of uncertified seeds, which was not authorized by seed companies who were the rightful owners.

As regards this last point, an analysis by the General Accounting Office of the United States (GAO, 2000) has shown that in the period 1998-2000, U.S. farmers faced a seed cost that was almost double that of their Argentine counterparts. According to the GAO report, the main determining factors for such cost increase were the existence of a more competitive market, the use of farm-saved seed, and the illegal sale of seeds.

GM maize was introduced in Argentine agriculture in 1998 when lepidopteran insect resistant seed was authorized. This technology adoption speed was also significant, since the area planted five years after its launch reached 50% of total crop area, and currently stands at around 100% (Figure 5). This dynamic trend represents an unprecedented process of incorporation of GMO technologies both locally and internationally. Trigo (2011) compares the speed of adoption of GM crops in Argentina with the experience in other regions and comparable technologies in world agriculture. His findings show that the speed of adoption of GM crops in Argentina exceeds the experience of both the American Corn Belt and, in other parts of the world, the so-called Green Revolution technologies.

Figure 5. Evolution of GM Crops Share in the Total Area Planted for each Crop



Source: 1996 - 2015, ArgenBio (2015); 2016-2020 and ReTAA (2016, 2017, 2018, 2019, 2020).

Relative to soybean and maize, the speed of adoption of insect resistant cotton was much slower (see Figure 5) mainly due to factors associated with germplasm quality, which did not initially have the same degree of adaptation to local conditions as conventional seed, even though it quickly reached 100% adoption once the event was available in a suitable germplasm. On the other hand, Qaim and De Janvri (2003) point out that Bt technology had significant advantages in terms of insecticide reduction and increased yields, even though the adoption speed was slow in Argentina as a result of high initial Bt seed costs. Chudnovsky (2007) also links the slower adoption of Bt cotton to the marketing strategy of seed companies, which made Bt technology cost four times more than conventional technology.

Applied Agricultural Technology Survey (*ReTAA*)

The *Relevamiento de Tecnología Agrícola Aplicada* (*ReTAA*) report produced by the Bolsa de Cereales (Brihet *et al.*, 2016, 2017, 2018, 2019 and 2020) measures the GMO technology adoption in the main extensive crops in Argentina since the 2010/11 season. Based on data collected through telephone surveys of agricultural advisors across the country, information is generated on the use of technology in terms of inputs and technical management of crops.

Seed biotechnology is one of the most important variables examined in the ReTAA report due to the sustained growth of its use in recent decades. This subsection presents some of the survey findings.

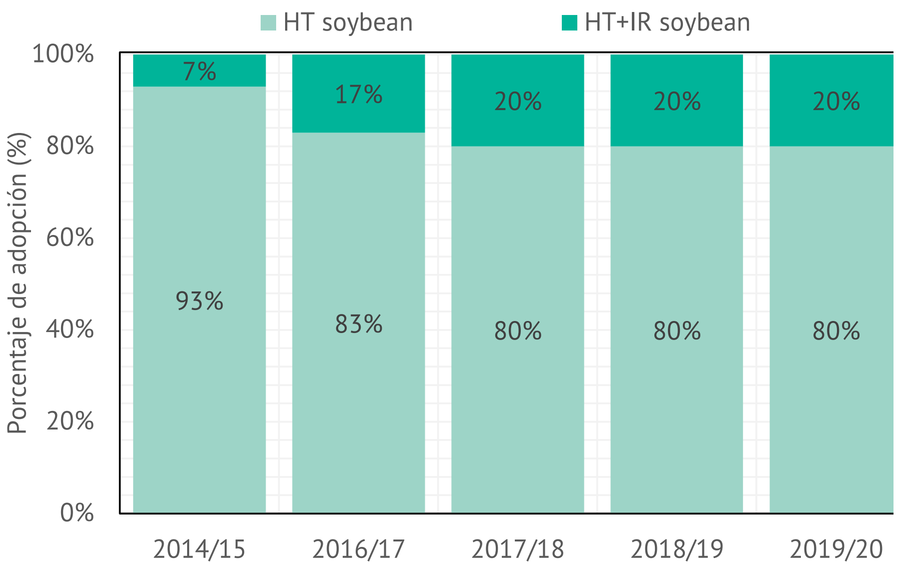
Cultivation of GM Soybean

After the introduction of glyphosate-tolerant soybeans, one of the most important technological leaps in soybean seeds occurred in 2012 with the authorization to commercialize soybean seeds, products and by-products with stacked insect resistance (IR) and herbicide tolerance (HT) events, also called Bt + RR2 stack.

In the last four seasons, the use of IR+HT (or Bt+RR2) technology has recorded significant growth from 7% in the 2014/15 season to 20% in the 2019/20 season (see Figure 6).

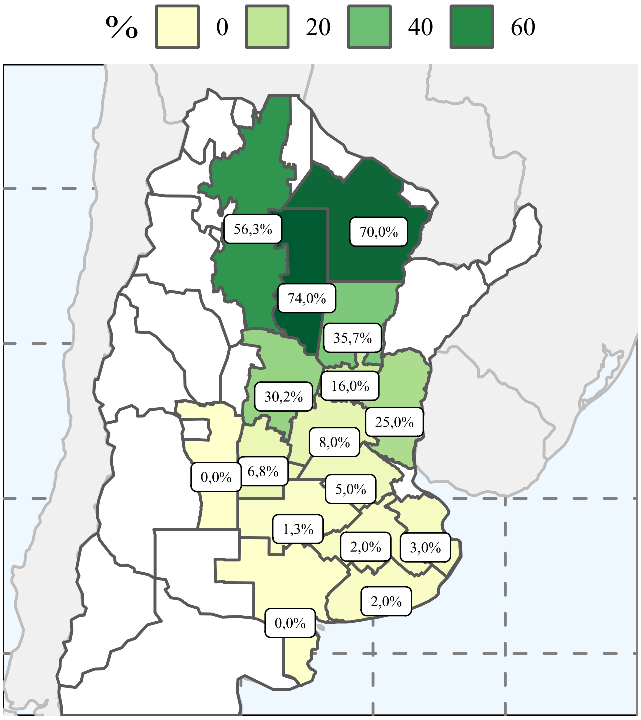
Reasonably, the adoption of IR+HT soybean recorded the highest adoption levels in the northeastern region, where there is a higher incidence of lepidopterans. Towards the south of the country, adoption decreases significantly (see Figure 7).

Figure 6. Adoption of GM Soybean: Single and Stacked Events



Source: ReTAA (2016, 2017, 2018, 2019, 2020).

Figure 7. Soybean: Adoption of Herbicide-Tolerant and Insect-Resistant Varieties (stacked) in 2019/20



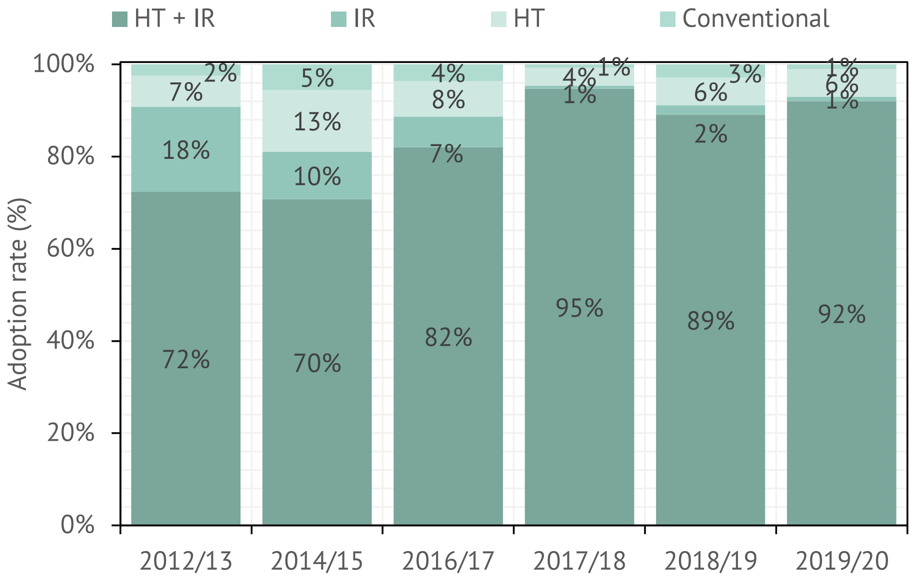
Source: ReTAA (2020).

Cultivation of GM Maize

Over the last decade, there has been a dramatic change in the adoption of maize hybrids. The creation of hands-on know-how and the development of new hybrids contributed to a decrease in the use of single events at the expense of stacked events. In the 2019/20 season, stacked events (HT+IR) accounted for 92% of total seed planted, while single events (HT or IR) accounted for 7% and conventional seed for 1% (see Figure 8).

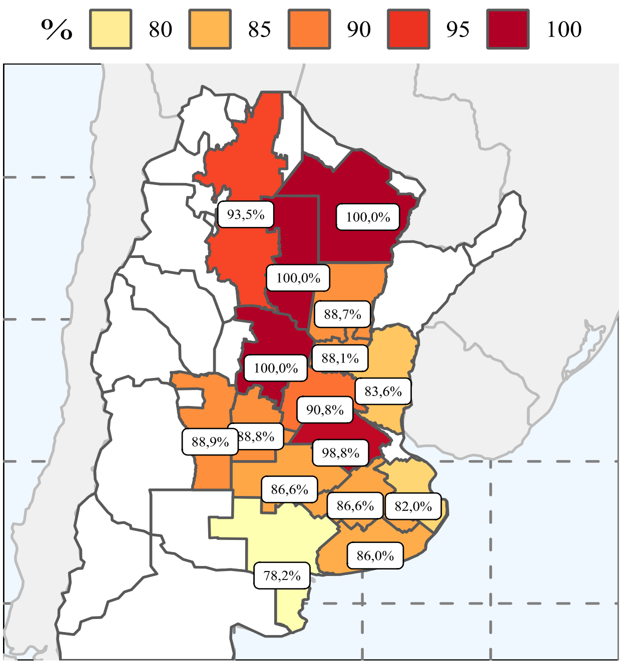
Hybrids with stacked events have been adopted across the whole crop area, even though at different levels by region (see Figure 9). These hybrids are chosen because they combine herbicide tolerant events with insect resistant events, and enable good management of such adverse conditions. At the same time, they reduce the number of crop protection products applied and consequently their associated costs (Brihet *et al.*, 2019). Other characteristics are better crop health behavior, higher yield potential and easier drying process.

Figure 8. Adoption of GM Maize: Single Events and Stacked Events



Note: HT: Herbicide Tolerant, IR: Insect Resistant. Source: ReTAA

Figure 9. Maize: Adoption of Herbicide-Tolerant and Insect-Resistant Varieties (stacked) in 2019/20



Source: ReTAA (2020).

Likewise, the use of hybrids with stacked events for insect and weed control becomes important in late maize crop production schemes. The delay in crop planting date favors an increase in the large population of major pests (stem borer, armyworm, and bollworm), exposing the crop to high pressure at phenological stages of increased susceptibility. Figure 9 shows the adoption rates of stacked events in the 2019/20 season, showing a high adoption rate nationwide.

IV. Economic Impact of GM Crops Adoption

IV. a. Economic Impact at Farmer Level

Many studies have evaluated the factors exerting influence on technology adoption, as well as the effects of GM crops on yields, margins, and agrochemical use. These factors vary by crop and technology.

Table 1 contains a summary of selected papers on the effects of GM crops on yields, agrochemical use, and economic returns in Argentina. Most papers find positive results on one of these three variables.

In the case of herbicide resistant soybeans, Groves (1999) estimates that GM soybeans reduce production costs by 25 to 30 USD/ha, while they increase yields compared to conventional soybeans. Qaim and Traxler (2003) surveyed 59 farmers in Buenos Aires, Santa Fe and Chaco and reported that GM soybean costs are lower than USD 20/ha, while margins are higher than 10%; yet there were no significant increases in yields or in the use of crop protection products. Penna and Lema (2002) did not find significant changes in yields or in the use of agrochemicals, even though they did find a significant improvement in the cost of production, which they estimate to be lower than that of conventional soybeans, between 15 and 17 USD/ha. Both Penna and Lema (2002) and Qaim and Traxler (2003) associate lower production costs with smaller number of pesticide applications required consistently with the new technology.

In a comparison between insect resistant cotton and conventional cotton, Qaim and De Janvri (2003), using a survey of 299 farmers in Chaco and Santiago del Estero, found that GM cotton recorded 29.5% higher yields, higher margins of 88.2 USD/ha, and insecticide doses reduction by 73% on average[4]. Likewise, De Bianconi (2003) identifies that Bt technology entails benefits to farmers by increasing yields (+54%), reducing insecticide use (-63%), and earning higher margins (+16 USD/ha). Finger *et al*. (2011), analyzing the

[4] The drop in insecticide use is estimated to be greater in the case of insecticides with higher toxicities.

case of Argentina and six other cotton producing countries, reported a positive effect of Bt cotton on yields (+46%), margins (+86%) and insecticide expenditure (-48%).

In a comparison between insect resistant and conventional maize, Paredes (2002) estimates a positive impact on yields (+26%) and margins (+48 USD/ha) for a sample of 120 farmers in Entre Ríos. Similar results are found by Brookes and Barfoot (2020), who estimate a positive impact on yields of 5% in core zones, and 33% in marginal zones.

Table 1. Summary of Selected Papers on the Effects of GM Crops on Yield, Agrochemical Use, and Economic Return in Argentina

Crop/ Authors/ Publication Date	Data Source	Impact on		
		Yield	Agrochemicals Use	Economic Return
Herbicide Tolerant Soybean				
Groves, 1999	N/A	Increased	N/A	Increased
Qaim and Traxler, 2003	Survey	Same	Same	Increased
Penna and Lema, 2002	Expert	Same	Same	Increased
Insect Resistant Cotton				
De Bianconi, 2003	Survey	Increased	Decreased	Increased
Qaim and De Janvri, 2003	Survey	Increased	Decreased	Increased
Finger *et al.*, 2011*	Meta-analysis	Increased	Decreased	Increased
Insect Resistant Maize				
Paredes, 2007	Survey	Increased	Same	Increased
Finger *et al.*, 2011	Meta-analysis	Same	Same	Same
Brookes and Barfoot, 2020	Industry Information	Increased	N/A	Increased

Note: *Argentina and six countries.

Methodology

For this paper, a comparative analysis was made between GM and conventional seed scenarios, estimating both production costs and gross margins. The difference between the two scenarios allows measuring the cost savings delivered thanks to GM events, as well as the net production margin.

To this end, theoretical crop production schemes were developed for a typical farm, both under the assumption of using GM and conventional crop planting material. For the first case, the average input utilization rates published by ReTAA (Brihet *et al*., 2019) were taken as a reference, while for the counterfactual scenario (conventional seed), input and tillage requirements were modified with agronomic criteria.

Since the ReTAA does not contain cotton data, references for such crop were taken from Quirolo *et al*. (2019), De Bianconi (2003), Argentine Cotton Chamber (*Cámara Algodonera Argentina*) and expert consultations. Based on these theoretical models, together with input and product prices, the Tables developed by product are shown below.

Soybean

In the case of herbicide-resistant soybeans, the results show that a GM soybean crop production scheme involves lower herbicide and field operations costs, even though it has higher seed costs (see Figure 10).

The lower herbicide costs are attributed to the lower glyphosate price compared to herbicides used in conventional crop schemes[5], while the lower insecticide costs and the lower number of pesticide applications account for the lower costs in 'other chemicals' and field operations. On the other hand, seed expenses are higher because GM seed has a higher market price than conventional seed[6].

Considering that yields are similar in both crop schemes, the lower costs allow for a significant improvement in gross margins (see Figure 11). On average between 1996 and 2020, a GM soybean crop scheme margins exceeded those of a conventional crop scheme by 29.1 USD/ha. In recent years there has been a slight drop in the spread between GM and conventional margins, due to a drop in herbicide prices.

[5] Glyphosate is used in conventional crops, however to a lesser extent, mainly when applied on fallow land.
[6] No assumptions were made for the use of brown bags or farm-saved seeds.

Figure 10. GM vs. Conventional Soybean Crop Production Scheme Savings by Item (in USD/ha)

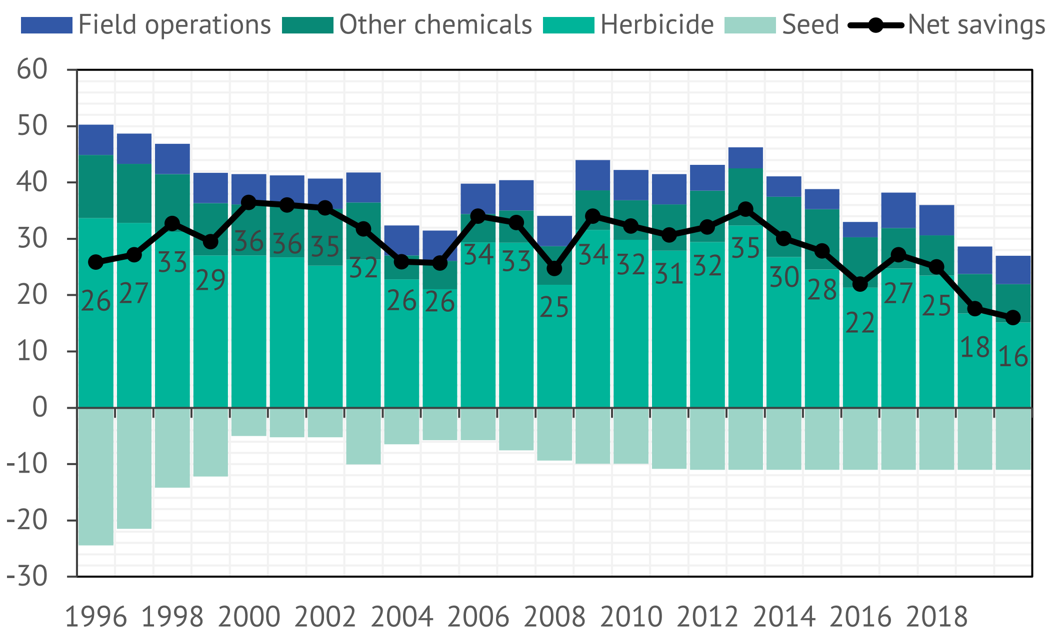
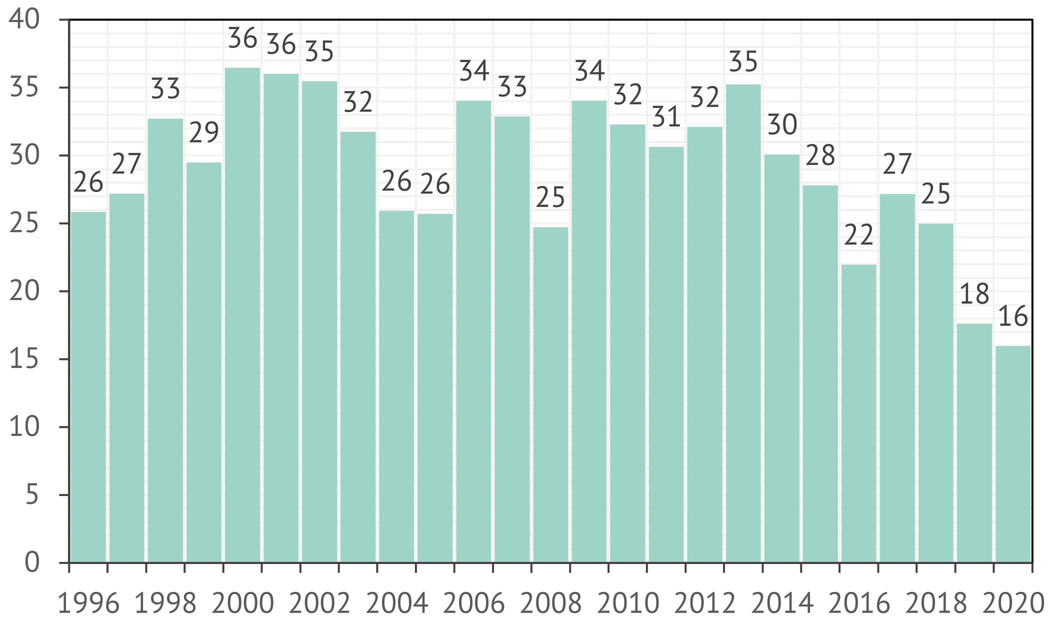


Figure 11. Increase in Margins earned from Applying a GM Soybean Crop Production Scheme (in USD/ha)



Source: Own estimates.

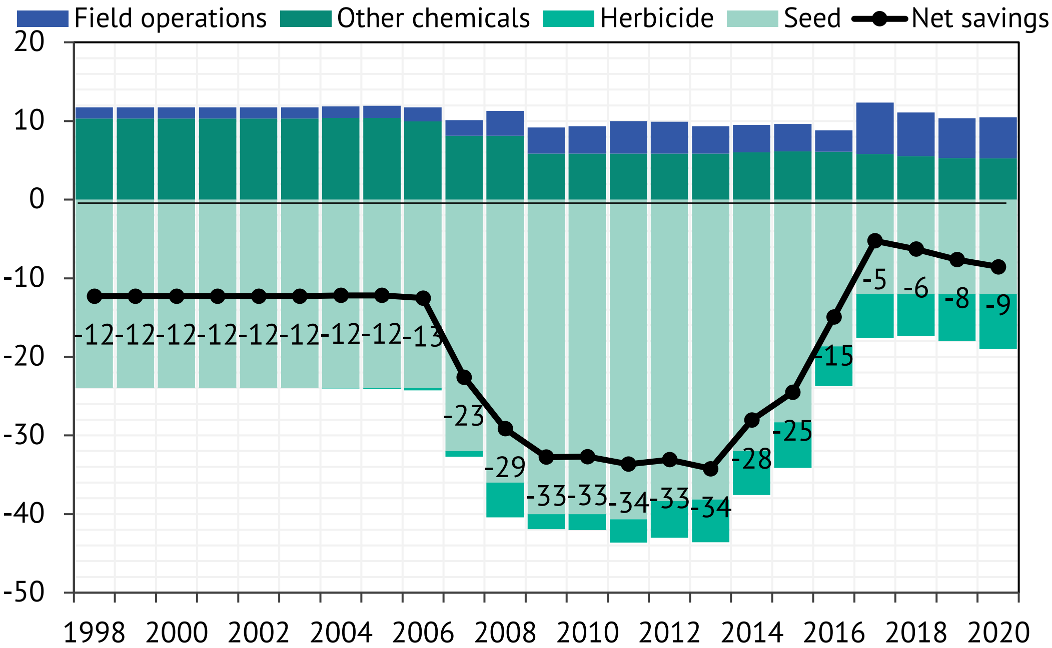
Maize

In the case of GM maize, average crop production schemes were considered, taking into account the proportion of Bt and Bt+RR (stacked) seeds used in each season. Unlike soybeans, in the case of maize, the costs of a GM crop scheme greatly exceed those of the conventional crop scheme. In this case, the results are also consistent with those of the literature.

The GM maize crop scheme has higher costs for seeds and herbicides and lower costs for field operations (see Figure 12). Again, in the case of seeds, this is attributed to the higher market price of GM maize seed over the conventional hybrid, while the higher herbicide costs are attributed to the higher doses applied. Field operations, on the other hand, are lower due to the need for fewer insecticide applications.

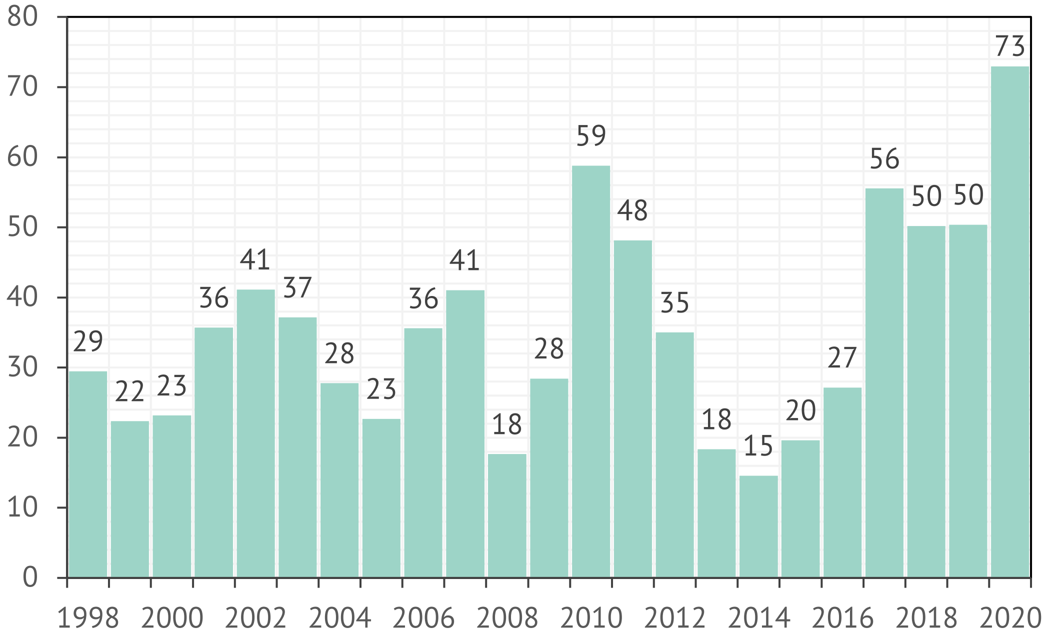
Although the costs of a GM crop scheme are higher, improved yields allow margins to be significantly higher than those of a conventional crop scheme. Figure 13 shows the evolution of the benefits of adopting a GM maize crop scheme. On average, the benefits of adopting a GM crop scheme meant a margin improvement of 35 USD/ha. There is also high variability in returns. In most cases, lower margins are attributed to declines in international maize prices. However, in the case of the 2013-2016 period, lower margins

Figure 12. GM vs. no-GM Maize Crop Production Scheme Savings by Item (USD/ha)



Source: Own estimates.

Figure 13. Increase in Margins earned from Applying a GM Maize Crop Production Scheme (in USD/ha)



Source: Own estimates.

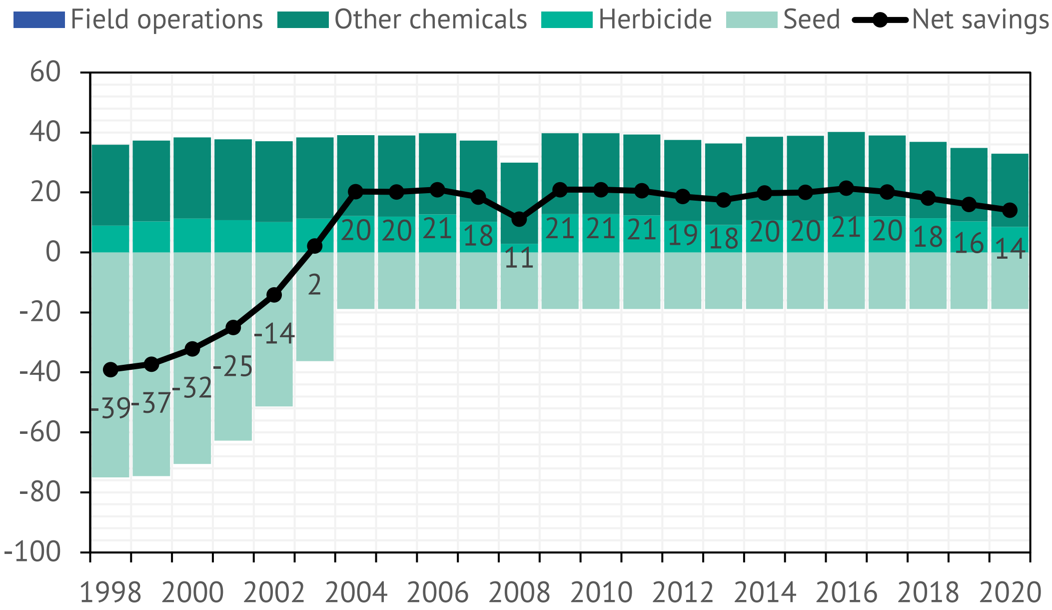
are the result of export duty rates and export restriction policies implemented in such period, which weakened domestic maize prices.

Cotton

The comparison between a cotton crop scheme with conventional seed and one with GM seed shows that the GM crop scheme implies lower herbicide expenses (on average 9 USD/ha of annual savings) and lower expenses in the application of other agrochemicals (on average 27 USD/ha per year), mostly attributed to lower doses of insecticides. As explained in the previous section, in the period 1998-2001 one of the factors limiting the technology adoption was the high cost of GM seed compared to conventional seed. This is also reflected in our estimates which show that seed expenses are higher in the GM crop scheme, that is, on average 30 USD/ha per year (see Figure 14).

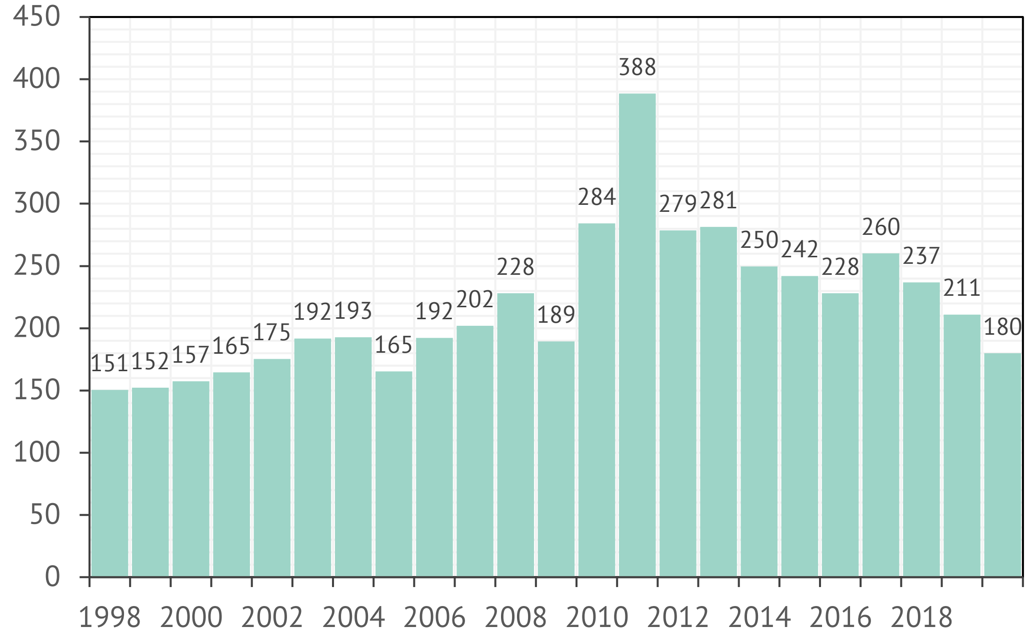
The higher seed expenses of the GM crop scheme implied a more expensive approach in the early years of technology adoption in the country. However, with the introduction of new events and players in the commercialization of GM crops, seed costs were reduced. As a result, from 2004 onwards, the GM crop scheme recorded positive average net savings of 16 USD/ha.

Figure 14. Savings of a GM vs. Non-GM Cotton Crop Production Scheme by Item (in USD/ha)



Note: Conventional and GM seed expense for the period 1998-2000 was obtained from De Bianconi (2003) then interpolated to 2004 market prices to complete the period 2001-2003. Source: Own estimates based on De Bianconi (2003), Márgenes Agropecuarios, Quirolo *et al.* (2019), Cámara Algodonera Argentina and expert consultations.

Figure 15. Increase in Margins earned from Applying a GM Cotton Crop Production Scheme (in USD/ha)



Source: Own estimates based on De Bianconi (2003), Márgenes Agropecuarios, Quirolo *et al.* (2019), and expert consultations.

Since GM cotton yields are much higher than those of conventional cotton[7], the comparison of gross margins between both crop production schemes delivers very positive results for the GM scheme. In the period 1998-2020, GM cotton growers earned on average 213 USD/ha more than conventional cotton growers (see Figure 15). Over the years, this figure has ranged between USD 127/ha and USD 388/ha, depending on the market price of cotton[8].

IV. b. Impact at Aggregate Level

In aggregate terms, there are three types of impacts: (i) extension of area planted due to improved margins, (ii) improved margins due to increased yields and reduced production costs, and (iii) impacts on crop value chains. This subsection presents an estimate of these margins.

Area under Cultivation

Since the introduction of GM soybeans, there has been a clear break in the trend of expansion of the area planted with soybeans, that is, between the 10 seasons from 1985/86 to 1995/96, the area planted with soybeans increased by 2.6 million hectares, while in the 10 seasons from 1995/96 to 2005/06 it rose by 9.4 million hectares.

In order to estimate the magnitude and evolution of gross margin flows resulting from the adoption of GM crops, a counterfactual approach was used, contrasting the serial area actually planted with soybean, maize and cotton estimated by the Ministry of Agriculture, Livestock and Fisheries with the results of an alternative scenario in which the growth rate remains the same as that recorded in the period 1990-1996, discounting the effect of international prices, as explained below.

This approach was chosen because, when we analyze the impact of the emergence of GM seeds in Argentine agribusiness, it is difficult to isolate the sole effect of this phenomenon, because in practice we noticed that there was a large expansion of no-till farming and a growth in the area under double cropping (winter and summer) at the same time in the same season, which was also feasible thanks to GM crops.

Thus, the impact was estimated indirectly. Based on the historical crop area series, growth was broken down into three components: the effect caused by international price

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7 We assume that GM yields are 42% higher, in line with De Bianconi (2003), Finger *et al.* (2009) and expert consultations.

8 These results are in line with estimates by other authors. Brookes and Barfoot (2020) assume that yields of GM crops are 30% higher than those of conventional crops, and calculate that gross margin of GM crops ranged between 25 USD/ha and 317 USD/ha in the 1998-2018 period.

fluctuations, policies and production costs; the effect of GMOs and the technologies associated with their implementation; and a historical trend in the area planted with GM crops.

The first component was calculated based on a partial equilibrium model developed for this report, which explains domestic changes in sowing decisions depending of prices. The trend was calculated from historical information on the crop seasons between 90/91 and 95/96, as extrapolated forward. Discounting both effects of the series concerned, the remaining evolution is attributed to the technological changes under study[9].

This methodology delivers results validated by experts and in line with the papers surveyed. However, it is limited by the fact that it is impossible to isolate it is not possible to isolate what proportion of the effect corresponds to GM crops from other closely related innovations such as no-tillage or the organizational change implied by the network organization scheme (Bisang *et al*., 2008).

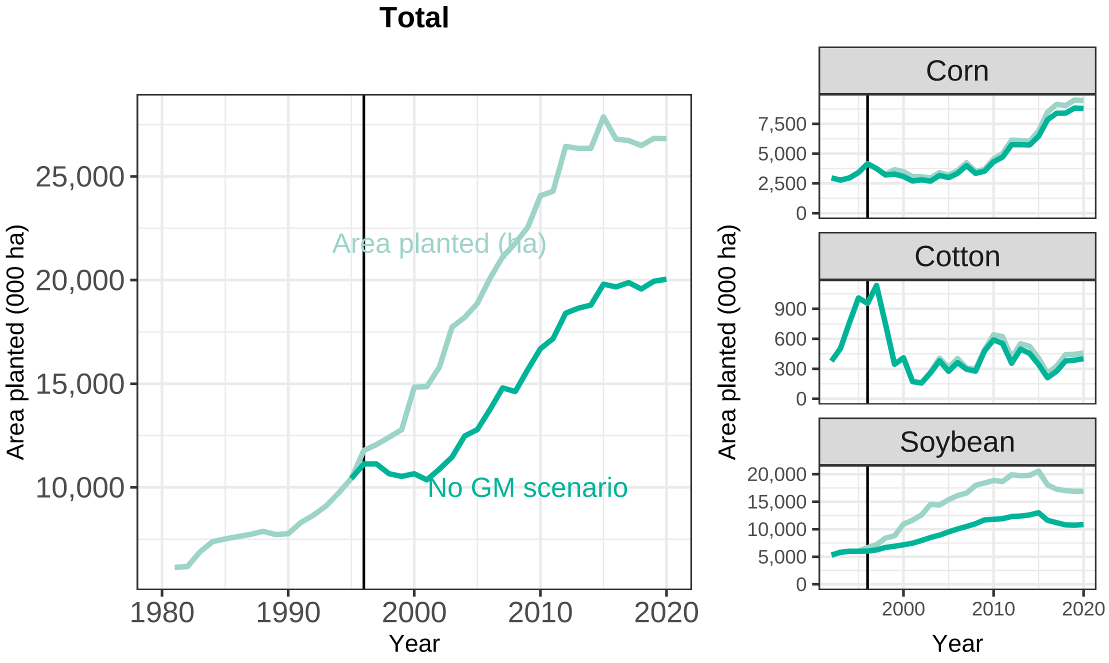
These calculations were performed at departmental level and the results are reported in Figure 16 and Figure A1 in Annex II.

Most of the benefits are concentrated in the soybean crop, which expanded both outside and inside the core zones. We estimate that, outside the provinces of Santa Fe, Córdoba and northwestern Buenos Aires, between 75% and 90% of soybean would not have been planted in the absence of GM crops (see Figure 17). In terms of crop area, GM soybeans implied an additional area sown averaging 5.4 million hectares per year between 1996 and 2020.

Part of the expansion of the area planted with soybean is attributed to the substitution of other crops such as maize and cotton, so the impact of the introduction of GM crops has been moderate in the case of these crops. Indeed, it is estimated that, if the technology had not been introduced, the area planted with maize and cotton would be 333 and 32 thousand hectares lower, respectively.

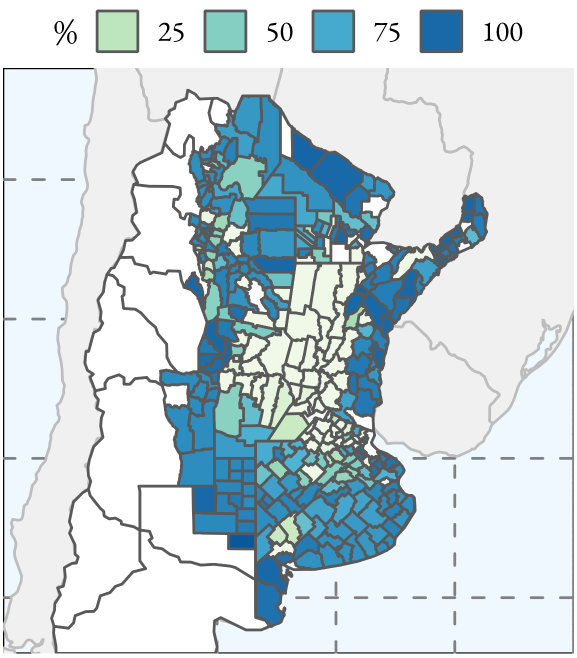
[9] A further development of the calculation methodology is shown in Annex II.

Figure 16. Evolution of Actual Crop Area vs. Area Planted with Non-GM Crops (in thousand hectares)



Source: Own estimates based on Directorate of Agricultural Estimates – Ministry of Agriculture, Livestock and Fisheries.

Figure 17. Percentage of Soybean Area Expansion due to the Introduction of GM Varieties. Median for the Period1996-2025



Source: Own estimates based on Directorate of Agricultural Estimates – Ministry of Agriculture, Livestock and Fisheries (2020).

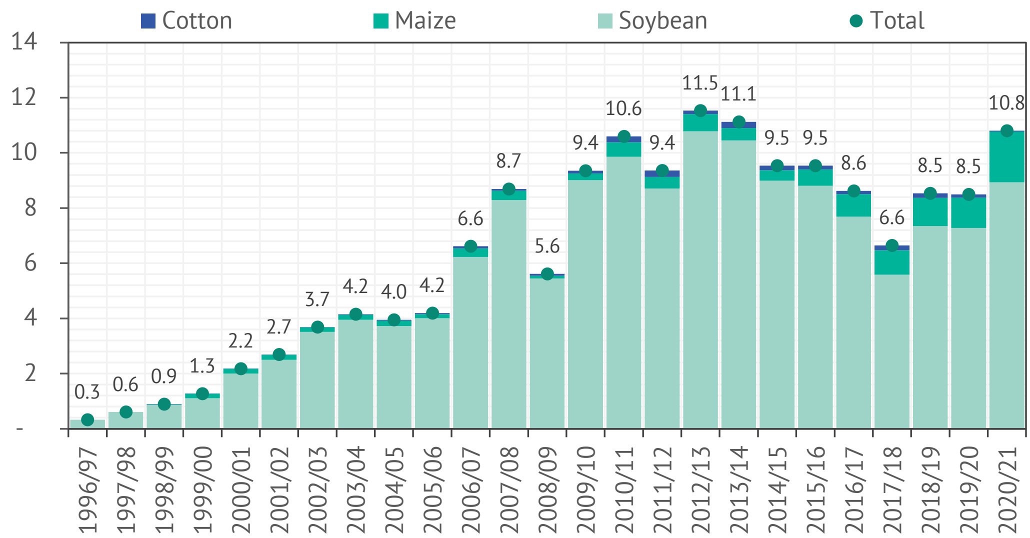
Impact Resulting from Yield Improvements, Cost Reductions, and Crop Area

Assuming the yield improvements described in the previous Section, and considering both crop area expansion and cost reduction, GM crop gross margins are estimated here. These are reported in Figure 18 and Tables A3, A4 and A5 in Annex I.

Between 1996 and 2020, GM crop gross margins averaged U$S 6,342 million per year, reaching a maximum of 11,500 million in 2012, and averaging 9,000 million from that year onwards.

In cumulative terms, in the period 1996-2020, profits amounted to US$ 159 billion, which is similar to the production of 7 crop seasons in Argentina. Out of this total, 92% (USD 146 MM) correspond to soybean crops, 7% (USD 10.9 MM) to maize, and the rest (USD 2.1 MM) to cotton.

Figure 18: Evolution of Gross Margins earned from GM Crops (in billion USD)



Source: Own estimates.

Exports

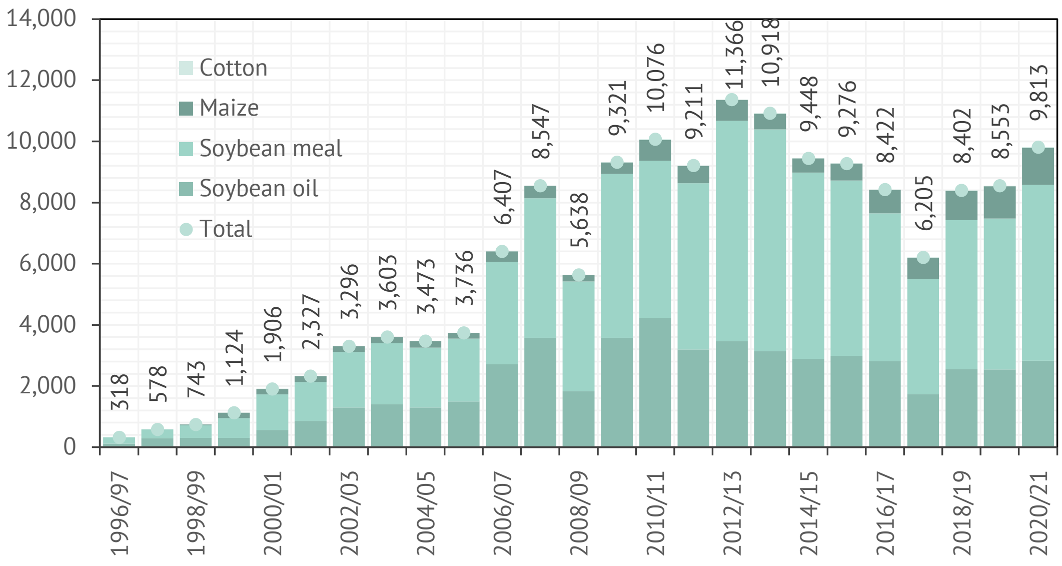
Based on production impacts, it is possible to calculate GM crop margins in terms of foreign exchange earnings for the country. Figure 19 shows the increase in exports for the products concerned.

If the 25 years of GM seeds are added up, export growth amounts to 153 billion dollars. A large share of soybean meal stands out of this total, amounting USD 89,673 million, and soybean oil reaching USD 51,997 million. On the other hand, maize has contributed some additional USD 10,868 million thanks to GMO technology, while cotton totaled USD 169 million, a relatively low figure given that it was assumed that production growth was mainly intended for consumption by local industry.

One caveat is that the above data focused on the value chains relevant to the three GM species under study, without including the impact that the area planted expansion might have on other crops. In response to this scenario, the 20/21 crop season was taken as a reference, and the partial equilibrium model PEATSim-Ar (INAI, 2018) was used, which allowed estimating that the GM scenario is effectively associated with lower production of other crops, even though the net impact continues to be positive.

In fact, as shown in Table 2, compared to the 6.5 million additional hectares harvested of crops with GM seeds, a drop of 1.1 million hectares was estimated for the rest, relative to a scenario without the approval of this technology. This drop is distributed among 743 thousand hectares of wheat, 211 thousand hectares of sunflower, 79 thousand hectares of barley, and 77 thousand hectares of sorghum. Similarly, both the increases in value added and exports are moderated by what happens to other crops, with wheat having the greatest impact.

Figure 19: Export Impact of GMO Technology (in million USD)



Source: Own estimates.

Table 2: Impact of GM Technology on Other Field Crops - 2020/2021 (in thousand hectares and million USD)

	Area	VA	Exports
GM crops	6,465	8,883	9,813
Wheat	-743	-426	-442
Sunflower	-211	-241	-58
Barley	-79	-73	-95
Sorghum	-77	-56	-75
Total	**5,354**	**8,086**	**9,143**

Briefly, it is possible to estimate the net impact on exports at USD 9,143 million for 20/21, which is lower than the USD 9,813 million estimated for GM crops, due to a USD 670 billion shrinkage in other crops.

Margins within Value Chains

In order to focus on the Value-Added Indicator, the Gross Agro-Industrial Product (GAP) model was used. This measures the main economic indicators of these activities in relation to the top six extensive crops in Argentina. This strategy provides information on value added growth, its structure, its distribution among value chain members, as well as its level, which makes it possible to compare the sector size, for example, in relation to the economy as a whole.

As an introduction, the calculation method can be described as indirect. That is, it does not work with income and expenditure surveys of value chain players, but it restructures the accounts for each subsector based on information gathered by the Buenos Aires Grains Exchange, both at production level (Estimates) and at crop production scheme level (Applied Agricultural Technology or ReTAA). This allows for incorporating the changes in crop production schemes, area planted and crop yields described above. An estimate for primary cotton production was also incorporated, in order to cover the main GM crops.

The baseline scenario under study constitutes the one projected for the 2020/2021 season (Bolsa de Cereales, 2021), and is compared to an alternative scenario without GMOs in which the quantities produced are adjusted according to the changes in area planted and crop yields described in the previous section. This implies an increase in soybean production of 15.7 million tons with respect to the scenario without GM crops. The increase is 5.18 million tons for maize, and 338 thousand tons for cotton.

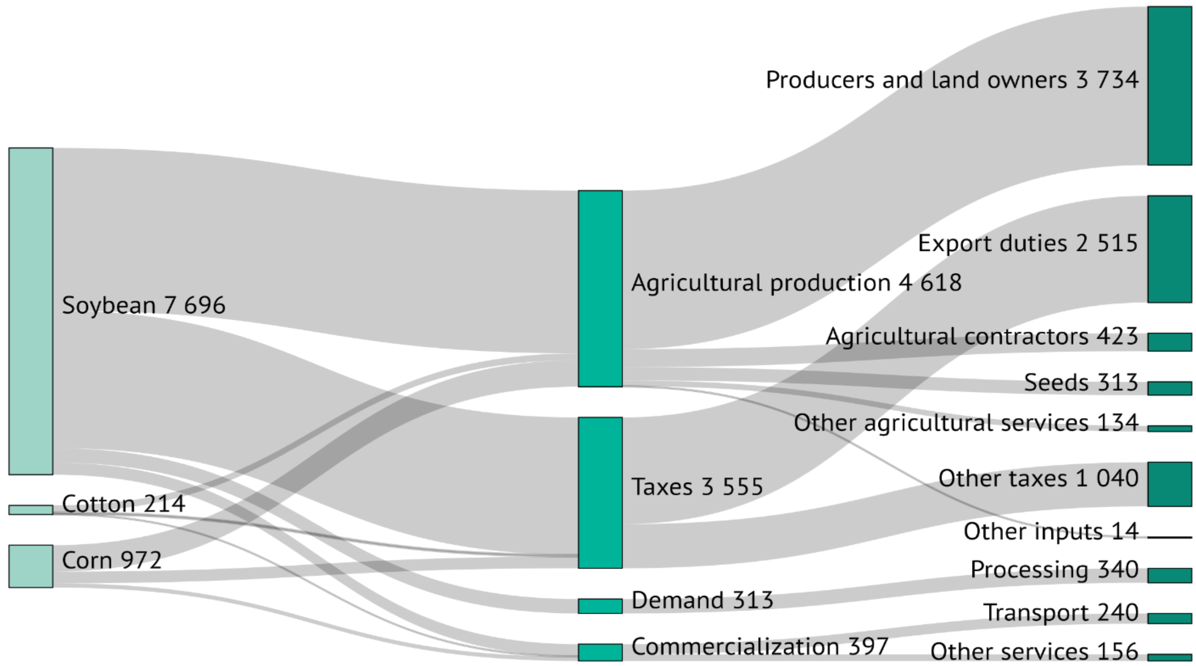
These changes in the sector's quantities were incorporated into the Gross Agro-Industrial Product calculation model. In order to properly consider the new technology packages, the impacts on production costs and demand for inputs associated with GM crops were also included. Finally, the use of estimates at regional level allowed a more precise evaluation of the impact on the demand for transportation services.

Combining the impact of the 3 products, an improvement in Gross Product of USD 8,883 million is estimated and segregated as follows: USD 7,696 million for soybeans, USD 972 million for maize, and USD 214 million for cotton. This represents a direct impact of 2.12% of the GDP projected by the IMF for 2021.

This variation in the sector’s value added can be expressed according to the different value chain stages. On the one hand, USD 4,618 million corresponds to the primary production stage. In particular, the production and/or leasing activity would involve USD 3,734 million, as shown in Figure 20, USD 423 million would correspond to the activity of contractors, USD 313 million to seed production, USD 134 million to other agricultural services, and USD 14 million to other inputs.

On the other hand, USD 3,555 million represents an increase in tax revenue thanks to GM crops, divided between USD 2,515 million corresponding to export duties and USD

Figure 20: Impact of GM Technology on Gross Agro-Industrial Product: Crop Share and Main Sector Players – Crop Season 2020/2021



Source: Own estimates

1,040 million to other national, provincial and municipal taxes, with income tax being the main component.

The rest of the incremental value added is generated at commercialization stage (including freight and other services), and it is also fueled by an increase in the volume of grains processed by the oil industry.

These are great changes, especially if we consider that these are not scenarios differing in a specific event, such as a drought period, but this is a comparison between two long-term equilibria, the first in which Argentina has 25 years of history of using GM seeds, and the second relating to a hypothetical 2020/21 crop season in a country (Argentina) in which the use of this technology has never been approved.

As a result of the size of the shocks, it is to be expected that there will be strong structural differences between the two scenarios, for example, in terms of investment in transportation, storage and grain processing infrastructure or, to a lesser extent, in relation to positioning on the international market. The economic impact linked to these investments is not considered here, so it is interesting to note that the benefits are not exhausted in the estimated figures due to the economic interactions with other production chains.

Job Demand

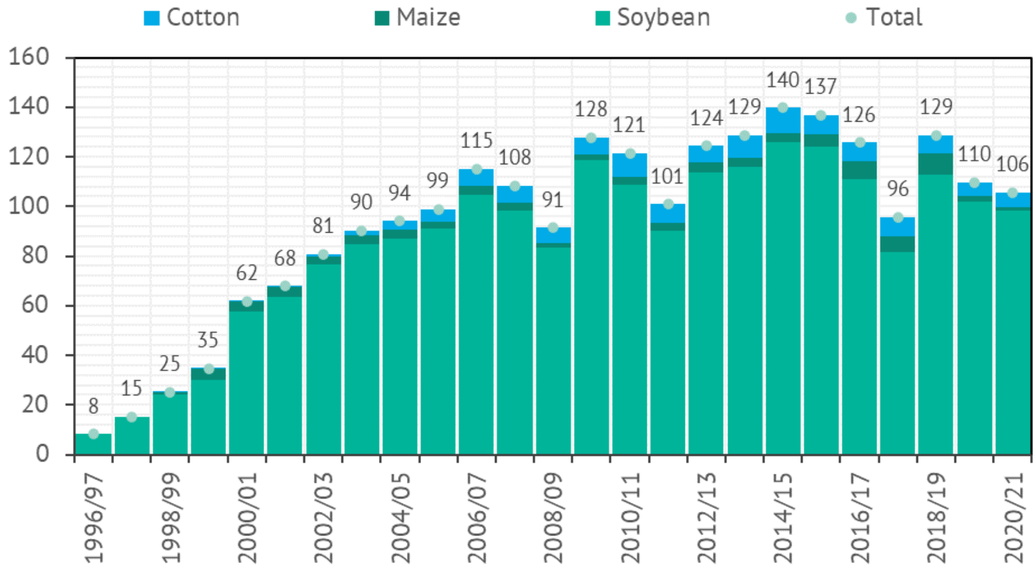
Based on the impacts on production, it is also possible to estimate what happens with the demand for jobs. The methodology took as a reference the estimates of the number of employed people by product for 2015 (Bisang *et al*., 2018), which includes information for the primary, processing and transportation links of each agro-industrial chain. Variations in area planted and production for both GM and non-GM scenarios were applied to these data to calculate changes in employment.

For both transportation and industrial processing stages, fixed labor requirement coefficients were assumed in relation to the volume produced. Soybean crushing was calculated by a difference with production, taking trade as given, and then applying fixed coefficients.

On the one hand, for the primary link, the impact was estimated on sowing season-related employment and the application of nutrients or crop protection products, whose requirements per hectare are not fixed, but follow the historical evolution of crops as the adoption of GM planting material progresses. On the other hand, for the harvest season, fixed coefficients are applied with respect to the volume produced.

The result is shown in Figure 21, where we can see that the additional demand for workers due to GM crops in relation to the non-GMO scenario. This demand grows gradually until it stabilizes at over 100,000 jobs each season. On the other hand, we can notice that the figure is strongly dependent, as expected, on weather conditions in each season.

Figure 21: Impact of GM Technology on Direct Job Demand (in thousand jobs)



The greatest impact can be noticed in soybean, due to the large crop area expansion in the primary stage, and the higher crushing volume. This effect occurs despite the fact that the crop schemes under study contemplate that employment requirements decrease with enhanced technology adoption. In fact, for each million hectares of soybean, primary production required 11,445 jobs in 2020/2021, while in the no-GMO scenario the figure would increase by 648 workers, but the crop area expansion more than makes up for this difference.

Table 3: Impact of GM Technology on Direct Jobs – 25 Years average

	Primary	Processing	Transportation	TOTAL
Maize	2,457	723	325	**3,505**
Soybean	56,774	14,648	13,658	**85,080**
Cotton	1,388	3,338	165	**4,891**
Total	60,619	19,303	14,148	**93,475**

Table 3 provides an average of these 25 years, showing an mean effect of 93,475 additional jobs demanded by growth in the GM crop sector.

It is important to underscore that these job demand increases relate to a comparison between the two scenarios for each crop season. Therefore, such effects are free of other exogenous phenomena that can move the level of employment beyond the variables concerned. For example, if there are trend changes in requirement patterns during the processing stage due to investments in that sector, this effect is left out of the estimate. However, given that these phenomena would impact on both scenarios, the bias should not be significant for the purposes of this research.

V. The Current Technology Package: Yield Gaps and Nutrient Balance in Argentine Soils

Soil nutrient balance is an important indicator, which has gained relevance in the Argentine productive system during the last decade. Given its importance both in the environmental and productive dimension, a great number of estimates have been made to find out the situation in Argentine soils.

It is important to understand that these estimates are made on the basis of a model that only considers inputs via fertilization and outputs by grain extraction in relation to yields measured in each crop season; and that these yields still show an important gap with respect to potential yield. The transformations undergone by nutrients within soil fractions are not considered.

Over the last five seasons, nutrient replenishment in Argentina has improved, reaching 58% in the 2019/20 season. However, it is still deficient, that is, more nutrients are extracted than replenished. The increase in fertilization rates and fertilized area account for this improvement in replenishment. And the implementation of management practices such as no-tillage and cover/service crops contribute to maintain the levels of organic matter (OM) in the soil which, through a mineralization process, makes nutrients available.

GMOs have made it possible to achieve higher yield levels since, as part of a technology package, they help to control adverse conditions (weeds, pests) that cause yield losses. However, there is still potential for increasing yields per hectare in Argentina. Their use, together with improvements in the rest of the technology package, including fertilization, will make it possible to reduce and/or close the current yield gaps, and thus achieve higher production levels in a sustainable manner. According to the Applied Agricultural Technology Survey (ReTAA) prepared by the Buenos Aires Grains Exchange, there are gaps in the yields obtained by farmers in the different productive regions of the country, depending on the technology package applied (High, Medium or Low).

Putting in place appropriate incentives to encourage that those who adopt low or medium technology packages decide to adopt high technology packages, average yields would increase by 12% for soybean and maize. On the other hand, there are also gaps between average yields and those obtainable for each crop, defined as the highest yield achievable without limiting nutrients, crop protection products and diseases, under dryland conditions. These latter gaps can reach 37% in Argentina in the case of maize (*Reaching the Potential for Argentine Agriculture*, Bolsa de Cereales, 2019).

The importance of estimating the nutrient balance lies in understanding that negative balances imply that less nutrients are being incorporated than extracted and, on the contrary, overstated positive balances result in low nutrient use efficiencies. Both situations can have negative consequences on the soil and the environment.

Nutrient balance can also be expressed as a percentage of replenishment, which represents the kilograms of nutrients that are replenished for every 100 kg of nutrients extracted. In the present analysis, only the main extensive crops of Argentina are considered.

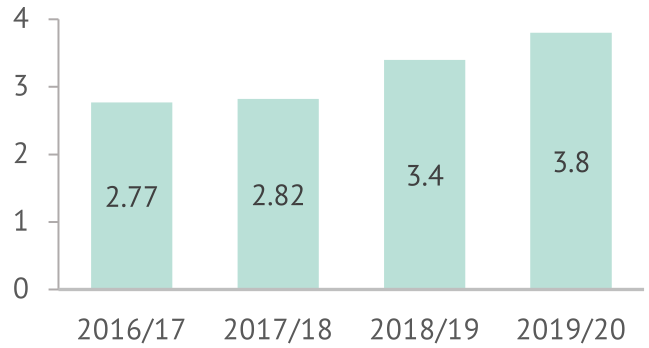
Nutrient Input

The input of nutrients is mainly attributed to the contribution made by fertilizers and, to a lesser extent, to a series of practices that contribute to maintaining the level of soil organic matter.

In the 2019/20 season, extensive crops accounted for 82% of the fertilizer market as a whole, which reached 4.68 million tons; and among such crops, soybean, maize and wheat accounted for about 90%. Wheat and maize accounted for a significant portion of the nitrogen fertilizer market, while soybean accounted for the largest share of the phosphate fertilizer market. The evolution of fertilizer consumption in Argentina has recorded a positive and sustained trend since the 2016/17 season. This is mainly attributed to increases in the area sown with maize and wheat, and also by improved fertilizer doses for all crops generally (Monthly ReTAA Monthly No. 40, 2021).

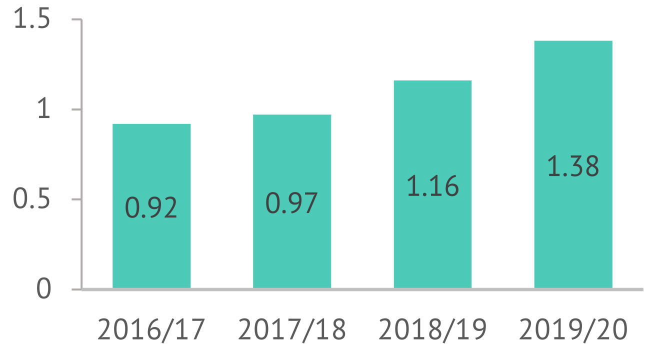
Anyway, there is still a long way to go. In Argentina, only 23% of farmers performed soil analysis to diagnose soil chemical fertility in the 2019/20 season. Since the availability of nutrients in the soil is unknown, it is difficult to establish the nutrient supply needed to cover the nutritional requirements of crops, and thus ensure the maintenance of soil fertility levels. (Monthly ReTAA, No. 41, *Soil fertility in Argentina*).

Figure 22. Fertilizer Use for the Top 6 Crops (in million tons)



Source: Based on ReTAA data.

Figure 23. Nutrient Contribution N+P+S (in million tons)

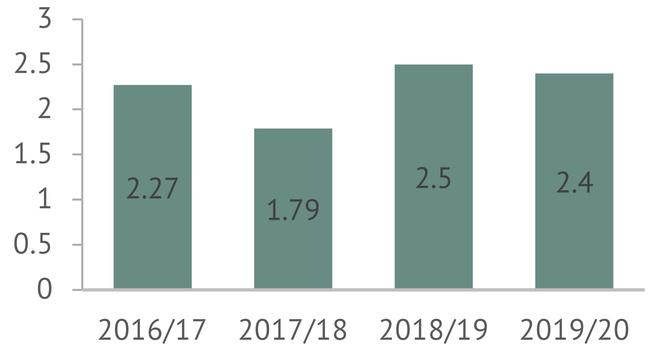


Source: Based on ReTAA data.

Nutrient Output

The output of nutrients is mainly attributed to the extraction of nutrients through grain harvesting. Stemming from an increase in crop area and an improvement in the technology applied to crops, grain production in Argentina has increased and reached a record volume of 137 million tons in the 2018/19 season. Along with higher production, nutrient extraction from the soil has also increased. The lowest level of extraction was recorded in the 2017/18 season with almost 1.8 million tons, and it was directly related to the drought that affected a large part of the crop area.

Figure 24. Nutrient Extraction N+P+S (in million tons)



Source: Based on ReTAA data.

Nutrient Replenishment

From the difference between inputs and outputs, the nutrient balance is obtained in terms of replenishment percentage. As Figure 25 shows, nutrient replenishment at national level has improved over the last five seasons. When segregated by nutrient, improvements are also observed. In the 2019/20 season, nitrogen reached a replenishment of 60%, phosphorus 68% and sulfur 26%.

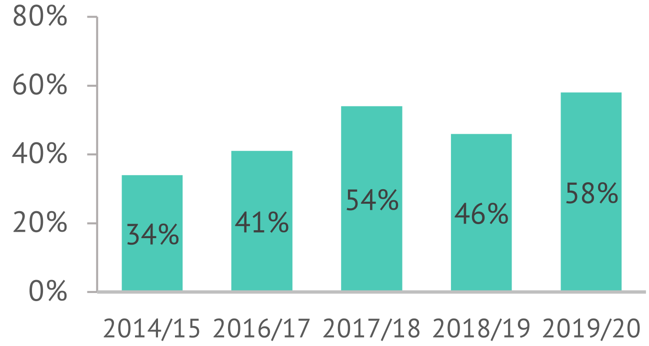
At crop level, wheat records the highest replacement levels as shown in Figure 26. This is partly due to a baseline fertilization aimed at wheat-soybean double cropping. It is important to clarify that the calculation of this nutrient balance was made for each crop individually, without considering the double crop scheme.

Soybean has the lowest nutrient replenishment. This crop is not usually fertilized with nitrogen, however, the nitrogen supply from phosphate sources containing nitrogen in their composition (i.e., diammonium phosphate) is accounted for. On the other hand, it is assumed that 60% of the nitrogen is contributed by biological fixation.

Although all these percentages of current replenishment (at country, nutrient and crop level) are the highest in the series, the amount of nutrients supplied is still below those extracted.

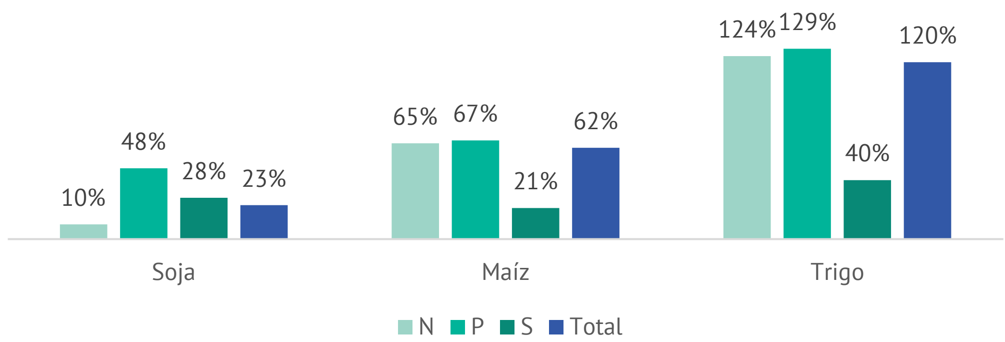
In Argentina, production levels are increasingly higher and these are being accompanied by continuous improvements in the management of and technology package applied to crops. However, a shown by this analysis, crop and soil nutrition are a key aspect to be improved for soil resource conservation and system sustainability.

Figure 25. Nutrient Replenishment N+P+ S



Source: Based on ReTAA data.

Figure 26. Nutrient Replenishment for Soybean, Maize and Wheat. Season 2019/20



Source: Based on ReTAA data.

In parallel, for the improvement of fertilization management with a view to achieving balance neutrality, the current yield gaps for each crop must be considered. The current technology package still has a lot to give in terms of benefits. It is possible to continue to improve yields in Argentina by closing the gaps between farmers and with deliverable yields. To achieve this, it will be instrumental to redouble efforts in order to keep on incorporating tools that allow adjusting fertilization, such as soil analysis, a technology available at low implementation cost. (Monthly ReTAA No. 39, 2020).

VI. Enviromental Impact of GM Crops

While the introduction of GM crops has offered many advantages for farmers and the country's economy, there are concerns about the environmental impact of GM crops. In particular, in the case of herbicide tolerant varieties, these concerns include the effects of herbicide use on health and on the persistence and spread within the environment due to excessive use or absence of good agricultural practices.

Within this framework, the aim of this section is to analyze the environmental impact of GM crops on two fronts: (i) on the quantities of herbicides, fungicides and insecticides applied, and (ii) on carbon dioxide emissions.

VI. a. Impact on Agrochemical Use

A methodology frequently used in scientific literature[10] when analyzing the environmental impact of herbicide, insecticide and fungicide use is the Environmental Impact Quotient (EIQ[11]). The EIQ is an index that integrates the various environmental impacts of agrochemicals (impact on the applicator, harvester, field worker, consumer, fish, birds and bees, among other factors) into a single value per hectare in order to make the different inputs comparable. The EIQ was initially developed in Kovach (1992) and it is periodically updated by Cornell University (Eshenaur *et al*. 2020). Higher EIQ levels are associated with higher toxicity levels. For example, atrazine has an EIQ of 22.9, and glyphosate has an EIQ of 15.33.

To determine the impact of GM crops on agrochemical use, the doses applied in GM seed versus conventional seed crops should be compared. As stated in section IV.a., the studies that carried out field surveys in the initial years of GMO technology adoption in the country (the only period in which GM and conventional crops coexisted simultaneously) found that GM crops recorded lower applied doses of herbicides and insecticides and, in turn, the inputs applied had a lower degree of toxicity. However, once technology adoption reaches levels close to 100%, the comparison between GM and non-GM crops through farmer surveys becomes impractical. In this regard, a common technique in scientific literature[12] has been to compare typical GM approaches with conventional approaches based on expert consultation.

GM Soybean

Tables 4 and 5 show typical GM and non-GM soybean crop production schemes. There, it can be seen that conventional seed crop schemes involve active ingredient applications of 3.71 kg/ha with a field EIQ value of 86.3, while GM seed crop schemes show active ingredient applications of 3.54 kg/ha but, given that the toxicity of these inputs is much lower, the field EIQ value is 60.62, 30% lower.

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[10] For example, see Naranjo (2009) and Brookes and Barfoot (2005).
[11] Environmental Impact Quotient (EIQ).
[12] For example, see Brookes and Barfoot (2020).

Table 4. Typical Conventional Soybean Crop Production Scheme (herbicides, insecticides, fungicides and seed treatment): Applied Dosis, Active Ingredient Dosis, EIQ and Field EIQ

Input	Active Ingredient	EIQ (1)	Active Ingredient Concentration (%) (2)	Applied Dosis (kg/ha) (3)	Active Ingredient (kg/ha) (4) = (2)*(3)	Field EIQ (5) = (1)*(4)
Inoculants + Fungicides	Carbendazim + Thiram	79.8	25 gr./100 ml	0.26	0.06	4.82
2-4D	2.4-D Dichlorophenoxyacetic Acid	16.7	50 gr./100 ml	1.38	0.60	10.0
Concentrated Glyphosate	Glyphosate	15.3	64.5 gr./100 ml	2.93	1.61	24.7
Metribuzin	Metribuzin	28.4	41%	1.39	0.57	16.19
Imazetapir	Imazapyr	22.3	11%	0.63	0.07	1.49
Diamides	Chlorantraniliprole	18.3	20 gr./100 ml	0.08	0.02	0.29
Confidor	Imidacloprid	36.7	350 gr./l	0.23	0.7	25.70
DECIS 10%	Deltamethrin	28.4	10 gr./100 ml	0.19	0.02	0.6
Fungicide (Estrob. + Triazol)	Pyraclostrobin	27.0	12.5%	0.46	0.06	1.56
	Epoxiconazole	57.7	4.7%	0.46	0.02	1.25
TOTAL				7.93	3.71	86.3

Source: Eshenaur *et al.* (2020), ReTAA, industry data, and expert consultation.

Table 5. Typical GM Soybean Crop Production Scheme (herbicides, insecticides, fungicides and seed treatment): Applied Doses, Active Ingredient Dosis, EIQ and Field EIQ

Input	Active Ingredient	EIQ (1)	Active Ingredient Concentration (%) (2)	Applied Dosis (kg/ha) (3)	Active Ingredient (kg/ha) (4) = (2)*(3)	Field EIQ (5) = (1)*(4)
Inoculants + Fungicide	Carbendazim + Thiram	79.8	25 gr/100 ml	0	0.06	4.82
2-4D	2.4-D	16.7	50 gr/100 ml	1.38	0.6	10.0

	dichlorophenoxyacetic Acid					
Concentrated Glyphosate	Glyphosate	15.3	64.5 gr/100 ml	5.04	2.78	42.6
Metsulfuron	Metsulfuron-methyl	16.7	60%	0.01	0.01	0.09
Diamides	Chlorantraniliprole	18.3	20 gr/100 ml	0.09	0.02	0.29
Fungicide (Estrob. + Triazol)	Pyraclostrobin	27.0	12.5%	0.46	0.06	1.56
	Epoxiconazole	57.7	4.7%	0.46	0.02	1.25
TOTAL				7.45	3.54	60.62

Source: Eshenaur *et al*. (2020), ReTAA, industry data, and expert consultation.

Comparing the doses currently applied with a scenario in which the total crop area would be sown with conventional seed, the savings in active ingredient applied in the 2019/20 season would be 2.89 million kg, and the value of EIQ applied would be 436.5 million lower. In other words, the existence of GM seeds resulted in a significant reduction in the use of herbicides and insecticides, both in terms of the amount of active ingredient released into the environment and their toxicity levels (see Table 6).

Table 6: Reduction in the Use of Herbicides, Insecticides and Fungicides in Soybean at Domestic Level (Active Ingredient and EIQ shown in kg)

Crop Season	Applied Active Ingredient Savings (in kg) (Negative means greater use)	EIQ Savings (Negative means greater use)
1996/97	62,645	9,463,080
1997/98	298,656	45,114,624
1998/99	815,388	123,171,552
1999/00	1,129,480	170,617,920
2000/01	1,563,932	236,245,728
2001/02	1,851,708	279,716,832
2002/03	2,077,740	313,860,960
2003/04	2,432,955	367,519,320
2004/05	2,423,520	366,094,080
2005/06	2,597,056	392,308,224
2006/07	2,737,000	413,448,000
2007/08	2,822,000	426,288,000
2008/09	3,060,000	462,240,000
2009/10	3,213,000	485,352,000
2010/11	3,213,000	485,352,000

Crop Season	Applied Active Ingredient Savings (in kg) (Negative means greater use)	EIQ Savings (Negative means greater use)
2011/12	3,179,000	480,216,000
2012/13	3,400,000	513,600,000
2013/14	3,349,000	505,896,000
2014/15	3,366,000	508,464,000
2015/16	3,485,000	526,440,000
2016/17	3,077,000	464,808,000
2017/18	2,941,000	444,264,000
2018/19	2,890,000	436,560,000
2019/20	2,890,000	436,560,000

Source: Bolsa de Cereales own data.

GM Maize

In the case of maize, the comparison between conventional seed (Table 7) and GM seed (Table 8) shows that the volumes of active ingredient are lower in conventional seed, 5.6 kg/ha vs. 6.29 kg/ha. However, field EIQ values are lower in the case of GM crop schemes 122.9 vs. 123.6. Once again, the lower toxicity of GM crop inputs accounts for the lower Environmental Impact Quotient.

Table 7. Typical Conventional Maize Crop Production Scheme (herbicides, insecticides, fungicides and seed treatment): Applied Dosis, Active Ingredient Doses, EIQ and Field EIQ

Input	Active Ingredient	EIQ (1)	Active Ingredient Concentration (%) (2)	Applied Dosis (kg/ha) (3)	Active Ingredient (kg/ha) (4) = (2)*(3)	Field EIQ (5) = (1)*(4)
2-4D	2.4-D Dichlorophenoxyacetic Acid	16.7	50 gr./100 ml	1.49	0.65	10.82
Atrazine	Atrazine	22.9	50 gr./100 ml	2.2	1.0	22.9
Concentrated Glyphosate	Glyphosate	15.3	64.5 gr./100 ml	2.9	1.6	24.7
Metolachlor	Metolachlor	22.0	96 gr./100 ml	1.7	1.4	31.7
Pychloram	Pychloram	18.0	24 gr./100 ml	0.4	0.1	1.3
Decis	Deltamethrin	28.4	10 gr./100 ml	0.2	0.02	0.6
Confidor	Imidacloprid	36.7	350 g/l	0.2	0.7	25.7

Fungicide (Estrob. + Triazol)	Pyraclostrobin	27	0.125	0.5	0.1	1.7
	Epoxiconazole	58	0.047	1.6	0.1	4.3
TOTAL				**11.2**	**5.6**	**123.7**

Source: Eshenaur *et al*. (2020), ReTAA, industry data, and expert consultation.

Table 8. Typical GM Maize Crop Production Scheme (herbicides, insecticides, fungicides and seed treatment): Applied Doses, Active Ingredient Dosis, EIQ and Field EIQ

Input	Active Ingredient	EIQ (1)	Active Ingredient Concentration (%) (2)	Applied Dosis (kg/ha) (3)	Active Ingredient (kg/ha) (4) = (2)*(3)	Field EIQ (5) = (1)*(4)
2-4D	2.4-D Dichlorophenoxyacetic Acid	16.7	50 g/100 ml	1.49	0.65	10.82
Atrazine	Atrazine	22.9	50 g/100 ml	4.11	1.85	42.3
Concentrated Glyphosate	Glyphosate	15.3	64.5g/100 ml	3.95	2.18	33.4
Metolachlor	Metolachlor	22.0	96 g/100 ml	1.67	1.44	31.68
Pychloram	Pychloram	18.0	24 g/100 ml	0.18	0.04	0.68
Diamides	Chlorantraniliprole	18.3	20 g/100 ml	0.28	0.05	0.91
Fungicide (Estrob. + Triazol)	Pyraclostrobin	27	0.125	0.51	0.06	1.73
	Epoxiconazole	57.7	0.047	0.51	0.02	1.39
TOTAL				**12.71**	**6.29**	**122.89**

Source: Eshenaur *et al*. (2020), ReTAA, industry data, and expert consultation.

GM Cotton

Cotton is one of the crops that uses the most agrochemicals during its cycle. GM cottons were proposed to overcome two key crop problems: the high cost of weed management and the serious losses caused by lepidopteran pests. At world level, although there was a clear 43% reduction in cotton pesticide consumption in Latin America, the evolution has been the opposite, that is, between 1999 and 2009, the value of herbicide sales for cotton crops has more than doubled, while insecticide sales have virtually been four times higher (Wakelyn and Chaudhry, 2010 and Valeiro, 2018). Argentina did not escape this trend.

After the initial success in the first years of technology adoption in the country, in which there were indeed significant reductions in the applied doses of herbicides and insecticides with increased yields and improved benefits, since 2003 the importance of the technology has begun to go unnoticed due to the expansion of the cotton boll weevil, one of the pests that most affects this crop. Valeiro (2018) highlights this in his paper:

> *"Since 2003, the weevil expanded throughout northeastern Argentina, exponentially increasing the use of insecticides, masking the advantage of Bt cottons in terms of reduced use and lower production costs"*.

Tables 9a to 9e show the evolution of herbicide and insecticide use according to different typical crop schemes in the period 1997-2015 (Table A10a). In 1997, the conventional seed crop scheme recorded a field EIQ of 107.3, a higher record than the GM crop schemes in force until 2008, with EIQ values of 66.2 and 81.5 (see Table A10b and Table A10c). In other words, GM crops effectively managed to mitigate the environmental impact in the first decade of GM cotton in Argentina.

Already in 2013, the emergence of resistant weeds partly driven by poor technology management, and the expansion of the cotton boll weevil pest raised average glyphosate doses from 4 to 8 liters per hectare. The time lag in the introduction of new biotech events resulting from weak ownership rights and the inability to generate returns that promote innovation is also one of the determining factors identified by scientific literature for the loss of effectiveness. (Vaquero and Fried, 2019).

This trend continued in subsequent years. By 2015, according to data from Quirolo *et al.* (2015), glyphosate doses climbed to 13 liters per hectare on average, which has reduced profitability and increased the environmental impact of cotton production. In fact, the EIQ levels of post-2015 crops are higher than 170, i.e., they exceed those prior to the introduction of GM crops, reversing the environmental gains achieved during the first decade.

Tables 9. Conventional and GM Cotton Crop Production Schemes in Different Regions of Argentina. Years 1997, 2008 and 2015. Applied Dosis, EIQ and Field EIQ

Table 9a

Source	Seed Type	Region	Input Type	Active Ingredient	Dosis (l)	Concentration (%)	EIQ	Field EIQ
Agromercado Magazine, 1997	Conventional	Santiago del Estero	Herbicides	Haloxyfop	0.5	54	20.2	5.5
			Herbicides	Pyroxsulam	2	4.5	12.3	1.1
			Herbicides	Metsulfuron	2	60	16.7	20
			Herbicides	Diuron	1	65	26.5	17.2

			Herbicides	MSMA	2	96	18	34.6
			Insecticides	Beta cyfluthrin	0.13	80	31.6	3.3
			Insecticides	Cypermethrin	0.3	25	36.4	2.7
			Insecticides	Endosulfan	1.7	35	38.6	22.9
			Total					**107.3**

Table 9b

Source	Seed Type	Region	Input Type	Active Ingredient	Dosis (l)	Concentration (%)	EIQ	Field EIQ
Ybran y Lacelli. 2008	RR	Reconquista (Sta. Fe)	Herbicides	Glyphosate	4.0	62.0	15.3	37.9
			Herbicides	2.4 D	0.5	50.0	16.7	4.2
			Insecticides	Dymethoate	0.3	50.0	33.5	4.2
			Insecticides	Novalurone	0.1	10.0	14.3	0.1
			Insecticides	Cypermethrin	0.1	25.0	36.4	0.5
			Insecticides	Chlorpyrifos	1.5	48.0	26.9	19.3
			Total					**66.2**

Table 9c

Source	Seed Type	Region	Input Type	Active Ingredient	Dosis (l)	Concentration (%)	EIQ	Field EIQ
Elena. 2009	NuOpal RR	Sáenz Peña (Chaco)	Herbicides	Diuron	1.0	65.0	26.5	17.2
			Herbicides	Acetochlor	1.3	84.0	19.9	21.7
			Herbicides	Glyphosate	2.0	62.0	15.3	19.0
			Insecticides	Thiamethoxam	0.2	14.1	33.3	0.9
			Insecticides	Lambdacyhalothrin	0.2	10.6	44.2	0.9
			Insecticides	Methoxyphenocide	0.4	24.0	32.1	2.8
			Insecticides	Mercaptothion	1.0	51.5	23.8	12.3

			Insecticides	Dimethoate	0.4	50.0	33.5	6.7
			Total					**81.5**

Table 9d

Source	Seed Type	Region	Input Type	Active Ingredient	Dosis (l)	Concentration (%)	EIQ	Field EIQ
Ybran. 2013	BG o RR	Reconquista (Sta, Fé)	Herbicides	Glyphosate	8.0	62.0	15.3	75.9
			Herbicides	2.4D	0.5	50.0	16.7	4.2
			Insecticides	Dimethoate	0.3	50.0	33.5	4.2
			Insecticides	Cypermethrin	0.1	25.0	36.4	0.5
			Insecticides	Novaluron	0.1	10.0	14.3	0.1
			Total					**84.8**

Table 9e

Source	Seed Type	Region	Input Type	Active Ingredient	Dosis (l)	Concentration (%)	EIQ	Field EIQ
Quirolo. 2015	BGDP 1238 BG/RR NuOpal RR DP 402 BG/RR G 2000 RR	Sáenz Peña (Chaco)	Herbicides	Glyphosate	13.0	62.0	15.3	123.3
			Herbicides	2.4D	1.0	50.0	16.7	8.3
			Herbicides	Acetochlor	1.5	84.0	19.9	25.1
			Herbicides	Diuron	1.0	65.0	26.5	17.2
			Total					**173.9**

Source: Bolsa de Cereales own data based on Valeiro (2018) and cited sources.

VI. b. Impact on Carbon Dioxide Emissions

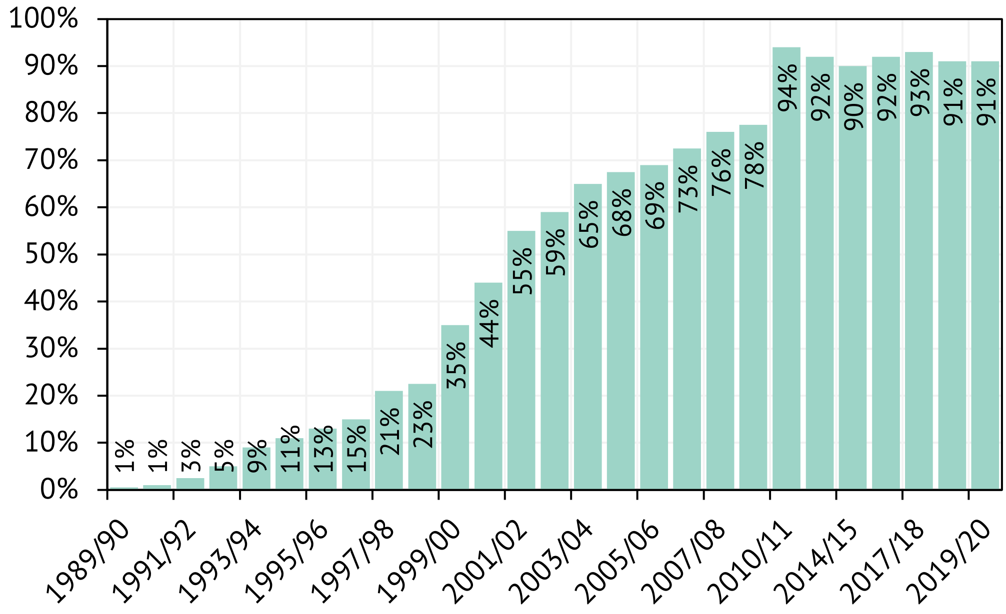
One of the main benefits of the adoption of GM crops was that it facilitated the adoption of no-till agriculture. Since the introduction of GM crops, no-tillage rapidly gained ground and was an effective solution to the problem of soil erosion (see Figure 27). Among the main benefits of this agronomic practice are the following:

- it improves water use,
- it protects against erosion (90% less erosion compared to traditional tillage),
- it improves the balance of organic matter,
- it decreases the formation of surface crusts,
- it increases seeding opportunity,

- it allows sowing where plowing was not possible due to lack of water,
- it extends the agricultural cycle,
- it gives greater stability in yields,
- it extends the useful life of the tractor (66% reduction in use),
- it saves use of fossil fuels and pollutant emissions, and
- it significantly increases the hectares worked per person.

According to the National Institute of Agricultural Technology (INTA) estimates (2011), it reduces the amount of machinery used, decreases fuel consumption by 40% compared to traditional tillage, and allows obtaining from 25 to 40% higher crop yields at the same rainfall levels with greater stability over the years.

Figure 27: Percentage of Farmers who Practice No-Tillage in Argentina



Source: AAPRESID and Bolsa de Cereales – ReTAA.

In environmental terms, no-tillage generates environmental benefits on at least two fronts: on the one hand, it reduces gas emissions due to fewer pesticide applications and less use of fossil fuels; on the other hand, no-tillage facilitates the absorption of organic carbon from the soil. Both effects are estimated in this subsection.

Emissions Reduction from Decreased Use of Fossil Fuels

In order to estimate fuel savings from NT (no till) systems, we turn to the paper by West and Marland (2002), who estimate fossil fuel energy requirements and carbon dioxide emissions from farm machinery for different tillage systems. Their research findings are shown in Table 10, where we can see that the NT systems record emissions of 23.26 kg

C/ha, while conventional and reduced tillage record carbon emissions of 72 and 40.27 kg C/ha in the case of maize, and 67.45 and 40.7 kg C/ha in the case of soybean. In other words, according to the authors' estimates, NT implies a reduction in CO_2 emissions compared to conventional sowing of 48 kg C/ha in the case of maize, and 44 kg C/ha in the case of soybean.

Table 10. Annual Fossil Fuel Energy Requirements and Carbon Dioxide Emissions from Agricultural Machinery for Different Tillage Practices

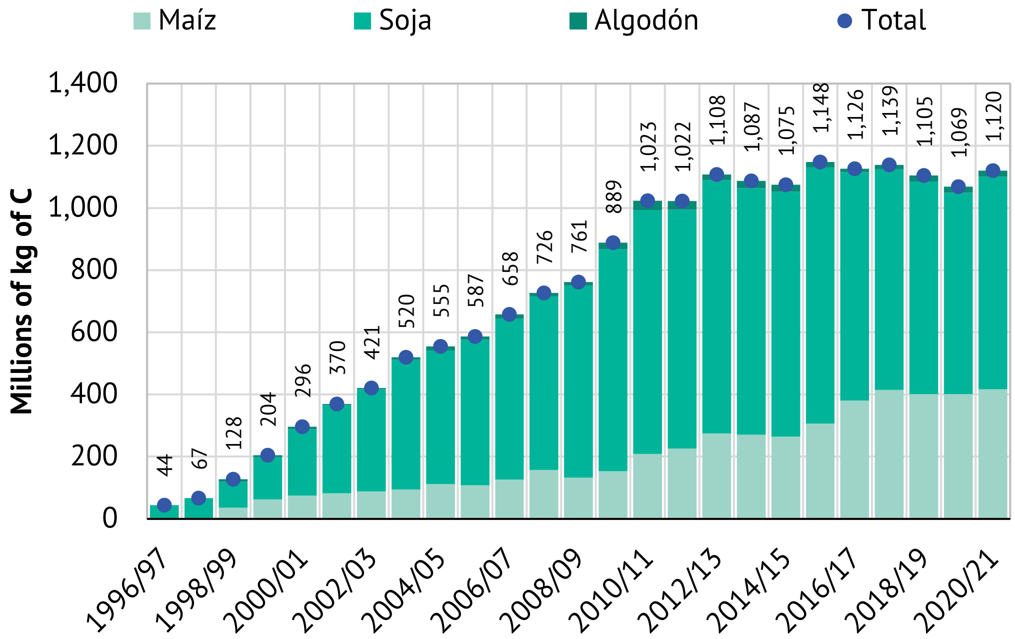
	Diesel Fuel		Energy (a)	Carbon Emissions	CT (b)	RT (b)	NT (b)
	l/ ha	MJ/ ha	MJ/ ha	kg C/ ha	kg C/ ha	kg C/ ha	kg C/ ha
Mouldboard Plough	21.78	1122	102	26.75	26.75	–	–
Disc Plough	6.7	345	55	8.72	17.44	17.44	–
Planting	4.93	254	58	6.79	6.79	6.79	6.79
Single Crop (c)	3.26	168	42	4.57	4.57	4.57	–
Fertilizing	9.82	506	60	12.35	–	–	–
Spraying	1.22	63	56	2.54	–	–	–
Harvesting	11.14	574	186	16.47	16.47	16.47	16.47
Total emissions (kg C/ha)							
Maize					72.02	45.27	23.26
Soybean and Wheat (c)					67.45	40.7	23.26

Notes:
(a) Energy embodied in the manufacture, transportation and repair of machinery.
(b) CT, RT and NT are conventional tillage, reduced tillage and no-till, respectively.
(c) Single crop is not included in the analysis of wheat, soybean or other non-row crops.
Source: Adapted from West and Marland (2002).

Based on the evolution of the area under NT and the estimates in Table 10, the reduction in carbon dioxide emissions due to a reduction in the use of fossil fuels was estimated for the three crops below. The results are reported in Figure 28.

With the NT adoption rates in effect until 1996, carbon dioxide emissions would be higher by more than 1 billion kg per year, the equivalent of the annual fuel consumption of 240 thousand cars (EPA, 2011). In the cumulative period 1996-2020, more than 18 billion kg of carbon, equivalent to the annual fuel consumption of 3.9 million private cars would have been released into the environment.

Figure 28. Carbon Dioxide Emissions Reduction due to Less Use of Fossil Fuels 1996-2020 (in million kg)



Emission Reduction from Carbon Sequestration

Agriculture and livestock farming are economic activities that contribute to the generation of greenhouse gases (GHG). Land use change associated with these activities is one of the sources of the three main GHGs: carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). The main sources of GHGs in agriculture are the production of nitrogen fertilizers; the use of fossil fuels (such as coal, gasoline, diesel and natural gas); and waste management. In livestock farming, fermentation that takes place in the digestive systems of ruminants is a source of methane emissions.

While soils contribute a significant portion of agricultural emissions, improved soil management practices can substantially reduce these emissions and capture some CO2 from the atmosphere (Paustian *et al.*, 2016). Carbon dioxide is removed from the atmosphere and converted into organic carbon through the process of photosynthesis. As the organic carbon degrades, it is converted back into carbon dioxide through the process of respiration. No-tillage, cover crops and crop rotation can significantly increase the amount of carbon stored in soils.

In turn, soil organic carbon plays a fundamental role in determining and maintaining important soil physical conditions and functions, as well as influencing soil structure and related properties (e.g., water retention and bulk density) to a large extent by contributing to the formation of stable aggregates. A reduction in soil organic carbon implies a deterioration of soil quality and productivity.

Soil management practices can significantly influence the ability of soils to sequester carbon from the environment. Alvarez *et al*. (2014) have performed an experiment for 15 years in the Argentine Pampas to evaluate the impact of three planting systems (no-tillage, no-tillage with cover crop in winter, and conventional tillage) and two crop sequences (soybean-maize and soybean single crop) on the total organic carbon (TOC) stock in the soil. The authors conclude that both factors (tillage system and crop sequence) affect TOC. Their results show that no-till systems accumulate 333 kg/ha/yr more TOC than conventional tillage for depths up to 100 cm, while soybean-maize rotations build up 133 kg/ha/yr more than soybean single crop. For a depth of 0 to 30 cm, their results show that no-till systems recorded 267 kg ha/yr more than conventional seedings systems.

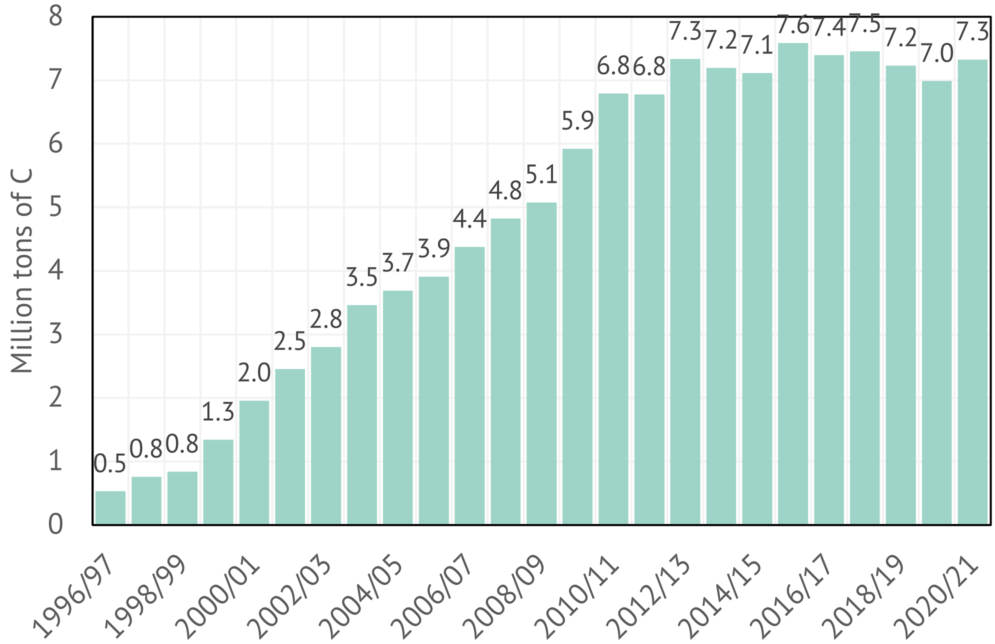
Table 11 shows the results of a set of selected papers that measure the increase in soil carbon from the use of no-till agriculture instead of conventional tillage. Estimates range between 0.04 and 0.45 tn/ha/year. The studies carried out in the Argentine Pampas record carbon accumulation values of 0.3 tn/ha/year.

**Table 11: Soil Carbon Accumulation vs. Conventional tillage.
Selected Paper Results**

Paper	Region	Soil Carbon Accumulation vs. Conventional tillaje
Alvarez *et al*., (2013)	Argentina	0.3 tn/ ha year
Franzluebbers, (2010)	United States	0.45 tn/ ha year
Powlson *et al*., (2011)	United Kingdom and Wales	0.31 tn/ ha year
Smith *et al*., (2001)	Europe	0.73% of existing stock
Smith *et al*., (2008)	Global	0.04–0.19 tn/ ha year
Steinbach y Alvarez, (2006)	Argentina	0.276 tn/ ha year
VandenBygaart *et al*., (2008)	Canada	0.06–0.16 tn/ ha year

Based on the results of these papers, it is assumed that the use of no-tillage, whose dissemination was made possible by GM or transgenic crops, has an impact of 0.3 t/ha each year with respect to conventional tilling. Thus, considering the area sown with no-tillage agriculture (NT), the organic carbon in soil increased 7.3 million tons last year with respect to a scenario without GM. The total for the 25 seasons amounts to 121 million tons (see Figure 29 and Table A6 in Annex II).

Figure 29. Total increase in organic carbon in soil per season with respect to the no-GM scenario (million tons)



VII. The Challenge of Continuing to Leverage the Benefits of Technology

The introduction of GM crops in Argentine agriculture marks a turning point in agricultural production and, give its importance both in the economy and the country's development. In this regard, the results of this study emphasize that what has happened in the 25 years since the introduction of the first GM crop is highly positive, not only for production sectors, but also for society as a whole, through its impact on GDP growth, employment and tax revenues, which enables the fight against poverty and the promotion of social development.

It is important to emphasize that much of what happened was possible because when these technologies became available internationally, Argentina had a set of strategic capabilities to leverage them: the existence of the regulatory framework required for the safe incorporation of technologies into production processes, a consolidated input and service industry capable of quickly reflecting the new proposals in its technological supply, and proactive business and institutional capabilities to promote the incorporation of new technologies into production processes. In addition to these capabilities, other factors linked to economic and sectoral policies, and even the synergy between GM crops and no-tillage, which by then had already begun to spread, were decisive for the innovation process to have the depth and significance it has had in these two and a half decades. All these aspects were important, but at this point there is no doubt about the strategic character of GMOs in these processes. (Trigo *et al*., 2009).

Although the economic and environmental benefits have been the focal point of discussion in this report, it is important to highlight that the transformations driven by the massive adoption of GM crops have triggered other types of benefits that should be taken into account. One of them is the consolidation of the country as a strategic player in international markets, just in time when these entered a strongly expansive cycle.

In this regard, the fact that Argentina was an "early adopter" of the new technologies was not only reflected in the fact that the country began to leverage them before the competition, but also, and more importantly, because the country managed to take advantage of this period in terms of its positioning on international markets, being recognized as a leader and reference in the structuring of the new rules of the game that began to be outlined with the emergence of GM crops, for example, in regulatory aspects (See, for example, Supercampo, 2014).

The importance of this process is highlighted when we consider the size of the transformations that took place in these 25 years. An idea of what this meant derives from considering what would have happened to the global food price index had it not been for the increase in the global supply of commodities that can be associated with the adoption of GM crops in Argentina. According to one estimate, the FAO global index could have been more than 15% higher than what actually occurred. The relevance of this is highlighted when we take into account the political and social problems that had to be faced in many countries as a result of the increase in food prices that occurred towards the peak of the crisis in 2008 (Trigo, 2016).

In relation to, but independently of this scenario, and taking into consideration the growing importance of issues associated with climate change that must be anticipated in the field of international trade, there is the already mentioned synergic nature of GM seeds with no-till farming and good agricultural practices, in the strategy of sustainable agricultural intensification, which allows presenting national production as "climate sustainable", an aspect that will undoubtedly gain increased importance in the future (Trigo, *et al*., 2009).

In another vein, there is the role of transformations associated with the adoption of GM crops as a fundamental driver of the Argentine bioeconomy, as a new development model for the country, which allows overcoming the stagnation of the last decades resulting from the exhaustion of the import substitution model (See Bisang and Trigo, 2017 and Trigo *et al*., 2015).

Bioeconomy - understood as "the knowledge-intensive production and use of biological resources, processes and principles for the sustainable production of goods and services in all sectors of the bioeconomy"[13] - is based on two fundamental drivers: the availability of biomass, and biotechnology as the scientific-technological platform for its utilization (quantities, functionalities, products). In this regard, the process developed in the last 25 years with GM crops has been instrumental for the consolidation of national capabilities in both aspects.

The availability of biomass has more than doubled, which has been a determining factor in the development of the biofuels industry, one of the basic bioeconomy platforms. In fact, increased feedstock available boosted an important investment cycle, with significant impacts in terms of value addition, job creation and territorial development, which enabled Argentina to become one of the main players in international bioenergy markets in a few years (Torroba, 2020).

On the other hand, advances in the use of GM crops in agricultural production have undoubtedly had a positive impact on the consolidation of R&D capabilities in biotechnology, both in the public and private sectors, allowing the country to join the exclusive circle of new technology developers. It should be stressed that this process, which is not currently limited to GM crops because it is beginning to include developments from other fields (bioproducts, bioinputs, and the like), is a cycle that expands and enhances the benefits discussed in this report (Anlló, G., *et al*., 2016).

In retrospect, there is no doubt about the weight of the adoption of GM crops both for Argentine agriculture and the country at large. Such benefits can be traced not only on the economic front, but also on the positioning of the Argentine economy in the world and the specific opportunities that these benefits are starting to bring in terms of new development avenues for the country.

Of course, many factors exerted great influence, not only these new technologies, but also other factors linked to economic and sectoral policies, other innovations such as no-till farming and changes in international market conditions. However, there is no doubt that without agricultural biotechnology, this process would have evolved differently and the country's economy would have been different as well.

All this suggests that at this point, it is essential not only to face the discussion on how to maintain and expand the validity of technology assets currently on the market (since to date achievements have been based on such assets), but also to leverage the review of the experiences gained in these 25 years. This is crucial to ensure that the country can

[13] Global Bioeconomy Summit (2020)

continue to be an "early adopter" in the new technology cycles that are beginning to take shape, and which may be strategic in the international scenarios that are already emerging, starting with the discussions underway around the United Nations World Summit on Food Systems and the UN Climate Change Conference (COP26), to be held in 2021.[14]

In this regard, there are several dimensions to consider. A first aspect is related to deepening the utilization and extending the useful life of those technologies that are currently on the market. The available information (ReTAA, Brihet *et al*., 2019) shows that there is still a huge yield potential to be leveraged in the current technology proposals, particularly in relation to maize. According to estimates, the current scenario has the potential to increase production up to 200 million tons, if progress is made in closing the current productivity gaps with respect to potential yields and making improvement in crop management issues, particularly in crop nutrition and other aspects, such as those concerning logistics systems, in order to close the productivity gaps that still exist, especially in regions most far away from ports. (Bolsa de Cereales, 2016).

In line with the above, there is still an issue about dealing with the growing evidence of the presence of glyphosate herbicide resistant weeds, and the loss of efficacy in insect control of Bt crops. The presence of resistant weeds is a strategic problem that is already reflected in the greater number of pesticide applications and higher concentration formulations, the need for the combined use of herbicides, and the ensuing decrease in the economic appeal of these technologies (*Bolsa de Cereales*, 2016). Similarly, insect control technologies (Bt) are also facing significant challenges, as a result of the low levels of compliance with refuge requirements, far from what is recommended to ensure the full leveraging of the potential for this type of technology. All these aspects are strategic, since these technologies are not only essential for crop productivity and profitability, but also for Argentina's competitiveness in world markets, and the country leadership in sustainable agricultural intensification. The erosion of technologies is a factor that may affect this condition[15] (See Box: Bt Technology Care).

[14] See https://www.un.org/en/food-systems-summit; and https://unfccc.int/es

[15] In fact, the stagnation and/or fall of areas under no-tillage in some of the main productive areas of the country (Figure 27) can be associated with the status of these technologies, particularly in terms of herbicide tolerance.

Box: Bt Technology Care

Modern biotechnology techniques applied to plant breeding have made it possible to obtain herbicide tolerant and insect resistant crops, among other traits of agronomic interest. These crops represent a very important production tool because, in addition to facilitating technical management, they have allowed crop expansion and development to non-traditional regions. In the case of maize, for example, they allowed planting in the northwestern and northeastern regions of Argentina and, as planting date is flexible, they also favored late planting (November to January) with respect to traditional planting (September-October). The appropriate use of technology will ensure the sustainability of this system and its durability over time.

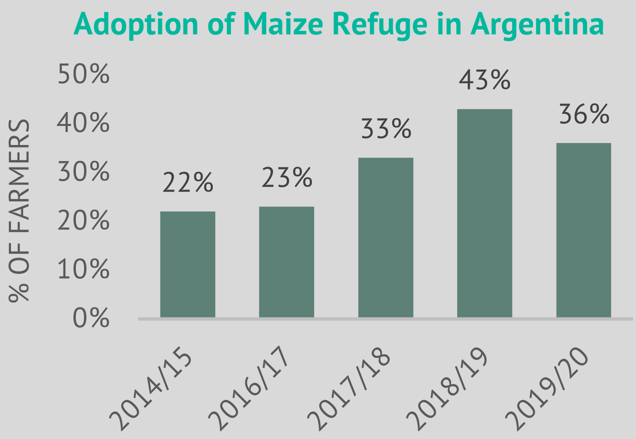
Genetically modified insect resistant crops are also called Bt crops because they carry genes from *Bacillus thuringiensis*, a soil bacterium that produces proteins with insecticidal effect to control lepidopteran pests. In our country there are three commercial Bt crops: maize, soybean and cotton.

The efficient use of this technology implies an adequate and sustainable management that guarantees its care, since insect resistance to Bt proteins or other insecticides is a natural phenomenon that, even though it cannot be avoided, it can be delayed with proper management techniques. One of the most important aspects of Bt technology management is the planting of refuges. This practice is part of Insect Resistance Management programs, whose purpose is "to delay the evolution of insect resistance to Bt technologies or to other types of insecticides. They are essentially based on good field management including crop rotation, good weed control and stubble treatment, good crop implantation, periodic pest monitoring, and refuge planting."

"Refuge is a portion of the lot planted with a non-Bt variety/hybrid of similar maturity cycle to the Bt crop and on the same planting date. This area is a reservoir for susceptible insects. It serves to decrease the probability that resistant insects, born in the Bt portion of the lot, will only mate with each other and generate resistant offspring. Conversely, when a resistant insect mates with a susceptible insect from the refuge, the offspring will be susceptible and controlled by the technology. Therefore, for all Bt technologies, refuge planting is fundamental since it generates an adequate number of susceptible insects that cross with the resistant ones, keeping the frequency of resistant insects at low levels within the lot." (Questions and answers on Bt crops and insect resistance management. MRI-ASA Program. 2nd. Edition, October 2017). A refuge has particular characteristics in terms of size, location and management, depending on the crop in question.

Therefore, refuge planting constitutes a kind of long-term insurance. In the short/medium term, the commercialization of new Bt proteins is not foreseen, so it is important to adequately manage the current ones in order to ensure their sustainability over time.

In Argentina, the adoption of maize refuge has grown steadily in recent years. The percentage of farmers engaged in refuge practices increased from 22% in the 2014/15 season to 43% in the 2018/19 season. In the 2019/20 season it dropped to 36%.



Source: ReTAA, Bolsa de Cereales.

There is still work to be done to improve this indicator and, although resistance begins at the lot level, it is important to emphasize that Bt technology care is a responsibility of the entire agribusiness chain.

All these trends are the result of multiple reasons, inter alia, those concerning decisions made by farmers and technology providers, among others, the analysis of which is beyond the scope of this report. However, we should underscore one of those reasons which, due to its importance, is a major determining factor for global trends. This refers to the institutional and policy framework within which the different players make decisions regarding the technology process.

On the one hand, there are issues about intellectual property, biosafety regulations, and the like, which directly affect the availability of technologies on the local market. On the other hand, there are economic policies and, particularly, tax policies and their distorting impact on farmers' decisions.

As to regulatory issues, the uncertainty over the real possibility that technology providers protect technologies has been, and continues to be, a factor restricting the conditions of access to a wider spectrum of technologies to face, for example, the growing problem of resistant weeds. The importance of the impact of uncertainty scenarios on these aspects has already been shown in the case of soybean, where the lack of clarity regarding intellectual property protection issues has been crucial for Argentine farmers to tackle this problem because they have fewer options available than their competitors in other countries.

As regards economic policy, the predominance of withholding taxes as the main tax collection instrument has a dramatic impact on relative prices on which decisions are made concerning productive strategies and, therefore, on the selection of technologies and their management, both in terms of nutrient replenishment, use of growing available varieties and weed modes of action, and the decision as to whether or not to comply with refuge requirements. A brief analysis of the variables involved would underscore that the economic potential for these technologies gives enough space to advance in alternative approaches that are not so disruptive, even though they are equally beneficial in terms of aggregate impacts on the economy (*Bolsa de Cereales*, 2021).

In the future, transformations in the foregoing direction would also have other benefits, beyond those already mentioned, since in addition to the effects that can be observed today, it can be anticipated that climate change will inevitably tend to aggravate the problems that have arisen up to now. In this sense, an increase in temperature is expected in the main producing areas, which will result in new weeds and pests, as well as more rapid changes in the existing areas, which will in turn require more complex technological strategies (IICA, 2015).

In the case of Bt crops, it is even more important to take care of existing technologies through the correct management of insect resistance and, in the case of weed control, it will be inevitable to resort to a more diverse basket of technologies allowing for the rotation of active principles and modes of action, which is recommended by both no-tillage and good agricultural practices.

In this context, several of the technologies currently available gain a strategic value that goes beyond economic benefits, since they are essential to guarantee the sustainability of agricultural production in Argentina. Progress in this direction is a priority task, since these are mature technologies, well established in today's prevailing production strategies, for which there are no regulatory problems to be solved, not even in terms of access to international markets, so that such benefits are not subject to conditions other than the natural risks of agricultural production.

Beyond these aspects, there is an issue about the renewal of existing technologies and the positioning of Argentina in the new technological cycle implied by the onrush of new methodologies, such as gene editing. The various benefits described and discussed in this report make it redundant to discuss whether being part of this new cycle would be beneficial. Indeed, the preliminary conclusion is that every effort should be made to be present in this new cycle with the same “early adopter" attributes as in the current cycle.

As for the new technologies of the GM cycle, the challenges remain basically the same as they have been up to now. On the one hand, the above-mentioned intellectual property issues, where Argentina continues to have the same liabilities as it has had up to now, particularly concerning mechanisms to ensure effective compliance with existing approaches.

In this regard, the way in which the first GM herbicide tolerant soybean varieties were accessed 25 years ago established a set of behaviors regarding the seed market, which may have been effective to speed up the initial process stages, but which are hardly viable for what lies ahead (Trigo *et al*., 2002). In fact, one could argue that they have been a hurdle for faster access to some of the technologies that have recently emerged on seed markets. Ad-hoc mechanisms have been developed, which appear to be effective in boosting the market in some cases, but it is arguable whether they could play their own role in some of the future scenarios that can be anticipated.

On the other hand, there is a need to integrate international policy aspects with international trade negotiation policies. Here again, in the initial cycle stages, this was a minor issue because new technologies had already been approved for import and consumption when they were introduced in Argentina. But this has been changing, and today in practice, approvals have virtually become a para-tariff measure, in a scenario that is unlikely to change in the impending future. That is why a clear and effective integration of technology development policies with commercial diplomacy becomes a pivotal element in defining where to go. Recent experiences with soybean and HB4 wheat are a clear example of the importance of both presence and absence of such policy interfaces.

Finally, let us mention the opportunities offered by new technologies, such as gene editing. Along this line, it is worth stressing that once again Argentina has favorable elements to be considered. One of them, which was already strategic before, is that the country has been a leader in establishing a proactive biosafety regulatory framework to manage such opportunities. Moreover, at international level, Argentina has been one of the first countries to set up a framework in this regard, which is now being used as an international reference[16].

This is undoubtedly strategic, since it would seem that as these technologies have lower development costs, they can be used both for a broader spectrum of crops and within scenarios where domestic companies can have a greater participation. However, there are still very few specific experiences of products on the markets and there has already been evidence of similar regulatory conflicts to those that have occurred in the past,

[16] See https://www.magyp.gob.ar/sitio/areas/prensa/index.php?accion=noticia&id_info=190409131059

especially with the EU. Therefore, the aforementioned commercial diplomacy issue is a very relevant one.

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Annex I: Tables

Table A1: GM Events Authorized for Planting, Consumption and Commercialization in Argentina

	Species	Inserted Trait	Event	Applicant	Year
1	Soybean	Glyphosate Tolerance	40-3-2	Nidera	1996
2	Maize	Lepidopteran Insect Resistance	176	Ciba-Geigy	1998
3	Maize	Glufosinate-Ammonium Tolerance	T25	AgrEvo	1998
4	Cotton	Lepidopteran Insect Resistance	MON531	Monsanto	1998
5	Maize	Lepidopteran Insect Resistance	MON810	Monsanto	1998
6	Cotton	Glyphosate Tolerance	MON1445	Monsanto	2001
7	Maize	Lepidopteran Insect Resistance	Bt11	Novartis	2001
8	Maize	Glyphosate Tolerance	NK603	Monsanto	2004
9	Maize	Lepidopteran Insect Resistance and Glufosinate-Ammonium Tolerance	TC1507	Dow AgroSciences and Pioneer Argentina	2005
10	Maize	Glyphosate Tolerance	GA21	Syngenta	2005
11	Maize	Glyphosate Tolerance and Lepidopteran Insect Resistance	NK603xMON810	Monsanto	2007
12	Maize	Lepidopteran Insect Resistance and Glufosinate-Ammonium Tolerance	1507xNK603	Dow AgroSciences and Pioneer Argentina	2008
13	Cotton	Lepidopteran Insect Resistance and Glyphosate Tolerance	MON531xMON1445	Monsanto	2009
14	Maize	Glyphosate Tolerance and Lepidopteran Insect Resistance	Bt11xGA21	Syngenta	2009
15	Maize	Glyphosate Tolerance and Coleopteran Insect Resistance	MON88017	Monsanto	2010
16	Maize	Lepidopteran Insect Resistance	MON89034	Monsanto	2010
17	Maize	Glyphosate Tolerance and Coleopteran/Lepidopteran Insect Resistance	MON89034 x MON88017	Monsanto	2010
18	Maize	Lepidopteran Insect Resistance	MIR162	Syngenta	2011
19	Soybean	Glufosinate-Ammonium Tolerance	A2704-12	Bayer	2011
20	Soybean	Glufosinate-Ammonium Tolerance	A5547-127	Bayer	2011
21	Maize	Lepidopteran Insect Resistance and Glyphosate Tolerance	Bt11xGA21xMIR162	Syngenta	2011
22	Maize	Tolerance to Glyphosate and Inhibitor Herbicides	DP-098140-6	Pioneer	2011
23	Maize	Coleopteran/Lepidopteran Insect Resistance and Herbicide Tolerance	Bt11xMIR162xMIR604xGA21	Syngenta	2012

24	Maize	Coleopteran Insect Resistance	MIR604	Syngenta	2012
25	Maize	Lepidopteran Insect Resistance and Glufosinate Tolerance	MON89034xTC1507xNK603	Dow AgroSciences and Monsanto	2012
26	Maize	Lepidopteran Insect Resistance and Glyphosate Tolerance	MON89034xNK603	Monsanto	2012
27	Soybean	Lepidopteran Insect Resistance and Glyphosate Tolerance	MON87701xMON89788	Monsanto	2012
28	Soybean	Imidazolinone Herbicide Tolerance	CV127	Basf Agricultural Solutions	2013
29	Maize	Lepidopteran Insect Resistance and Glufosinate Tolerance	TC1507xMON810xNK603	Pioneer	2013
30	Maize	Lepidopteran Insect Resistance and Glyphosate Tolerance	Bt11xMIR162xTC1507xGA21	Syngenta	2014
31	Soybean	2,4 D, Glufosinate-Ammonium and Glyphosate Tolerance	DAS-44406-6	Dow AgroSciences	2015
32	Soybean	High Oleic Acid Content and Glyphosate Tolerance	DP-305423-1 x MON-04032-6	Pioneer	2015
33	Cotton	Glufosinate-Ammonium and Glyphosate Tolerance	BCS-GHØØ2-5 x ACS-GHØØ1-3	Bayer	2015
34	Soybean	Drough Resistance and Glufosinate Tolerance	IND-00410-5	INDEAR	2015
35	Papa	Virus Resistance	TIC-AR233-5	Tecnoplant	2015
36	Maize	Lepidopteran Insect Resistance and Glufosinate-Ammonium/Glyphosate Tolerance	TC1507xMON810xMIR162xNK603 and all intermediate cumulative events	Pioneer	2016
37	Soybean	Glyphosate Tolerance	MON-89788-1	Monsanto	2016
38	Soybean	Lepidopteran Insect Resistance	MON-87701-2	Monsanto	2016
39	Maize	Lepidopteran Insect Resistance and Glufosinate-Ammonium Tolerance and a glifosato	MON-89034-3 x DAS-01507-1 x MON-00603-6 x SYN-IR162-5 and all intermediate cumulative events	Dow AgroSciences	2016
40	Soybean	Lepidopteran Insect Resistance and Glufosinate-Ammonium/Glyphosate Tolerance	DAS-81419-2 x DAS-444Ø6-6	Dow AgroSciences	2016
41	Maize	Lepidopteran Insect Resistance and Glufosinate-Ammonium/Glyphosate Tolerance	SYN-BT011-1 x SYN-IR162-4 x MON-89034-3 x MON-00021-9 and all intermediate cumulative events	Syngenta	2016
42	Soybean	Tolerance to Glufosinate-Ammonium and p-Hydroxyphenylpyruvate dioxygenase (HPPD) Enzyme Inhibitor Herbicides	SYN-000H2-5	Syngenta and Bayer	2017
43	Safflower	With Bovine Pro-Chymosin Expression in Seed	IND-10003-4, IND-10015-7, IND-10003-4 x IND-10015-7 and all intermediate cumulative events	INDEAR	2017

44	Maize	Tolerance to Herbicides formulated with Aryloxy-Phenoxy Family Products, and to 2,4-D, Glufosinate-Ammonium and Glyphosate; Lepidopteran Insect Resistance	DAS-40278-9 MON-89034-3 x DAS-01507-1 x MON-00603-6 x DAS-40278-9	Dow AgroSciences	2018
45	Soybean	Herbicide Tolerance to Isoxaflutole, Glyphosate and Glufosinate-Ammonium	MST-FG072-2 and MST-FG072-2xACS-GM006-4	Bayer	2018
46	Maize	Glufosinate-Ammonium/Glyphosate Tolerance, and Coleopteran/Lepidopteran Insect Resistance	SYN-05307-1 and SYN-BT011-1xSYN-IR162-4xSYN-IR604-5xDAS-01507- 1xSYN-05307-1xMON-00021-9 and all intermediate cumulative events	Syngenta	2018
47	Maize	Glyphosate Tolerance and Coleopteran/ Lepidopteran Insect Resistance	MON-87427-7, MON-87411-9, MON-87427-7 × MON-89Ø34-3 × SYN-IR162-4 × MON-87411-9 and all intermediate cumulative events	Monsanto	2018
48	Alfalfa	Glyphosate Tolerance and Decreased Lignin Content	MON-ØØ179-5, MON-ØØ1Ø1-8 and MON-ØØ179-5 x MON-ØØ1Ø1-8	INDEAR	2018
49	Soybean	For Processing Only	MON-877Ø8-9 x MON-89788-1	Monsanto	2018
50	Papa	Virus Resistance	TIC-AR233-5	Tecnoplant	2018
51	Maize	Glyphosate Tolerance and Coleopteran/ Lepidopteran Insect Resistance	MON-87427-7 x MON-89Ø34-3 x MON-88Ø17-3	Monsanto	2018
52	Soybean	Glufosinate/Glyphosate Tolerance and Drought Resistance	IND-ØØ41Ø-5 x MON-Ø4Ø32-6 (OECD)	INDEAR	2018
53	Cotton	Tolerance to Glyphosate and HPPD Inhibitor Herbicides	BCS-GH811-4	Basf Agricultural Solutions	2019
54	Soybean	Glufosinate/Glyphosate Tolerance	DBN-Ø9ØØ4-6	INDEAR	2019
55	Maize	Tolerance to Herbicides formulated with Aryloxy-Phenoxy Family Products, and to 2,4-D, Glufosinate-Ammonium and Glyphosate; Lepidopteran Insect Resistance	MON-89Ø34-3 x DAS-Ø15Ø7 x MON-ØØ6Ø3-6 x SYN-IR162-4 x DAS-4Ø278-9	Dow AgroSciences	2019
56	Cotton	Glyphosate/Glufosinate-Ammonium Tolerance, and Lepidopteran Insect Resistance	SYN-IR1Ø2-7 and BCS-GHØØ2-5 x BCS-GHØØ4-7 x BCS-GHØØ5-8 x SYN-IR1Ø2-7, all intermediate cumulative events and BCS-GHØØ4-7 and BCS-GHØØ5-8 events	Basf Agricultural Solutions	2019
57	Maize	Lepidopteran/Coleopteran Insect Resistance and Glyphosate/Glufosinate-Ammonium Tolerance	MON-89Ø34-3 x DAS-Ø15Ø7-1 x MON-88Ø17-3 x DAS-59122-7	Monsanto, Dow AgroSciences and Pioneer	2019

58	Maize	Coleopteran/Lepidopteran Insect Resistance, and Glufosinate-Ammonium/Glyphosate Tolerance	MON-87427-7 × MON-89Ø34-3 × DAS-Ø15Ø7-1 × MON-88Ø17-3 × DAS-59122-7	Monsanto	2019
59	Maize	Coleopteran/Lepidopteran Insect Resistance, and Glufosinate-Ammonium/Glyphosate Tolerance	MON-87427-7 × MON-89Ø34-3 × MON-ØØ6Ø3-6	Monsanto	2019
60	Maize	Lepidopteran Insect Protection and Glyphosate Tolerance	MON-87427-7 x MON-89Ø34-3 x SYN-IR162-4 x MON-ØØ603-6	Monsanto	2019
61	Cotton	Lepidopteran Insect Protection	SYN-IR1Ø2-7	Syngenta	2019
62	Trigo	Drought Tolerance and Glufosinate-Ammonium Tolerance	IND- ØØ412-7	INDEAR S.A.	2020

Source: Ministry of Agriculture, Livestock and Fisheries

Table A1: Area Planted with GM Crops (in million hectares)

	GM Maize		GM Soybean		GM Cotton	
Year	Million Hectares	Maize Area Percentage	Million Hectares	Soybean Area Percentage	Million Hectares	Cotton Area Percentage
1996/97	0	0,0%	368.866	5,5%	0	0%
1997/98	0	0,0%	1.751.525	24,4%	0	0%
1998/99	32,701	1,0%	4,800,000	57,1%	271	0%
1999/00	365,190	10,0%	6,640,378	75,5%	745	0%
2000/01	698,905	20,0%	9,225,701	84,4%	2,033	0%
2001/02	918,498	30,0%	10,923,742	93,9%	5,449	3%
2002/03	1,224,150	40,0%	12,228,640	97,0%	31,642	20%
2003/04	1,481,200	50,0%	14,342,141	98,7%	71,163	27%
2004/05	2,042,302	60,0%	14,254,076	99%	162,568	40%
2005/06	2,169,499	68,0%	15,272,898	99%	185,456	60%
2006/07	2,576,329	72,0%	16,141,338	100%	322,910	80%
2007/08	3,093,980	73%	16,608,935	100%	276,533	90%
2008/09	2,871,089	82%	18,042,895	100%	279,454	94%
2009/10	3,010,433	82%	18,860,732	100%	482,909	99%
2010/11	3,876,936	85%	18,884,309	100%	640,765	100%
2011/12	4,600,304	92%	18,670,937	100%	622,146	100%
2012/13	5,826,709	95%	20,035,572	100%	410,650	100%
2013/14	5,854,930	96%	19,704,642	100%	552,246	100%
2014/15	5,913,790	98%	19,792,100	100%	523,680	100%
2015/16	6,835,493	99%	20,479,090	100%	406,130	100%
2016/17	8,401,827	99%	18,057,162	100%	253,310	100%
2017/18	9,048,368	99%	17,259,260	100%	327,465	100%

2018/19	8,949,198	99%	17,010,277	100%	441,103	100%
2019/20	9,500,000	99%	16,900,000	100%	450,000	100%

Source: Own estimated based on Trigo (2016), National Directorate of Agriculture – Directorate of Agricultural Estimates – Ministry of Agriculture, Livestock and Fisheries (2019), and Applied Agricultural Technology Survey- *ReTAA* (2020).

Figure A1: Evolution by Province of Actual Area Planted and Area Planted within a Non-GMO Technology Scenario. Years 1995-2020 (thousand hectares)

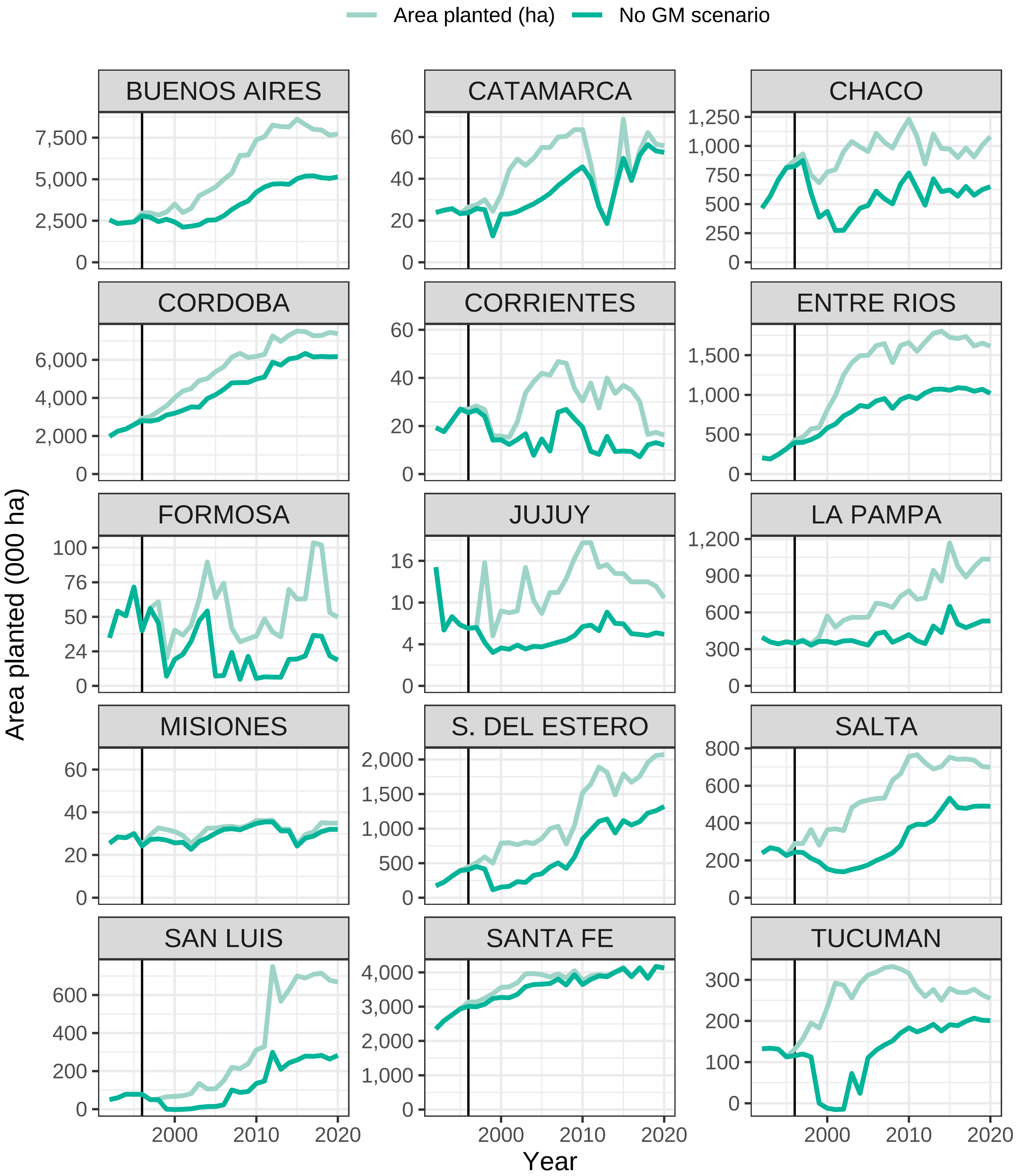

Table A3: Gross Margins earned from GM Crops Adoption (in million USD)

	Maize	Soybean	Cotton	Total
1996/97		330	0	330
1997/98		607	0	607
1998/99	26	860	1	887
1999/00	172	1,102	1	1,275
2000/01	174	2,003	1	2,178
2001/02	194	2,498	2	2,694
2002/03	173	3,511	7	3,690
2003/04	194	3,946	18	4,159
2004/05	179	3,724	37	3,940
2005/06	121	4,005	42	4,169
2006/07	284	6,230	74	6,588
2007/08	304	8,293	65	8,661
2008/09	60	5,450	64	5,573
2009/10	223	9,010	96	9,329
2010/11	489	9,862	222	10,574
2011/12	384	8,714	225	9,323
2012/13	580	10,780	128	11,487
2013/14	410	10,450	224	11,083
2014/15	332	8,995	165	9,492
2015/16	545	8,808	139	9,492
2016/17	753	7,689	121	8,563
2017/18	816	5,585	179	6,580
2018/19	956	7,348	173	8,476
2019/20	641	7,275	117	8,033
2020/21	735	9,059	30	9,825
Cumulative Total	**8,747**	**146,133**	**2,129**	**157,009**

Table A4: Soybean: Evolution of Gross Margins from GM Crops Adoption (million USD)

Crop Season	FOB	GM Crops Adoption	Actual Crop Area	Non-GMO Area	Area Difference	Gross Margin/Area	Cost Change	Gross Margin / Costs	Average Yield	Non-GMO Yield	GMO Crop Yield	Gross Margin / Yield	Total Gross Margin
	(1)	(2)	(3)	(4)	(5) = (4)-(3)	(6)=(10)*(5)*(1)	(7)	(8)=(7)*(3)*(2)	(9)	(10)	(11)	(12)	(12)+(8)+(6)
	USD /Ttn	%	MM Ha	MM Ha	MM Ha	MM USD	USD/ha	MM USD	Tn/Ha	Tn/Ha	Tn/Ha	MM USD	MM USD
1996/97	301	6%	6.7	6.0	0.6	321	26	10	1.7	1.7	1.7	0	330
1997/98	231	24%	7.2	6.2	0.9	560	27	48	2.6	2.6	2.6	0	607
1998/99	174	57%	8.4	6.7	1.7	703	33	157	2.4	2.4	2.4	0	860
1999/00	187	76%	8.8	6.7	2.1	906	29	196	2.3	2.3	2.3	0	1,102
2000/01	177	84%	10.9	7.2	3.8	1,666	36	336	2.5	2.5	2.5	0	2,003
2001/02	196	94%	11.6	7.5	4.2	2,105	36	393	2.6	2.6	2.6	0	2,498
2002/03	238	97%	12.6	7.9	4.7	3,077	35	434	2.8	2.8	2.8	0	3,511
2003/04	267	99%	14.5	8.5	6.0	3,491	32	455	2.2	2.2	2.2	0	3,946
2004/05	230	99%	14.4	8.9	5.5	3,355	26	370	2.7	2.7	2.7	0	3,724
2005/06	234	99%	15.4	9.5	5.9	3,613	26	393	2.6	2.6	2.6	0	4,005
2006/07	317	100%	16.1	10.1	6.1	5,681	34	549	2.9	2.9	2.9	0	6,230
2007/08	456	100%	16.6	10.5	6.1	7,747	33	546	2.8	2.8	2.8	0	8,293
2008/09	414	100%	18.0	11.0	7.0	5,003	25	446	1.7	1.7	1.7	0	5,450
2009/10	408	100%	18.9	11.7	7.1	8,368	34	642	2.9	2.9	2.9	0	9,010
2010/11	505	100%	18.9	11.8	7.1	9,253	32	610	2.6	2.6	2.6	0	9,862
2011/12	561	100%	18.7	11.9	6.8	8,141	31	572	2.1	2.1	2.1	0	8,714
2012/13	536	100%	20.0	12.4	7.7	10,137	32	643	2.5	2.5	2.5	0	10,780
2013/14	492	100%	19.7	12.4	7.3	9,755	35	694	2.7	2.7	2.7	0	10,450
2014/15	377	100%	19.8	12.6	7.2	8,400	30	595	3.1	3.1	3.1	0	8,995
2015/16	382	100%	20.5	13.0	7.5	8,238	28	570	2.9	2.9	2.9	0	8,808
2016/17	372	100%	18.1	11.6	6.4	7,293	22	397	3.0	3.0	3.0	0	7,689
2017/18	386	100%	17.3	11.2	6.1	5,116	27	469	2.2	2.2	2.2	0	5,585
2018/19	343	100%	17.0	10.8	6.2	6,923	25	425	3.2	3.2	3.2	0	7,348
2019/20	383	100%	16.9	10.7	6.2	6,978	18	297	3.0	3.0	3.0	0	7,275
2020/21	517	100%	16.8	10.7	6.1	8,791	16	268	2.8	2.8	2.8	0	9,059

Table A5: Maize: Evolution of Gross Margins from GM Crop Adoption

Crop Season	FOB	GM Crops Adoption	Actual Crop Area	Non-GMO Area	Area Difference	Gross Margin/Area	Cost change	Gross Margin/ Costs	Average Yield	Non-GMO Yield	GMO Crop Yield	Gross Margin/ Yield	Total Gross Margin
	(1)	(2)	(3)	(4)	(5) = (4)-(3)	(6)=(10)*(5)*(1)	(7)	(8)=(7)*(3)*(2)	(9)	(10)	(11)	(12)	(12)+(8)+(6)
	USD/Tn	%	MM Ha	MM Ha	MM Ha	MM USD	USD/Ha	MM USD	Tn/Ha	Tn/Ha	Tn/Ha	MM USD	MM USD
1998/99	96	1%	3.3	3.2	0.1	25	-6	0	4.1	4.1	4.5	1	26
1999/00	87	10%	3.7	3.2	0.4	162	-6	-2	4.6	4.6	5.0	13	173
2000/01	88	20%	3.5	3.1	0.4	155	-6	-4	4.4	4.3	4.7	24	175
2001/02	98	30%	3.1	2.7	0.4	163	-6	-6	4.8	4.7	5.1	38	195
2002/03	103	40%	3.1	2.8	0.3	128	-6	-7	4.9	4.7	5.2	54	174
2003/04	105	50%	3.0	2.7	0.3	137	-6	-9	5.0	4.8	5.2	67	195
2004/05	91	60%	3.4	3.2	0.2	120	-19	-38	6.0	5.7	6.2	96	178
2005/06	126	68%	3.2	3.0	0.2	111	-23	-49	4.5	4.4	4.6	60	122
2006/07	161	72%	3.6	3.3	0.2	221	-23	-58	6.1	5.9	6.2	121	284
2007/08	205	73%	4.2	4.0	0.2	246	-31	-96	5.2	5.0	5.3	159	310
2008/09	168	82%	3.5	3.3	0.2	95	-37	-108	3.8	3.6	3.8	87	74
2009/10	197	82%	3.7	3.5	0.1	168	-39	-117	6.2	5.9	6.2	176	227
2010/11	289	85%	4.6	4.3	0.3	363	-39	-150	5.2	5.0	5.3	280	493
2011/12	270	92%	5.0	4.7	0.3	321	-40	-183	4.2	4.1	4.3	252	390
2012/13	243	98%	6.1	5.8	0.4	460	-39	-234	5.2	5.0	5.2	363	588
2013/14	199	96%	6.1	5.8	0.3	351	-40	-236	5.4	5.2	5.4	302	418
2014/15	169	93%	6.0	5.7	0.3	276	-34	-192	5.6	5.4	5.6	255	338
2015/16	175	93%	6.9	6.4	0.5	439	-31	-198	5.8	5.5	5.8	310	552
2016/17	160	96%	8.5	7.8	0.6	570	-21	-173	5.8	5.6	5.8	363	760
2017/18	172	99%	9.1	8.4	0.7	577	-11	-102	4.8	4.5	4.8	354	829
2018/19	165	97%	9.0	8.4	0.6	637	-12	-105	6.3	6.0	6.3	434	966
2019/20	179	99%	9.0	8.4	0.6	689	-13	-118	6.3	6.0	6.3	480	1,052
2020/21	234	99%	9.4	8.7	0.7	1,098	-14	-130	7.4	7.0	7.4	769	1,737

Table A6: Carbon Dioxide Emissions Savings from Carbon Sequestration

Crop Season	NT Area	Carbon Dioxide Emissions Savings
	Million Hectares	Million Tons
1996/97	1.8	0.5
1997/98	2.5	0.8
1998/99	2.8	0.8
1999/00	4.5	1.3
2000/01	6.5	2.0
2001/02	8.2	2.5
2002/03	9.3	2.8
2003/04	11.5	3.5
2004/05	12.3	3.7
2005/06	13.0	3.9
2006/07	14.6	4.4
2007/08	16.1	4.8
2008/09	16.9	5.1
2009/10	19.7	5.9
2010/11	22.6	6.8
2011/12	22.6	6.8
2012/13	24.5	7.3
2013/14	24.0	7.2
2014/15	23.7	7.1
2015/16	25.3	7.6
2016/17	24.7	7.4
2017/18	24.9	7.5
2018/19	24.1	7.2
2019/20	23.3	7.0
2020/21	24.4	7.3
Cumulative Total 1996-2020		**121.1**

Annex II: Partial Equilibrium Model

When analyzing the impact of the emergence of GMO seeds on the Argentine agribusiness, it is difficult to isolate the exclusive effect of this phenomenon, given that in practice it was observed simultaneously with a large expansion of no-till farming and the growth of the area under double cropping (winter and summer) in the same season.

Thus, it was decided to estimate the impact of GMOs indirectly. Basically, it was assumed that the evolution of the area observed responds to a process composed of three separable effects:

$$Area_{i,t} = \Phi_i . Trend_{i,t} . Prices_{i,t} . Ogm_{i,t}$$

where $Area_{i,t}$ is the area allocated to planting crop i (maize and soybean) in season t, Φ_i is a constant, $\mathrm{Trend}_{i,t}$ is an exponential growth line, $Precios_{i,t}$ is the effect of the set of prices and policies on farmers' decisions, and $Ogm_{i,t}$ groups the rest of the effects not explained in the other components that can be associated with the technological changes occurred in the sector, which were possible thanks to GMO seeds.

In order to extract the $Prices_{i,t}$ effect, a partial equilibrium model was used, whose planting decision equation is given by:

$$Area_{i,t} = \prod_j \left(\frac{P_{jt} . Yield_{jt}}{Costs_{jt}} \right)^{\mu_{i,j}} . R_{it}$$

Here P_{jt} is the price received by the farmer, which considers both the evolution of the FOB export price and discounts for export duties, fobbing and commercialization expenses, transportation costs and harvesting costs, $Yield_{jt}$ is the yield per hectare of each crop, and $Costs_{jt}$ is an index that considers the evolution of production costs considering both inputs and tillage, including their evolution as a function of the GMO adoption rate.

The elasticities $\mu_{i,j}$ indicate the expansion of areas as a function of price incentives and were taken from Brescia and Lema (2001), with the exception of the cross-price elasticity between maize and soybean areas that was assumed to be zero. This is because in the tests it was observed that the price of maize had far-fetched impacts on soybean area, and its elimination is reasonable because the P value of the significance test shown by the authors is 0.1254.

On the other hand, the residual Y_{it} contains the rest of the unexplained effects, so it is possible to define:

$$Prices_{it} = \prod_{j} \left(\frac{P_{jt} . Yield_{jt}}{Costs_{jt}} \right)^{\mu_{i,j}}$$

Thus, $Yield_{it} = \Phi_i . Trend_{i,t} . Ogm_{i,t}$, and estimating the trend from historical information, it derives $Ogm_{i,t}$.

Glossary

Environmental Impact Quotient (EIQ): The Environmental Impact Quotient (EIQ) is one of the tools used to measure achievements in agrochemical risk reduction. It was developed in 1992 by Cornell University, USA, and provides an indication of the potential environmental and health risks of pesticides.

Cultivar or Plant Variety: A cultivar is a group of plants artificially selected by various methods from a more variable crop, with the purpose of fixing in them characteristics of importance to the breeder that are maintained after reproduction (Brickell, 2002).

Partial Equilibrium: Economic model that analyzes the behavior of prices and quantities in a given market, assuming unchanged prices of products not explicitly contemplated, including those of production factors.

Event or Genetically-Engineered (GE) Event: An event is a particular DNA recombination or insertion that occurred in a plant cell from which the transgenic plant originated. Transformation events are unique, and differ in the elements and genes inserted, the insertion sites in the plant genome, the number of copies of the insert, the expression patterns and levels of expression of the proteins of interest, and so on. The events can also be stacked by conventional crossing, what we call "stacked events", to easily obtain plants with several stacked traits (ArgenBio, 2020).

Carbon Sequestration: Carbon sequestration is the process of capturing and storing carbon dioxide from the atmosphere. As crops photosynthesize to produce food, they absorb carbon dioxide from the atmosphere and generate oxygen. Through this chemical process, carbon is sequestered in the soil.

25 YEARS OF GENETICALLY-MODIFIED CROPS IN ARGENTINE AGRICULTURE

Bolsa de Cereales