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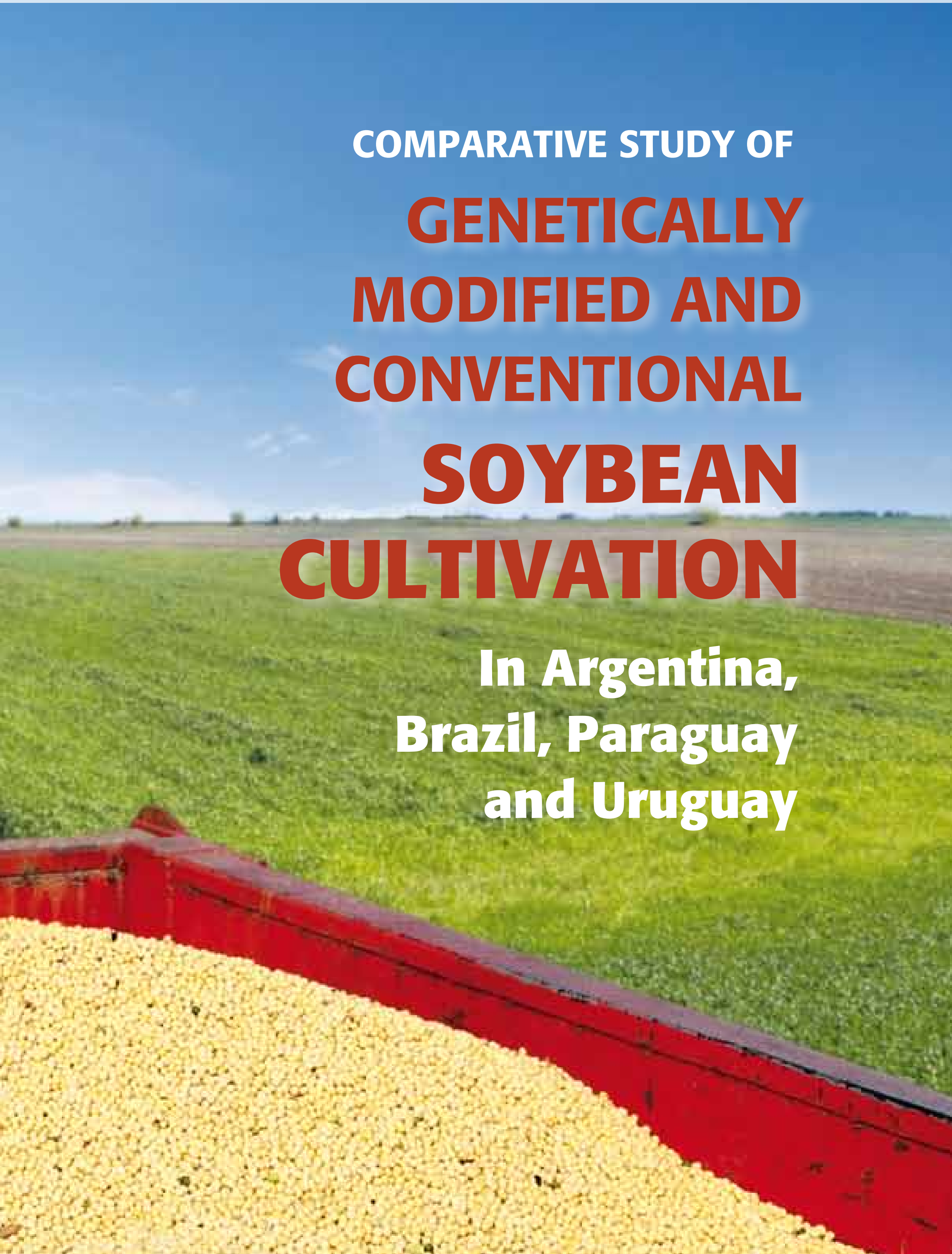

COMPARATIVE STUDY OF GENETICALLY MODIFIED AND CONVENTIONAL SOYBEAN CULTIVATION

In Argentina, Brazil, Paraguay and Uruguay

Comparative study of genetically modified and conventional soybean cultivation

The technology package based on GM soybean, direct seeding, and fertilization has facilitated crop management, reduced the negative environmental impact of production, and generated economic benefits for farmers and countries alike.

Ministry of Agriculture, Livestock and Fisheries of Argentina
Inter-American Institute for Cooperation on Agriculture

Comparative study of genetically modified and conventional soybean cultivation in Argentina, Brazil, Paraguay, and Uruguay

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Executive Summary

In recent years, the steady increase in soybean production (*Glycine max* L. Merr) in Argentina, Brazil, Paraguay, and Uruguay has been due to several factors. Noteworthy among them are: (i) the incorporation of new land into soybean cultivation, (ii) the availability of genetically modified herbicide-resistant (GM-HR) soybean (also known as transgenic soybean), (iii) the existence of regulatory biosafety frameworks, and (iv) the keenness of farmers to incorporate innovative technologies into the agricultural production system used in the various soybean-producing areas of the four countries.

Complementary technologies, such as direct seeding, nutrition (chemical and biological), the use of biocides (herbicides, fungicides and insecticides) and genetically modified or transgenic soybean varieties, comprise the technology package that has made soybean the largest export crop of all four countries, contributing close to 50 per cent of global production of this oilseed. There is evidence–presented in detail in this document–to suggest that this technology package has reduced the environmental impact as a result of less working of the soil and a decrease in the use of herbicides.

The direct seeding system minimizes soil erosion, which makes more efficient use and retention of water possible. Together with crop rotation, it also increases soil organic matter. Plant nutrition, based on chemical fertilization, has made it possible to improve soils in areas where organic matter content is inadequate, and recover degraded areas. The use of nitrogen-fixing bacteria has helped reduce chemical fertilization with nitrogen, which is responsible for generating nitrous oxide, the main gas responsible for the greenhouse effect. GM soybean has simplified the work involved in cultivation, particularly weed control activities, through the use of the glyphosate herbicide. All of this has made crop production more efficient, and generated agronomic, environmental, and economic benefits for farmers in the four countries.

This study presents important aspects of the development of soybean cultivation in Argentina, Brazil, Paraguay, and Uruguay. It includes a brief history of soybean growing in the four countries; a description of the components of the technology package; a summary of current biosafety legislation; production-related, environmental, and economic impacts of soybean production technology; and an analysis of possible production scenarios.

The study's conclusions may be summed up as follows: (i) GM soybean cultivation in Argentina, Brazil, Paraguay, and Uruguay has developed positively since it was first introduced in the region. This is reflected in the increase in the crop area, which rose from 1.37 million hectares in 1976 to 45 million hectares in 2011, generating estimated economic returns of more than USD5 billion for farmers in the region that same year (Del Río 2012); (ii) the technology package used for soybeans is more efficient than the application of any of its components separately; (iii) the introduction of GM soybean revolutionized the crop in the four countries because of the ease of agronomical management, weed control, and lower production costs; (iv) the technology package generates more environmental and economic benefits when used with GM soybean than it does with conventional varieties.

Finally, and based on official statistics (Del Río 2012) and field studies (Rovea 2012), this study is intended to contribute up-to-date information on the production system of this oilseed in Argentina, Brazil, Paraguay, and Uruguay, which together account for approximately 50 per cent of global soybean production. While GM soybean cultivation in the four countries has proven to be very efficient, the challenge will be to maintain the high level of performance by optimizing agricultural practices and the technologies available in order to meet the growing demand for the product in a context of population growth, environmental conservation, and climate change, thereby guaranteeing food security.

Chapter 1

Introduction

Over the past 15 years, the countries of South America have been world leaders in agricultural production, particularly in the supply of grains for international markets. In the last ten years, Argentina, Brazil, Paraguay, and Uruguay have increased their soybean production by 234 per cent, and maize by 166 per cent (FAO 2012). No other region of the world has contributed as significantly to increasing world productivity as these four countries together.

A variety of factors has impacted this major development in agriculture. They include technological advances, the agribusiness vision of producers, increasing demand and the attractive prices of grains in emerging countries, and government support through public policies that have encouraged investment and generated stability in the sector.

The recognized success of South American agriculture is even more obvious in the case of soybean cultivation. In fact, Argentina, Brazil, Paraguay and Uruguay currently account for around 50 per cent of world production and are, respectively, the world's second, third, fourth, and seventh largest exporters of this oilseed (FAO 2012). What is more, of the 45 million hectares sown in the 2009-2010 crop year, 87.5 per cent were planted with transgenic soybean (James 2010, Table 1).

Table 1.1. Area under cultivation and volume of soybean production (conventional and transgenic) in the 2009-2010 crop year in Argentina, Brazil, Paraguay, and Uruguay

Country	Conventional soybean[1]		GM-HR Soybean[2]		Soybean cultivation (conventional + GM-HR)[3]	
	Area (millions of hectares)	Production [4]	Area (millions of hectares)	Production[4] (millions of tons)	Area (millions of hectares)	Total production (millions of tons)
Argentina	0	0	18.13	52.68	18.13	52.68
Brazil	5.49	16.12	17.8	52.4	23.29	68.52
Paraguay	0.14	0.37	2.54	7.09	2.67	7.46
Uruguay	0	0	0.86	1.82	0.86	1.82
Total	5.63	16.49	39.33	113.99	44.95	130.48

1 Estimated figure, because of the difference between the official figures reported by FAOSTAT (FAO 2012) and James (2010).
2. Figures reported by James (2010).
3. Based on FAOSTAT (official data reported for 2010, FAO 2012).
4. Production was estimated for conventional and GM soybean, based on the average yield in FAO (2012).

The four countries achieved their current share of the world soybean market thanks to the implementation of gradual processes of technological innovation (Chapter 2), ranging from efficient mechanical harvesting to the use of transgenic seeds, and the drafting and application of specific standards in each country.

The management of soybean cultivation in the four countries is now highly efficient due, in particular, to the adoption of a technology package that combines the system of direct seeding, plant nutrition (chemical and biological), chemical control of weeds and diseases, and use of transgenic seed. This technology package (Chapter 3) has made it possible to achieve progressively higher yields, generate savings in production costs, obtain cleaner harvests, gradually improve soils, and use water more efficiently.

The use of transgenic seeds has been possible because Argentina, Brazil, Paraguay, and Uruguay have regulatory biosafety frameworks (UN 2012) designed to ensure that genetically modified organisms (GMOs) that are released are safe for ecosystems and human and animal consumption, and desirable from the commercial standpoint (CAS and IICA 2010, Chapter 4).

The real impact of genetically modified herbicide-resistant (GM-HR) soybean on the environment can be gauged thanks to the availability of the technology package and the existence of biosafety regulations. This document also contains an analysis of the potential for introducing transgenic drought-tolerant (GM-DT) soybean and the need to do so in order to adapt agriculture to climate change.

The factors that have combined to define the economic impact of the activity in the countries of the region are the progressive increase in crop area in the four countries, the regulation of biosafety, and the environmental effect. Chapter 6 presents a comparative analysis of production costs and Chapter 7 evaluates potential production scenarios for this crop.

Much information about GM soybean cultivation is available. However, few studies include information obtained directly from producers in the region. From the methodological standpoint, this study is based on the review of available literature and on the study by Rovea (2012). Rovea conducted onsite interviews with various producers who made a decision to adopt the technology package described herein, which has made it possible to consolidate the crop.

With regard to soybean cultivation, there are considerable differences among countries and within each of them. However, this study documents the most important common aspects and, when necessary, highlights the specific features of each country or locality.

This study is part of the efforts of the Secretariat of Agriculture, Livestock and Fisheries of Argentina and the Inter-

American Institute for Cooperation on Agriculture (IICA) to provide scientifically-based information to decision makers, researchers, the media, farmers and the public. The analysis contained herein is based on the official statistics available (Del Río 2012) and on field studies (Rovea 2012). It does not take an ideological stance on the subject of transgenics (Rocha 2011) and will be used as a reference for future analyses and decisions (Chapter 7).

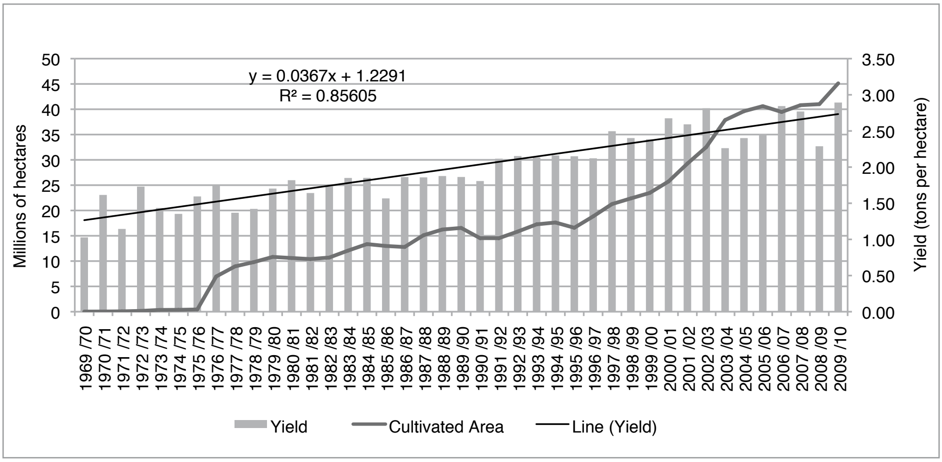
Chapter 2

Evolution of soybean cultivation in Argentina, Brazil, Paraguay and Uruguay

Prior to 1976, very little soybean was grown in Argentina, Brazil, Paraguay, and Uruguay. Between 1976 and 2010, however, soybean production in the four countries rose from 1.58 million tons grown on 1.37 million hectares of land to over 130 million tons on 45 million hectares (FAO 2012). In other words, there was an average annual increase of 1.09 million hectares planted and 3.22 million tons produced (Figure 2.1).

The system used to produce soybean in the 1970s was based exclusively on plowing the soil for planting and weed control. The crop was also rotated with perennial pasture species with four- five year cycles and in that way the effect of the tilling of the soil and soil degradation were reduced (Rovea 2012). In 1970, the average yield of soybean cultivation for the four countries was 1.15 tons per hectare, 28 per cent below the world average that year of 1.48 tons. In 1980, the area planted in the four countries was 11.3 million hectares (Brazil with 8.77 million and Argentina with 2.03 million), an eightfold increase in the surface area under cultivation. Yields rose by 45 per cent (1.70 tons per hectare), surpassing the world average of 1.60 tons.

Figure 2.1. Expansion of crop area, production, and average yield of soybean cultivation in Argentina, Brazil, Uruguay, and Paraguay between 1970 and 2010



Source: Rovea 2012, based on various sources.

In general terms, between the 1970s and the year 2000 the expansion in the area planted with soybean in the four countries was due to other crops (e.g., wheat, maize, sunflower seed) being replaced. In Argentina, Paraguay, and Uruguay, soybean replaced pastureland, as a result of which rotation of the crop with livestock farming was reduced. The area under cultivation increased significantly with the clearing of wild lands, mainly in Brazil and Argentina, and, to a lesser extent, in Paraguay (Rovea 2012).

As a result, the areas in which soybean is now currently produced are as follows (Rovea 2012): a) in Argentina, in the center of the country, between the central and southern regions of the province of Santa Fe, in the southeast of the province of Cordoba, and in the north of the province of Buenos Aires; b) in Brazil, in the states of Rio Grande do Sul and Santa Catarina, and in the south of the state of Paraná; c) in Paraguay, on the eastern border of the Paraná river, in the departments of Canindeyu, Alto Paraná and Itapu; and d) in Uruguay, on the western bank of the Uruguay river, in the departments of Paysandi, Rio Negro, Soriano and Colonia.

Although the development of soybean cultivation has varied in the four countries in terms of the timescale, size of production and performance, the increases in crop area and production experienced during the second half of the 1970s and the early years of the 1980s were achieved mainly thanks to the introduction of mechanized agriculture, which became more intensive with the installation of factories for tractors, combine harvesters and agricultural implements. This mechanization became more specialized with the design and development of machinery with more working width, such as seed drills, which were far more effective in terms of the planting of seeds and distribution of fertilizers. The use of fertilizers thereby became more efficient and less operating time was required (Rovea 2012).

The 1980s saw the incipient use of pre-sowing and post-emergent herbicides that effectively controlled Gramineae and broadleaf weeds. During that decade, glyphosate was commercialized.

Mechanization and chemical control during the 1980s gave rise to the first experiences with the double cropping of wheat and soybean. This was possible because wheat is a winter crop and soybean, a summer crop, was sown at the end of harvesting (second-crop soybean or soybean II). By the end of the 1980s, the direct seeding technique of double cropping soybean and wheat had become widespread, and in 1990 the area sown with soybean in the four countries was 17.38 million hectares, or 30 per cent of the total cultivated area worldwide, with yields of 1.87 tons per hectare, which is very close to the world average yield of 1.90 tons per hectare.

While the indicators for the 1980s highlight the importance of soybean in terms of increases in cultivated area, production and yield, increased soybean cultivation in each country was accompanied by accelerated processes of physical and chemical soil degradation. As a result, at the end of the 1980s and the beginning of the 1990s, the countries started to adopt and implement technologies to reverse the process. Subsequently, the practice of direct seeding became common in the four countries (Diaz-Rosell 2001, Ekboir 2001) and the use of terraces became widespread in Brazil and Paraguay, mainly to offset water erosion, and certainly proved to be the solution to the problem (Rovea 2012). The importance of the national agricultural research institutions in each country in developing and adapting this technology is worth noting (Ekboir 2001, Rovea 2012): in Argentina, the *Instituto Nacional de Tecnología Agropecuaria* – INTA; in Brazil, the *Empresa Brasileira de Pesquisa Agropecuária* – EMBRAPA; *in Paraguay,* the *Instituto Paraguayo de Tecnología Agropecuaria* – IPTA; and in Uruguay, the *Instituto Nacional de Investigación Agropecuaria* – INTA.

During the 1990s, the technological advances associated with soybean cultivation were more significant in the four countries. In Argentina, the direct seeding of first-crop soybean (soybean I) and the sowing of wheat/soybean II were consolidated, and in Brazil, the sowing of second-crop maize (maize II or safrinha) was implemented. It also became necessary to modify the machinery, which made it possible to consolidate companies (especially in Argentina) dedicated to supplying specialized equipment (Del Río 2012, Rovea 2012). Pre-emergent herbicides and new insecticides for controlling weeds and soybean insects also appeared on the scene.

From the end of the 1980s until the mid-1990s, significant advances were made in plant breeding due to the generation of soybean varieties that would become the maturity groups, and the incorporation of the indeterminate growth habit (Figure 2.2). These were characterized by the production of nodes on the main stem after flowering starts and consequently the height can be considerably greater than that of determinate cultivars that have the same duration of cycle and flowering date (Giorda and Baigorri 1997, Rovea 2012).

Figure 2.2. Distribution of soybean maturity groups for the Southern Cone

Source: Rovea 2012.

While the technological advances in plant breeding, mechanization, direct seeding and chemical control were taking place and farmers were making routine use of them in an effort to be more productive and efficient, in March 1996, the Secretariat of Agriculture, Fisheries and Food of Argentina issued resolution No. 167[1] authorizing the Nidera S.A. company to produce and market the seeds, products and byproducts of GM-HR transgenic soybean. This is how Argentina sowed the first variety of genetically modified glyphosate-resistant (GM-GR) soybean in the 1996-1997 crop year, ushering in the increased utilization

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[1] http://www.minagri.gob.ar/site/agricultura/biotecnologia/55-OGM_COMERCIALES/_archivos/res.167-1.pdf?HPSESSID=854ffccf50d778158b369e48a6bc31e9.

of seeds that made use of a previously developed technology package with which farmers were familiar.

After GM-GR soybean was released in Argentina, the seed entered Brazil (Rio Grande do Sul) and Paraguay (department of Itapuá). In Brazil, the request to introduce GM-GR soybean was submitted by Monsanto in 1998. Through process No. 01200.002402/98-60, the *Comisión Técnica Nacional de Bioseguridad* (CTNBio) approved its introduction for commercial use in 2005. In Paraguay, Monsanto submitted the request for its release in 2001 and the Comisión de Bioseguridad Agropecuaria y Forestal (COMBIO) approved its commercial release in 2004 (Resolution MAG 1691/2004). In Uruguay, Monsanto submitted the request in 1996 and its commercial release was approved the same year (Decree No. 249/000 of October 2, 1996).

In Argentina, Brazil and Paraguay, use of GM-GR soybean and its respective technology package spread rapidly because management of the crop was simplified, weed control was more efficient, and average production costs were reduced by USD15-30 per hectare in each of the three countries (Table 2.2, Del Río 2012, Rovea 2012). The main advantage, however, was not the cost, but rather the efficient eradication of weeds. In Brazil, Paraguay and Argentina, the priority was resistance to herbicides rather than production potential. Only those producers who had fine-tuned the technology gave priority to yield (Rovea 2012).

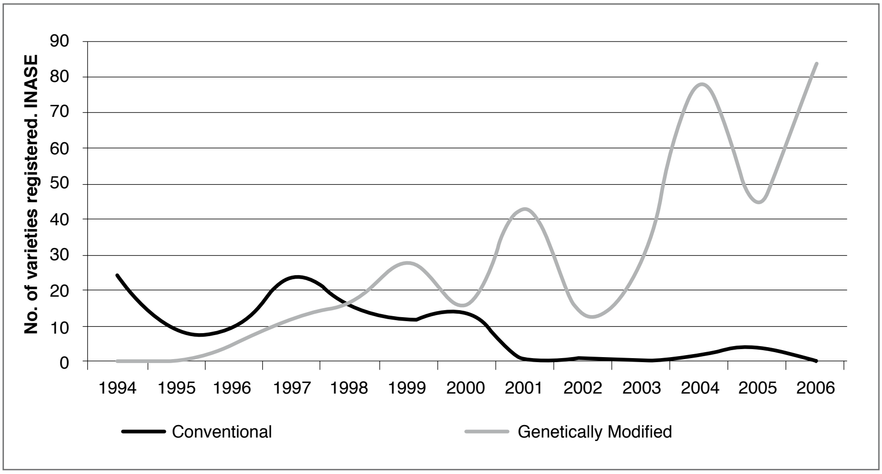
Table 2.1. Comparison of the costs* of the cultivation of GM-GR and conventional soybean in 1999

Item	Conventional soybean	GM-GR Soybean	Difference
Inputs	117.47	92.36	25.12
Labor	68.00	65.00	3.00
Total	185.47	157.36	28.12

*In USD per hectare
Source: Del Río 2012 and Rovea 2012.

As a result of the technological advances made in the 1990s, soybean cultivation grew in Argentina, Brazil, Paraguay and Uruguay, and during the 2000s, use of GM-GR seed overtook that of conventional soybean (Figure 2.3). The statistics for the year 2000 in the four countries were 23.46 million hectares and an average yield of 2.38 tons per hectare, thereby outpacing world productivity (2.17 tons per hectare) by nearly 10 per cent.

Figure 2.3. Record of conventional soybean varieties and GM soybean for the period 1994-2006 in Argentina



Source: Rovea 2012.

Experiments in fertilization with nitrogen, phosphorus, potassium and sulfur were carried out in an effort to increase productivity (*Red de Nutrición Región Sur de Santa Fe*, INTA, Casilda). Sowing dates and cultivation density were also modified to improve potential yield, with experimental figures reaching up to five tons per hectare (Hector Baigorri, personal communication, INTA-*Estación Experimental Agropecuaria Marcos Juárez*, mentioned by Rovea 2012). During the same decade, efforts were also initiated to improve areas under production based on measurements of the phreatic level to determine the effects on productivity. The use of yield maps was also introduced as a tool for detecting production problems and as a system to support decision-making (Manfredi, mentioned by Rovea 2012).

As a result of the increase in production and as part of the technology package, the use of silo bags was introduced. This is a simple, low-cost system under which dry grains are stored in a modified atmosphere (with a low oxygen level and a high concentration of CO_2) for storage on site. The result was highly positive in terms of functional operation and there was no risk as far as quality was concerned (Figure 2.4; Faroni *et al.* 2009). The use of silo bags triggered a highly significant change in the soybean storage and marketing system (Rovea 2012).

In the early 2000s, both GM-GR and conventional soybean cultivation were affected by Asian soybean rust (Formento 2004), a disease caused by the fungus *Phakopsora pachyrhizi* Sydow & Sydow, which reduced yields by 20-70 per cent. This problem has not been eliminated and, to date, the methods of tackling the disease are monitoring for early detection and chemical control (Quintana and Sasobsky 2006, USDA and CSREES 2012).

Since the conditions are conducive to rust development, Brazil and Paraguay are the countries that have been most affected by the disease. In Argentina, the effects have been less severe because of the prompt training of national technicians in early detection, plus the fact that the rust cannot find a host during the winter. However, this problem has increased production costs in Brazil and Paraguay, from USD50 to USD75 per hectare, as a result of two to three applications of pesticide during the cultivation cycle, and by USD25 per hectare in Argentina (Del Río 2012, Rovea 2012).

Many studies have been conducted on the effects of soybean fungicides. For example, thresholds have been determined for each type of disease, as well as the phenological stages, to obtain high levels of production and seed quality (Giorda and Baigorri 1997, Kantolic and Carmona 2006). In addition, traditional plant breeding has focused on identifying sources of resistance (Rovea 2012).

Figure 2.4. Silo bag system: (A) building of the silo, (B) silo bag completed and (C) extraction of the grain from the silo

Source: Rovea 2012.

The 2000s, especially after the 2002-2003 crop year, were very important for the growth of soybean cultivation in Uruguay, as a result of the participation of Argentine producers who transferred their production technology. GM-GR varieties belonging to groups V, VI and VII were introduced from Argentina (Rovea 2012). Soybean cultivation grew rapidly in Uruguay in traditional crop-growing areas as well as in areas used for livestock farming.

In 2010, Argentina, Brazil, Paraguay and Uruguay sowed soybean on around 44.96 million hectares (43.91 per cent of the world total), and produced 130.47 million tons (49.88 per cent of world production), with an average yield of 2.9 tons per hectare. This represented an increase of 11.7 per cent in relation to the global yield for that year, and a 252 per cent increase over the average yield of the four countries reported for 1970. It bears noting that Brazil had the largest yields in 2010 (2.94 tons per hectare), followed by Argentina (2.91 tons per hectare), Paraguay (2.79 tons per hectare) and Uruguay (2.1 tons per hectare). It should further be noted that 87.5 per cent of the seeds were GM-GR soybean (James 2011), which means that both conventional and transgenic soybean varieties were grown.

It is expected that, from the 2012 crop year onwards, new GM soybean events will be introduced in the countries, since in 2011 Argentina approved the sale and distribution of the Bayer's Liberty link soybean. In Paraguay also, mention has been made of the possible introduction of the Intacta RR2 soybean, which is resistant to lepidopterous insects and to the new generation of the Roundup herbicide (González 2012).

Although there are no official statistics on the area planted with conventional soybean, based on Rovea's field work (2012) it is estimated that the figure for Brazil in 2011-2012 was 15 per cent (Celeres 2011). In Argentina, the figure was two per cent, while in Paraguay it was one per cent (Rovea 2012, Del Río 2012). In Uruguay, all of the soybean sown is GM-GR.

Chapter 3

Technology package for soybean cultivation

In 1996, indeterminate growth material and the GM-GR soybean were introduced, which, along with direct seeding, make up the technology package that has been adopted on the widest scale in the history of soybean cultivation. Below is a description of the components of the technology package that is now applied for the cultivation of soybean.

3.1. Direct seeding

Soil tillage makes it possible to achieve a substantial increase in production mainly in the short term because it: (i) reduces density and resistance to penetration of the topsoil; (ii) oxygenates the soil, which increases the oxidation of the organic matter and releases a large amount of nutrients, including CO_2 into the atmosphere; and, (iii) eliminates weeds efficiently, even though it is costly (Ramírez *et al.* 2006). On the other hand, successive plowing reduces the organic matter content considerably and is accompanied by a decrease in the structural stability of the soil (Martino 2001b), which reduces permeability, makes the exchange of gases difficult and increases soil erosion. Therefore, excessive tilling of the soil causes loss of its fertility and, as a result, low productivity.

Direct seeding (also known as no-till or conservation tillage) emerged as an alternative for reducing the negative impacts of plowing the soil as well as encouraging soil conservation. Conservation tillage is the practice of cultivating the land without previous plowing. With this, the surface of the soil is kept permanently covered (with residues from the previous harvest) and there is no significant disturbance of the soil (no plowing or breaking). Instead, a small furrow is made to deposit the seed at a specific depth (Díaz-Rosello 2001, Dabala 2009, Aapresid 2012).

Numerous studies have demonstrated that direct seeding helps to maintain the soil's physical structure (Martino 2001b, Ferras *et al.* 2007), chemical conditions (Bordoli 2001, García, and Fabrizzi 2001), biological conditions (Fontanetto and Keller 2001, Moron 2001, Calegari 2001, Filho *et al.* 2001) and moisture conditions (Aapresid 2012, Micucci and Taboada, no date). It also increases the efficacy of the use of nutrients; offsets erosion (Marelli 2001) and eventually regenerates the soil (Ramírez *et al.* 2006). However, it is a technique that calls for the use of chemical herbicides (Papa 2010) and the application of fertilizers, particularly nitrogen, phosphorus, potassium, and sulfur (Bordoli 2001). Even though it requires the use of herbicides and fertilizers, direct seeding is considered a more environmentally friendly technique than conventional tillage (Calegari 2001, Ramírez *et al.* 2006, Aapresid 2012), since the cost/benefit ratio for the environment (Foloni 2001, Moron 2001, Martino 2001a) and for the producer (Del Río 2012) is positive, which explains its rapid growth and implementation of the technology package in the countries that are the subject of this study (Rovea 2012).

The intensification of conventional soybean cultivation in each country triggered physical and chemical soil degradation processes (Rovea 2012). Argentina has been affected by water and wind erosion, while water erosion has been the chief problem in Paraguay and Brazil, due to significant annual precipitation and soil type and slope. In Uruguay, water erosion is significant, though not as marked, because crops are rotated with livestock. Direct seeding has been supported and promoted in the four countries as an innovative and efficient production practice that reduces agriculture's impact on the soil (Bragagnolo 1995, Ekboir 2001, Dabala 2009).

Plant nutrition

Because it is a legume, soybean obtains a great deal of the nitrogen it needs (30-60 per cent) through biological fixation, which is done by nitrifying bacteria that live in the roots of the plant. This means that dependence on the soil's nitrogen content is minimal, which is a competitive advantage vis-à-vis other crops (*e.g.*, grasses such as maize and wheat) and the reduction of greenhouse gas (GHG) emissions – in particular, nitrous oxide (N_2O).

The efficiency of biological nitrogen fixation (BNF) in soybean, in terms of higher yields and protection of the environment, has been amply demonstrated (García and Fabrizzi 2001, Calegri 2001, Martino 2001 b, Filho *et al.* 2001), and has led to the creation and consolidation of bio-input industries in countries like Argentina, Brazil and Paraguay (CIAFA 2012, Engormix 2012). Particularly strong has been the development of bioinoculants, mixtures of bacteria that induce molecular signals that activate or accelerate metabolic processes in plants and bacteria, and promote greater BNF capacity.

With regard to chemical nutrition and other essential elements like phosphorus, soybean has the lowest threshold. When soybean was first cultivated, fertilizers were not used. However, experimental evidence concluded that fertilization with nitrogen, phosphorus, and sulfur increased yields of the crop and of the previous wheat and maize crops (García *et al.* 2006, Rovea 2012).

In Argentina, the process of soil degradation had become more acute in the 1990s, and water erosion became a problem in many areas. To tackle the depletion of chemicals in the soil, INTA-led efforts to adapt direct seeding and, subsequently, fertilization were implemented. The initial efforts related to fertilization with sulfur in soybean were spearheaded by INTA's staff in the district of Casilda (Fernando Martínez, personal communication in Rovea 2012). As a result, fertilization with phosphorus and sulfur in first-crop soybean (soybean-I) had good results and became widespread in those areas that had a longer agricultural history. Fertilization with phosphorus produced results in the central region (300-400 kg per hectare). In livestock farming areas and in cleared areas, fertilization did not increase yields due to the good natural fertility of the soils.

In Brazil, soils in the Cerrado region are very acid (pH4.0) and contain high levels of aluminum, which is toxic for tall plants. Consequently, grasses and low shrubs are the main types of vegetation. Since they can be cleared quickly, in the 1990s the region witnessed exponential growth in the area sown with soybean (Rovea 2012). However, because of the type of soil involved, large investments were needed to correct the soil, since crops could not be established as long as it remained in its natural state. Correcting the soil (then and now) has called for large applications of gypsum (1500-3000 kg of calcium sulfate per hectare) to wash out the aluminum, followed by lime (2000-4000 kg of calcium hydroxide per hectare) to correct the soil pH and raise it to more neutral values (between 6.0 and 6.5). After the soil has been corrected, it is fertilized with phosphorus (calcium triple phosphate source) and potassium (potassium chloride source); otherwise, the crop does not do well because the soils are chemically poor (Rovea 2012).

In Paraguay, agricultural growth was experienced on the eastern side of the country, some 100 km from the Paraná River towards the west, the area that has the best soil quality, with annual precipitation of 1600-2400 mm. The original soil is acid, so lime had to be applied (2000-3000 kg per hectare of calcium hydroxide) to correct the acidity and allow for development of the crops. Given the type of soil involved, fertilizers containing phosphorus and potassium were applied in Uruguay.

Given this scenario, chemical fertilization is clearly a key component of both conventional and transgenic soybean production systems. In his field studies, Rovea (2012) found a negative nutrient balance in a large proportion of the areas dedicated to soybean cultivation, because nutrient depletion is one of the effects of high yields and nutrient replacement is low (Rovea 2012).

A lot of research is now being carried out to explain the physiological and molecular mechanisms of plant nutrition, with a view to improving nitrogen fixation and transferring the characteristic to species that do not naturally possess the mechanism. On the other hand, the review of the literature found no reports of any differences between the fertilization systems or the behavior of GM-GR soybean and conventional soybean.

3.2. Herbicides

Another component that is essential for the efficiency of the direct seeding system in soybean is weed control with chemical herbicides.

Glyphosate (N-phosphonomethyl glycine, $C_3H_8NO_5P$) is one of the herbicides used most frequently in soybean cultivation at present. This molecule, developed in the 1970s and patented by Monsanto in 1980 (United States patent no. 4 226 611) interferes with the capacity to produce aromatic amino acids (essence of their biocidal activity). Consequently, this compound, which is absorbed through the leaves, acts as a broad-spectrum herbicide. A detailed list of the weeds that appear with soybean crops and that can be eradicated with glyphosate may be found in Dellaferra *et al.* (2007) and Papa (2010).

Another compound used successfully as a herbicide is glufosinate or its ammonium salt DL-phosphinothricin (2-amino-4-(hydroxymethylposphinyl)butanoic acid $C_5H_{12}NO_4P$), a compound developed in 1972 (Bayer *et al.* 1972, United States patent number 3 682 617). Plants treated with glufosinate die because this compound occupies the active site of the glutamate, which means that the glutamine is not synthesized, photosynthesis is interrupted, and ammonium accumulates (Benítez and Benítez 2011).

Glyphosate resistance (Roundup®, Buccaneer®, Cropsmart®, Prokoz®, etc.; Schuette 1998) is the basis for the development of GM-GR soybean, used predominantly in the countries of the Southern Cone. Its use has expanded, however, with the generation of GM glufosinate- ammonium-tolerant soybean (Basta®, Finale®, Rely®, Ignite®, Challenge®, Liberty®, etc.) for used in the 2012 crop year in Argentina. The use of these compounds has increased year on year (ECPA 2010) proportionally to the increase in the areas planted with GM herbicide-resistant crops, which has been the predominant transgenic event up to now (James 2011). In addition, glyphosate and glufosinate-ammonium are so efficient that they are routinely used in non-transgenic soybean crops and other species (ECPA 2010). Similarly, because the glyphosate patent expired in 2000 in Argentina, Brazil, Paraguay, and some other countries, industries have been developed to synthesize this compound (CIAFA 2012), which has lowered the cost (Chapter 6).

Glyphosate and glufosinate-ammonium are molecules synthesized to eradicate weeds (Gazziero *et al.* 2001, Snoo *et al.* 2001 and 2005, ILSI Research Foundation 2011) that have been classified by the United States Environmental Protection Agency (EPA) under toxicity groups III and II, respectively (EPA 1993a and 1993b). This means they are considered low toxicity herbicides as compared with other compounds. It should be noted that some experimental reports have been presented on these herbicides and on glyphosate, specifically, that mention negative effects of this molecule on animal health (Benachour and Gilles 2008).

Biosafety evaluations of GM herbicide-resistant soybean crops have shown that when used carefully (in terms of means of application, dosage and frequency), these herbicides are effective in destroying weeds in a short amount of time (less than ten days) and do not have negative effects on plant communities or on the environment in the medium or long term (Snoo *et al.* 2001 and 2005, ILSI Research Foundation 2011).

The characteristics of these two herbicides are an example of the cost-benefit equation with regard to soybean cultivation. Their use makes direct seeding efficient, which contributes to crop management and lowers energy costs and GHG emissions. The use of other, more toxic agrochemicals increases the work of plowing and the discharge of more potent biocides, with increased negative consequences for the environment, human health and the economy of the crop.

3.3. Genetically modified soybean seed (GM-GR)

Transgenesis is a process whereby genes from one species are introduced into another species (Villalobos 2011). Genetic engineering was first applied to the soybean for commercial purposes to develop tolerance to glyphosate (Shah *et al.* 1990) and, subsequently, tolerance to glufosinate-ammonium (Donn 1998). An overview of the transgenic events associated with these two herbicides is given below.

Glyphosate is degraded by the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS). The coding gene for this enzyme was isolated from the bacteria Agrobacterium CP4 (CP4 EPSPS) and used in genetic engineering experiments to build a plasmid construction which contained other genetic elements, including transcription initiation and termination sequences (signals). These sequences came from a DNA fragment (sequence 355) of a virus (Cauliflower Mosaic Virus – CaMV). It should be noted that although the construction used to generate GM-HR soybean came from a bacteria (*Agrobacterium tumefaciens*) and a virus (CaMV), at no point can it be said that technically or operationally, the bacteria or the virus from which the sequences came were introduced in the soybean plant.

A mechanism was also needed to identify the transgenic plants. As a result, simultaneously with the EPSPS gene, a gene was introduced that codes for the phosphinothricin transferase enzyme, which degraded the kanamycin antibiotic (a gene known as the selection marker gene). As in the previous clarification, it should be noted that soybean plants resulting from the transformation with the selection marker gene do not produce antibiotics.

The introduction of EPSPS and selection marker genes into the soybean plant was initially carried out through A. tumefaciens (Shah *et al.* 1990), a bacterium that is naturally capable of making this type of transfer of genetic material (Villalobos 2011). The biolistic transformation of the soybean was also effected by accelerating and introducing micro-particles coated with the plasmid that contained the genes of interest (Christou *et al.* 1991). At present, however, GM soybean materials are predominantly transformed using Agrobacterium.

The first GM-GR soybean plants that were cultivated produced seeds that generated glyphosate-resistant plants when they were subsequently incorporated into the crop. The glyphosate was metabolized while it acted on the surrounding weeds. The transgenic soybean seed, along with the use of glyphosate, were patented in 1990 (Shah *et al.* 1990) and released commercially in 1996, after a process of evaluation that led to their deregulation in the United States, followed by other countries (CAS and IICA 2010, UN 2012), after careful technical analyses. Argentina (1996), Uruguay (1996), Paraguay (2004), and Brazil (2005) are cases in point. In these countries, the national technical biosafety committees (CTNBio) conducted the process of analysis and contributed technical arguments that led the competent national authority in each country to issue official resolutions authorizing the marketing of GM-GR soybean.

The characteristic of herbicide resistance is subject to continual improvement. A case in point is the generation of GM glufosinate-ammonium resistant soybean (Donn 1998) in response to the Monsanto glyphosate-based system. Transgenic soybean plants that are resistant to glufosinate-ammonium (known as Liberty Link® technology) express the *bar* or *pat* gene, which codes for the phosphinothricin-N-acetyltransferase (PAT) and was isolated from two types of bacteria (*Streptomyces viridochromogenes* (pat gene) and *Streptomyces hygroscopicus* (*bar gene*). GM soybean sown commercially has been entirely resistant to glyphosate in the Southern Cone countries. However, in August 2011, Argentina announced the commercial approval of Liberty Link®, Bayer's soybean. It should be noted that all simple events that are to be commercialized in the countries are analyzed by the national technical biosafety committees independently of other events (case by case evaluation) (CAS and IICA 2010, UN 2012). However, there is still some discussion of the events that involve stacked genes, that is, plants that include several characteristics simultaneously, *e.g.*, resistance to herbicides and resistance to insects (Bt technology).

It is important to generate new events that improve the performance of a particular characteristic. However, creating a new event or a new GM crop and introducing it to the market is costly in terms of time and money. For example, for the specific case of soybean 16.3 years and approximately USD136 million are required (McDougall 2011) to discover, develop, and authorize a new characteristic. These estimates are based on commercialized events for each of the six multinationals that are leaders in genetic engineering technology (McDougall 2011) between 2008 and 2012.

The GM-HR soybean is different from its conventional (non-transgenic) equivalent only insofar as the gene that confers degradation of the herbicide is concerned. Consequently, if a soybean crop has been established with GM-HR seeds, grows alongside one derived from conventional seed, and is not treated with herbicide, the two crops would behave identically and would certainly be affected by the presence of weeds and other adverse factors. However, if the same dose of glyphosate is applied twice to the two crops, the weeds would be reduced significantly, the conventional crop would survive, and it would eventually become necessary to reduce the dose and increase the applications (Manning *et al.* 2003, Rovea 2012, Del Río 2012). The crop derived from transgenic seeds, on the other hand, would achieve optimum performance because the herbicide would have no negative effect. It should likewise be noted that the GM-HR soybean crop would behave like its conventional equivalent, for example, in the face of a severe drought or disease (*e.g.* Asian rust). It should also be borne in mind that for the development of a GM seed, the plant breeder remains indispensable, since the principles of genetics continue to apply for both the GM and the conventional crop. Likewise, the services of an agronomist are essential for the proper management of both types of crops (Villalobos 2011).

3.3.1. Selectable marker genes based on antibiotics

It has frequently been mentioned that there is a hypothetical scenario related to GM plants that contain certain antibiotic-resistant selectable marker genes, and that those genes could be taken up naturally by bacteria in the digestive tract and, as a result, it could be difficult to treat a possible bacterial infection because of resistance to the known antibiotics. Numerous scientific studies have demonstrated so far that there is no real evidence that genes that confer resistance to antibiotics in GM plants are a threat. According to GMO Compass (2006), some of the reasons that support that assertion are as follows:

1. The probability of a successful transfer of an antibiotic resistance gene to a bacterium is very low. Estimates from laboratory experiments place the probability at anywhere from 1 in 10^{10} to 1 in10^{24}.

2. Resistance genes for the antibiotics kanamycin and ampicillin, the most commonly used marker genes, are already widespread in organisms that cause diseases. For example, laboratory tests on people not taking antibiotics showed that in 60 per cent of cases, more than 10 per cent of bacteria had resistance to at least one type of antibiotic. Soil tests confirmed that antibiotic resistant bacteria, particularly kanamycin resistant bacteria, are widespread in nature.

3. Kanamycin is now rarely prescribed in human medicine. Ampicillin is still used to treat certain infections, but since resistance is so widespread, treatment is usually

combined with substances (*e.g.*, beta-lactamase inhibitors), which take away the effect of the resistance genes.

4. Whenever we eat fruits and vegetables, we are eating antibiotic resistant microorganisms from the soil. This has no known negative effects.

On the same subject, in 2004, a committee of experts from the European Food Safety Authority (EFSA) presented a technical study that concluded that a general prohibition on the use of antibiotic resistance marker genes was not justified. However, after considering certain assessment criteria with respect to those genes, including the medical importance of antibiotics and the distribution of micro-organisms that already naturally possess resistant genes, the EFSA suggested that antibiotic-resistant genes be classified into three groups: the first consists those antibiotic-resistant genes that can be used unrestrictedly in the generation of GM plants, *e.g.*, kanamycin; the second group comprises those genes that should not be used in the generation of GM plants because they confer resistance to antibiotics used in veterinary or human medicine for the treatment of specific infections (resistance to ampicillin falls into this group); and the third group includes marker genes whose use is not permitted for any reason, because they confer resistance to antibiotics that are highly specific and efficient, particularly in human medicine and, therefore, their effectiveness should not be made uncertain (*e.g. nptIII*-type genes that confer resistance to amikacin) (EFSA 2004).

3.3.2. Transgenic drought-tolerant soybean

The first generation of transgenic events in soybean has focused on facilitating the agronomic management of the crop. However, the drought conditions and high temperatures recorded over the past several years, which became more acute in the most recent crop year in certain regions of the globe (Sternberg 2011), including the soybean-producing regions of Argentina, the south of Brazil, Paraguay, and Uruguay (Agrodigital 2012), justify the incorporation of GM drought-tolerant soybean. Following is a brief technical description of the genetic basis of this characteristic and certain advances made on the topic. Discussion of the impact of GM drought-tolerant soybean is presented in greater detail in sections 5.4 and 7.

In agriculture, tolerance to drought or water stress means the ability of a plant or crop to produce an economic product with minimum loss in an environment where insufficient water is available. It is also a complex characteristic that, according to some estimates, involves at least 60 genes (ACB 2007), whose expression depends on the action and interaction of various characteristics, *e.g.*: morphological features (precocity, reduced foliar area, curling of the leaf blade, wax content, awns, root system, reduced tillering, stability in production); physiological factors (reduced transpiration, high efficiency in water use, stomatal closure and osmotic adjustment); and biochemical aspects (accumulation of proline, polyamines, trehalose, etc., increases in nitrate reductase and in the storing of carbohydrates) (Mitra 2001).

Although there are reports of the conventional generation of new materials from different drought-tolerant species (sorghum and cotton, Rosenow *et al.* 1983; cassava, El-Sharkawy 1993), the reality is that traditional improvement has not made significant strides in releasing commercial crop varieties, especially soybean (Goldman *et al.* 1989), Sloane *et al.* 1990, Oya *et al.* 2004) that are highly drought tolerant. The complex nature of drought tolerance limits management using conventional plant breeding methods (Mitra 2001). However, thanks to biotechnology, hundreds of water stress induced genes have been identified and genetic engineering has been used to introduce them into other plants, mainly in model species (tobacco and Arabidopsis), but in some cases they have been tested in species of commercial interest, like soybean, wheat and maize.

Recently, transgenic plants have been generated that express characteristics of various types of structural and regulatory genes that are related to water stress and that come from various organisms (Manavalan *et al.* 2009). Examples of structural genes are those involved in the bio-synthesis of proline (*P5CS* gene, which codes for pyrroline-5-carboxylate synthetase; Kavi Kishor *et al.* 1995), glycine betaine (*betA* and *betB* genes for choline dehydrogenase and betaine aldehyde dehydrogenase), fructan (*SacB* gene for levansucrase), mannitol inositol (*MT1* gene for myo-inositol O-methyltransferase, Sheveleva *et al.* 1997), trehalose (*TPS*1 gene for trehalose-6-phosphate synthetase; Holmstrom *et al.* 1996, Romero *et al.* 1997), etc. Within the regulatory genes associated with water stress, there are zinc finger proteins, NAC transcription factors, and DREB factors (Dehydration-Responsive Element Binding).

Results of experiments in genetic soybean transformation with DREB genes from Arabidopsis thaliana have been published (Anderson 2010). The resulting plants lost less foliage and resisted drought conditions created in the laboratory for 15-30 days more than their non-transgenic equivalents.

In 2010, the patent was reported (Chan *et al.* 2010) for the generation of drought-tolerant transgenic soybean through the introduction of a modified version of the *HAHB4* gene, a sunflower (*Helianthus annuus*) transcription factor, which triggers a domino-type global response to various conditions of environmental stress, such as water and salt stress and the attack of herbivorous insects. The GM soybean plants obtained by inserting the gene in question showed salt tolerance and an increase in productivity (of more than ten per cent) under moderate drought conditions (Chan *et al.* 2010). Thus, with a significant technological breakthrough Argentina has become an innovator with regard to transgenic soybean seed, and not just an importer, even though the modified seed is not yet being marketed with this event.

On the other hand, Pei *et al.* (1998) demonstrated that in *Arabidopsis thaliana* the loss of the function of the beta subunit (ERA1) of the farnesyltransferase (FT) enzyme resulted in a phenotype hypersensitive to abscisic acid (ABA) and, consequently, the plants tolerated drought. In this way, the alpha or beta subunit of the FT was manipulated to alter the expression and activity of the FT enzyme, and the gene was used to effect a genetic transformation of several species, including soybean, maize, and brassica (Huang *et al.* 2010). Maize MON-87460 was generated based on this principle; it has been deregulated by APHIS (APHIS 2011) and is expected to be used commercially in the United States for the

2012-2013 crop year. Thus, it seems that it is only a matter of time and a formality before drought-tolerant soybean becomes commercially available.

Although mention has been made of several of the mechanisms that have been studied for their ability to adapt crops to water stress, including some already patented to generate GM drought-tolerant soybean plants (Huang *et al.* 2010), the complex nature of the characteristic means that the options for obtaining new commercial soybean materials will be many and varied (Manavalan *et al.* 2009). More research on different aspects will be needed, such as (i) implementation of marker-assisted selection programs for the identification and selection of drought-tolerant soybean materials; (ii) bio-prospection of biological diversity focused on this characteristic; and, (iii) identification, isolation and characterization of multiple genes simultaneously, for example, through the use of sequencing, functional genomics and bioinformatics (IICA and PROCISUR 2010) in order to be able to incorporate them into crops using traditional plant breeding techniques or transgenesis. The decision as to the technological route to be taken depends, in the final analysis, on the drought, since the more severe it is (in time and intensity), the greater the pressure to make recourse to quick, effective options. Accordingly, biotechnology in general, and transgenesis in particular, will become indispensable tools for meeting the need to generate varieties of drought-tolerant soybean.

Chapter 4

Importance of regulation for GM soybean

So far, this study has presented analytical data that support the view that the use of GM-GR soybean generates benefits where production is concerned. For this to have been possible, however, regulatory biosafety frameworks were required to safeguard human health, the environment and biodiversity, while not standing in the way of trade (CAS and IICA 2010). Following is a summary of the regulatory frameworks of the four countries discussed in this study. It is based on the document entitled Regulatory Biosafety Frameworks and Situation of Commercial Approvals of Genetically Modified Organisms in the countries that are members of the Consejo Agropecuario del Sur-CAS (Southern Agricultural Council) (CAS and IICA 2010).

Argentina, Brazil, Paraguay, and Uruguay are all members of the CAS, along with Bolivia and Chile. The CAS countries face the challenge of contributing significantly to regional and global food production. Over the last 16 years, GM crops have become a key tool for achieving that objective.

Argentina, Brazil, Bolivia, Paraguay, and Uruguay allow the planting and cultivation of GM soybean; in other words, farmers are authorized to market it, which means that the sowing, processing, and human and animal consumption of the crop are permitted. To reach this stage, they had to devise and implement clear legal and institutional frameworks. The regulatory frameworks in Argentina, Brazil, Paraguay, and Uruguay are designed to ensure that GMOs released into the environment, either for commercial planting, human or animal nutrition, seed production or research are safe for the ecosystem and for human and animal consumption. The policies in Argentina, Brazil, and Uruguay also provide for studies to be conducted on the advisability of making certain GMOs commercially available (CAS and IICA 2010).

Although the policies governing the authorization of the marketing of GMOs vary from country to country, it is clear that the scale and productivity of soybean cultivation has grown so significantly in the four countries thanks to their efforts to develop and maintain their CTNBio (Table 4.1). It is equally clear that GM soybean cultivation in each country has been subject to rigorous analysis (UN 2012).

To generate a transgenic crop, the genes of interest and the transformation and regeneration system are required. Once the plants are obtained, it is essential to conduct molecular tests to detect the presence and expression of the transgenes introduced. Before they can be marketed, GM plants must undergo rigorous biosafety tests to analyze numerous parameters and thus guarantee that they present no risk to human health or the environment, among many other aspects. After the tests have been completed, a file is prepared and submitted to the respective CTNBio so the commission's experts can conduct risk assessments, produce impact estimates, and give a technical opinion as to the desirability of authorizing the commercial release of a GM event or crop. Once the product reaches the farm, the crop is planted and grown using the technology package that comes with the seed. There is no question that GM-HR soybean makes management easier, but the crop still requires careful attention.

Table 4.1. Regulatory framework governing GM soybean cultivation in the four countries analyzed in this study

Country	Argentina	Brazil	Paraguay	Uruguay
A. GMO policy framework				
Specific biosafety law		X		
Specific standards for GMOs for agricultural use	X		X	X
Institutional framework	X	X	X	X
UPOV Convention (1978 Act)	Approved	Approved	Approved	Approved
Cartagena Protocol	Signed	Ratified	Ratified	Ratified
B. Characteristics of the Biosafety Commission				
Acronym	CONABIA*	CTNBio**	COMBIO***	CAI****
Inter-institutional	X	X	X	X
Public sector	X	X	X	X
Private sector	X			
Researchers	X	X	X	X
Civil society		X		
Multidisciplinary	X	X	X	X
Advisory	X	X	X	X
Consultative	X	X	X	X
Deliberative		X	X	
Institutions involved	17	27	13	9
C. Evaluation criteria used in granting approval to market GMOs				
Possible negative effects for the environment	X	X	X	X
Possibility of negative effects for human health	X	X	X	X
Competence of the applicant	X	X	X	
Biological characteristics of the organism	X	X	X	X
Genetic stability	X	X	X	X
Molecular mechanism through which the phenotype is expressed	X	X	X	X
Sexually compatible species	X	X	X	X

* *Comisión Nacional Asesora de Biotecnología Agropecuaria*
** *Comisión Técnica Nacional de Bioseguridad*
*** *Comisión de Bioseguridad*
**** Institutional Coordination Committee

Source: Based on CAS and IICA 2010.

The Cartagena Protocol on Biosafety (CPB) is a legally binding instrument signed as a supplement to the Convention on Biological Diversity (CBD). Its purpose is to help ensure an adequate level of protection in the field of the safe transfer, handling, and use of living modified organisms (LMOs, a synonym for transgenics) that may have adverse effects on the conservation and sustainable use of biodiversity, focusing specifically on transboundary movements (exports/imports). The protocol entered into force in 2003 and to date has been ratified by 163 countries (UN 2012. http://bch.cbd.int/database/attachment/?id=10694).

Its ultimate objective is to equip the countries to assess the risks and benefits of agro-biotechnologies, in line with their own interests and sovereignty, giving them sufficient flexibility to create the legislation or mechanisms they need to meet their obligations under the protocol. In that sense, implementation of the CBD depends largely on the creation of capabilities in the country concerned and on the regulatory framework.

The rules and instruments provided for in the agreement include the requirement that a risk assessment be carried out prior to the making of decisions on LMOs, the Advance Informed Agreement procedure for the first importation of an LMO, the identification of shipments that contain or may contain LMOs, and the permanent exchange of information and legislation currently in force on LMOs among the competent authorities of the countries through the Biosafety Clearing-House (BCH).

Two of the issues currently being discussed under the CPB warrant special mention. The first concerns the guidelines related to risk analysis procedures, whose purpose is to complement the technical guidelines and criteria approved by the parties to the Protocol, specifically in Annex III. The other point is the discussion of socioeconomic aspects as factors in decision-making related to the authorization of activities involving LMOs.

Another important development was the approval, in October 2010, of the text of the Supplementary Protocol on Liability and Redress for damage resulting from the transboundary movement of LMOs, facilitated by Article 27 of the CPB. This new instrument, which is linked to the first, is designed to establish harmonized standards and procedures on liability and redress for damage resulting from the transboundary movement of LMOs. Basically, it establishes the administrative approach for addressing response measures, guidelines on the criteria to be adopted in each country for civil liability, and the direct recognition of the need for signatories to establish financial security mechanisms. Three countries have ratified this supplementary protocol so far (UN 2012, http://bch.cbd.int/database/attachment/?id=11064).

To date, 163 countries have ratified the CPB, including Brazil and Uruguay, two of the countries considered in this study. The fact that, although the CPB has been in force since September 11, 2003, important issues are still being negotiated is a matter of special concern for the developing countries and exporters, such as those considered in this study.

A number of other concerns exist, such as LLP (low level presence), coexistence and labeling that, depending on their implementation, could have a major impact on trade in commodities (and their byproducts) produced using GM seeds.

Chapter 5

Comparative environmental analysis

Agriculture is an essential activity for food production. It does, however, have a considerable environmental impact, including GHG emissions, deforestation, loss of biodiversity, changes in soil use, high fresh water consumption, and the eutrophication of water sources (Baumert *et al.* 2005).

A recent report from the OECD (2012) states that natural systems have "tipping points" beyond which damage becomes irreversible (for example, species loss, climate change, groundwater depletion, and soil deterioration), and the environmental, social and economic consequences of crossing those thresholds are not fully understood. To reduce those negative impacts as much as possible, agriculture must generate and make use of various technologies to meet the growing demand for food for a burgeoning population (both larger quantities and better quality). Given the importance of soybean for global agriculture, this section offers a brief analysis of the positive and negative impacts of the technology package for both conventional and GM soybean cultivation in the four countries considered in the study.

5.1. Soybean, change in soil use and direct seeding

GM and conventional soybean are monocultures and in order to grow them in Argentina, Brazil, Paraguay, Uruguay, as in other regions of the world, it was necessary to clear wild ecosystems for which, at the time, the population either had no specific use or utilized for other production activities, such as livestock farming. It should be remembered that in the 1980s, environmental services were not taken into account.

A major consequence of the land clearance that took place was a change in soil use, which was not always based on the aptitude of the soil. Under current conditions, a change in soil use must take into account how the land was cleared. If the slash and burn system was used, the environmental deterioration must have been high, given its contribution to GHG emissions. It should be noted that the regulations currently in force in the countries specify the methods that may be used to prepare land for soybean cultivation (Trigo 2011), unlike the situation that prevailed in the 1970s, 1980s and part of the 1990s.

Furthermore, the agricultural practices employed when soybean cultivation on the grasslands first began involved plowing, which had negative consequences for the structure and function of the soils (Ferreras *et al.* 2007). In fact, there are numerous reports and diagnostic studies for almost all the soybean-producing areas of the countries of the region that show, in quantitative terms, the process of degradation that the soils and production environments have suffered and continue to suffer (Ramírez *et al.* 2006). In addition, a considerable amount of CO_2 was produced as a result of the release of carbon stored in the soil (Álvarez 2006) and the fuel expended in associated activities, since it is estimated that the tilling of the soil contributes 5.2 per cent of GHG emissions (Calegari 2001, Baumeri *et al.* 2006). Clearly, if the system of plowing had continued to be used and technological alternatives had not appeared and been introduced, the soils of vast production areas would have been degraded and new areas would have had to be sought and adapted to achieve the area under cultivation that exists today. It would have been difficult to match current yields, of course. However, the soil degradation in certain areas of Argentina, Brazil, Paraguay, and Uruguay has been checked and even reversed as a result of the introduction and widespread use of the technology package described in this document (Aapresid 2012).

It should be noted that in estimating the global net effect of the GHG emissions generated by agricultural intensification between 1961 and 2005, Burney *et al.* (2010) found that while emissions from factors such as fertilizer production and application increased during that period, the net effect of high yields avoided emissions of up to 161 gigatons of carbon (GtC) (590 $GtCO_2e$). The same authors estimated that each USD invested in agricultural yields resulted in 68 fewer kgC (290 $KgCO_2e$, i.e., USD14.74/tC or USD4/tCO_2e), avoiding approximately 3.6 GtC (or 13.1 $GtCO_2e$) per year. Consequently, investment in yield improvements makes a direct contribution to strategies aimed at climate change mitigation.

The accumulation of organic carbon in the soil depends basically on the incorporation of stubble that the gramineae generate (Moron 2001, Álvarez *et al.* 2004). For example, single-crop soybean generates negative carbon balances (Álvarez 2006, Galantini and Suñer 2008), because, like all legumes, it has a low carbon to nitrogen ratio (30C:1N). Therefore, the higher the percentage of high-yield gramineae incorporated into the production system, the larger the carbon balance, since grasses have a ratio of 80C:1N. Thus, the system of soybean rotated with gramineae (maize-II, wheat-II) becomes an efficient system for improving the carbon balance with the planting of soybean (Rovea 2012), which is why crop rotation should be promoted.

There are areas that, because of their soil and climatic characteristics, are suffering the effects of water erosion despite a system of direct seeding being used, because of a failure to rotate soybean with gramineae (Rodolfo Gil, personal communication, mentioned in Rovea 2012).

Although each country is different (Table 5.1), the average ratio of soybean to maize for the region as a whole is 2.56:1, that is, 2.56 hectares of soybean are planted for each hectare of maize. With this ratio, the carbon balance is negative. There are areas where the gap is smaller and the carbon balances are more stable or slightly negative (Álvarez 2006).

Table 5.1. Comparison between countries of the ratio of the area planted with soybean to the area sown with maize, wheat, or wheat and maize

Country	Ratio of area under cultivation		
	Soybean/maize	Soybean/wheat	Soybean/ maize+wheat
Argentina	4.65/1.0	5.55/1.0	2.53/1.0
Brazil	1.81/1.0	10.92/1.0	1.55/1.0
Paraguay	4.74/1.0	4.97/1.0	2.26/1.0
Uruguay	7.81/1.0	1.24/1.0	1.07/1.0
Region	**2.56/1.0**	**6.79/1.0**	**1.86/1.0**

Source: Rovea 2012, based on data from the Ministry of Agriculture, Livestock and Fisheries of Argentina, the Ministry of Livestock, Agriculture and Fisheries of Uruguay, the Ministry of Agriculture and Livestock of Paraguay and the *Companhia Nacional de Abastecimento of Brazil*.

It has been estimated that zero tillage uses 40-45 per cent less energy (fuel) for pre-harvest activities than traditional tillage systems (Aapresid 2012). Therefore, direct seeding is a highly important alternative for intensive soybean cultivation, and an environmentally-friendly practice that contributes to global climate change mitigation by reducing the net GHG emissions released into the atmosphere (Martino 2001a, Álvarez 2006, Burney *et al.* 2010) and conserving the soil's physical characteristics (Martino 2001b).

However, as mentioned earlier, optimum fertilization regimes must be established to prevent impoverishment of the soil due to the intensity of production. The regimes should take into account the sources, dose and frequency of applications of nitrogen, phosphorous and sulfur (section 3.1). In experiments on the effects of fertilization, it has been found that inorganic fertilization (with nitrogen, phosphorus, sulfur, and micronutrients) increases soil fertility and glomalin content, an indicator of the presence of more microbes and microbial activity in the soil (Grumber *et al.* 2012). In addition, microbial communities in soils with balanced fertilization seem to be more active in the use of carbon substrates (Conforto *et al.* 2012). Similarly, studies to evaluate soil microbiota on plots that have been under cultivation for ten years, subjected to different nutrient regimes (witness, P+S, N+S, N+P, N+P+S and N+P+S+micro) and under a crop rotation system of maize-wheat/soybean-II have demonstrated, for example, that populations of Trichoderma increase when soybean is fertilized and combined with another crop in a rotation system (Meriles *et al.* 2009).

Since the era of the Green Revolution, agriculture has tended to use nitrogen-based fertilizers to maximize production by improving the nitrogen content in the soil. The environmental cost is very high, however, as it has been estimated that agriculture contributes close to 80 per cent of the total amount of nitrogen released into the atmosphere in the form of nitrous oxide (Baumert 2005). In addition, industrial nitrogen fixation calls for the use of 50 per cent of the fuel used in the mechanization of agriculture. Moreover, the run-off (or washing) of nutrients that are carried into rivers and seas is responsible for the eutrophication (enrichment of water) of ecosystems. In the face of this situation, soybean cultivation plays a positive role: because it is a legume, it establishes a symbiosis with nitrogen-fixing bacteria, with the consequent reduction in the need to use nitrogen-based fertilizers. Thus, soybean cultivation does more to reduce nitrous oxide emissions into the atmosphere than other crops (Bindraban *et al.* 2009, James 2010).

Apart from the environmental benefit (Foloni 2001, Calegari 2001, García and Fabrizzi 2001), biological nitrogen fixation in soybean has become an attractive business for companies producing bio-inputs (Engormix 2012). That also opens up the possibility of more active use being made of the microorganism collections of the different national institutions (a brief list of institutions may be found on the page of the *Asociación Argentina de Microbiología* -

http://www.aam.org.ar). The market offers strains of *Rhizobium, Bradyrhizobium,* and *Sinorhizobium* whose performance varies in different edaphic environments. In this way, soybean cultivation is becoming a major consumer of bio-inputs, demonstrating the complementarity of clean and chemical technologies for production systems, regardless of whether conventional or transgenic seeds are used (Bindraban *et al.* 2009).

5.2. Monoculture of soybean and its impact on biodiversity

As with any other monoculture (maize, rice, cotton, etc.), soybean cultivation has inevitably altered biodiversity due to the replacement of the (not necessarily wild) flora and fauna that lived there by a single species. Although no studies appear to have been conducted on the scale of the loss of plant and animal species in the ecosystems of the four countries and it is highly likely that no descriptions exist of the possible change in the dynamics of microbial biodiversity, it is safe to infer that, given the environmental conditions (soil, water, climate, solar radiation, etc.), the ecosystems of most of the areas (cerrados, pampas and prairies, mainly) where soybean is currently grown have a relatively low diversity of species, although not necessarily a small number of plants per species (Myers *et al.* 2000).

With regard to the impact of soybean on biodiversity, it has been demonstrated that direct seeding per se has a positive influence on increasing soil biota (Colozzi Filho *et al.* 2001). However, soybean grown from conventional seed requires a considerable range of broad-spectrum biocides (herbicides, fungicides, and insecticides) that can affect not only weeds but also other forms of life, particularly beneficial microorganisms and insects. In addition, these compounds must be applied regularly and in specific doses established through prior tests, but not necessarily by the producers following technical recommendations.

A conventional soybean crop may require between eight and twelve applications of agrochemicals (particularly glyphosate, 2,4-D, metolachlor, diclosulam and haloxyfop methyl) per production cycle (Rovea 2012). Obviously, the larger the quantity and variety of biocides applied, the greater the contamination of soil, water and air, and the undesirable and unpredictable biological resistance processes triggered.

GM-HR soybean crops are based on the predominant use of glyphosate (in the Southern Cone) or glufosinate ammonium (in other parts of the world). GM soybean cultivation may require four to six applications of agrochemicals, with the herbicide being applied a maximum of three times (Rovea 2012). At present, glyphosate is produced by numerous companies, because the patent expired in 2000. Given their positive effect for weed control, little residual activity, relatively low toxicity, wide availability, and lower prices, these herbicides have become popular and the volume of use in the agricultural sector has increased.

The fact that the volumes of glyphosate and glufosinate-ammonium produced have increased year after year should not be regarded as running counter to the idea of transgenesis generating "clean" benefits, since the two herbicides are used for both conventional and transgenic soybean (Brookes and Barfoot 2011). In addition, the use of glyphosate in activities that are the subject of a major public debate–for example, in the chemical eradication of illicit crops in other parts of the globe–has led to its importance being undervalued and demonized in the agricultural sector, and its contribution to reducing environmental degradation is not considered. Clearly, the application of any synthetic substance to the environment has an impact; however, an objective evaluation of the cost/benefit ratio needs to be carried out, since in the case of the application of glyphosate and glufosinate in both conventional and GM soybean crops, the benefit is obvious (Snoo et *al.* 2001 and 2005). Glyphosate and glufosinate-ammonium are compounds whose impact on the environment is definitely less negative than that of equivalent synthetic herbicides, provided they are used properly.

5.3. Environmental advantages of GM soybean

As has been shown throughout this document, the development of soybean cultivation in Argentina, Brazil, Paraguay, and Uruguay is based on the implementation of a technology package that involves direct seeding and the use of GM seeds. When both conditions are present, higher yields and economic returns are obtained, and the negative impact on the environment is reduced (Table 5.2, James 2010).

Table 5.2. Comparison of the environmental impact of conventional and GM soybean cultivation

	Type of soybean cultivation		
Characteristic	**Traditional**	**Conventional**	**GM-GR**
Use of direct seeding	No	Yes	Yes
Conservation of physical soil characteristics	None	High	High
Practice of fertilization with P and S	No	Yes	Yes
Biological N fixation	Medium	High	High
Impact on microbiota in the soil	Negative	Positive	Positive
GHG emissions (CO_2, N_2O)	High	Medium	Low
Weed management	High	Medium	Low
Efficiency input vs. yield	Low	Medium-high	High
Use of glyphosate	No	Yes	Yes
Use of other herbicides	Low-medium	Medium	Low
Contamination of soil, air and water sources	Very high	Medium	Low

Note: Traditional crops are those in which direct seeding is not used. In conventional crops, minimum tillage is used, while GM-GR crops involve the use of direct seeding and transgenic seed.
Source: Rovea 2012.

5.4. Drought tolerance in soybean

Tackling drought and using water efficiently have become increasingly important priorities because of the visible effects of the prolonged extreme drought and the higher temperatures across the region that also have a global impact (Sternberg 2011). Drought clearly undermines food security (FAO 2011), the economy (Cristaldo 2012) and the stability of countries (Catarious and Espach 2009).

Both conventional and GM-HR soybean crops have been severely affected by low rainfall over the last five years, especially during the 2008-2009 and 2011-2012 crop years. The situation has been dramatic in the soybean-producing areas of Argentina, Brazil, Paraguay, and Uruguay, especially during the 2011-2012 crop year (Agrodigital 2012), as a result of the presence of La Niña (DNM and UR 2011, SMN 2012, DISME/INMET and CPPMet/UFPEL 2012, Pasten and Vásquez 2012). On the other hand, climate simulation studies estimate that an increase in mean temperature in the soybean-producing areas of Brazil could result in the loss of 64 per cent of those areas (Eduardo Assad, EMBRAPA, according to Samora, no date).

The lack of rainfall at the end of 2011 and in early 2012 in Argentina reduced soybean yields by 30 per cent (Agrodigital 2012). According to estimates by the Consorcios Regionales de Experimentación Agrícola (CREA), the expected yield at the time of planting was 3545 kg/hectare, and in February that figure was only 2523 kg/hectare. However, the yield will not be as low as that recorded in the 2008-2009 crop year, which was 1800 kg/hectare (50 per cent less than the estimated figure at the time of planting). In Paraguay, producers estimate that they will harvest 45 per cent less soybean in 2012 than in the previous year (Cristaldo 2012). The impact will be so great that there will probably be a fall in Gross Domestic Product (GDP) and in the country's monetary reserves.

Droughts will continue. They may last for longer periods, which would lead to downturns in world food production and affect markets and prices. In the face of this scenario, the various bodies involved in technology generation and transfer must provide a prompt response to make it possible to mitigate the effects of this manifestation of climate change and adapt agriculture to the new conditions. For example, irrigation technology will have to be implemented in areas where it is needed, which will call for investment. At the agronomic level, practices that permit better use of water and biotechnology will have to be employed, drawing on all the tools offered by the latter (Rocha 2011), to expedite the generation of drought-tolerant varieties. Thus, genetic modification will not be the only solution to drought but will certainly form part of an array of efficient tools available for the conservation of the environment, the use of marginal areas, and the adaptation of agriculture to climate change. A technology package based on GM-HR drought-tolerant soybean, and not only GM-HR soybean, may be used in the near future.

It is likely that in coming years there will be new transgenic events of interest for the primary stage of cultivation, such as those related to salinity tolerance, nitrogen fixation and the efficient absorption of other nutrients. There is also expected to be a move towards the generation of GM plants with characteristics of greater interest to the end user (food consumers, various industries, etc), such as those associated with the enriched composition of oils for industrial purposes (*e.g.*, for the biodiesel industry), or the food industry (materials with a higher unsaturated fat content or with molecules that are more stable towards temperature or hydrogenation processes, etc.). In any event, all of those characteristics will be a response to not only the immediate needs of the end consumer, but also to the pressure imposed by climate change, which calls for the application of clean and environmentally-friendly methodologies and processes.

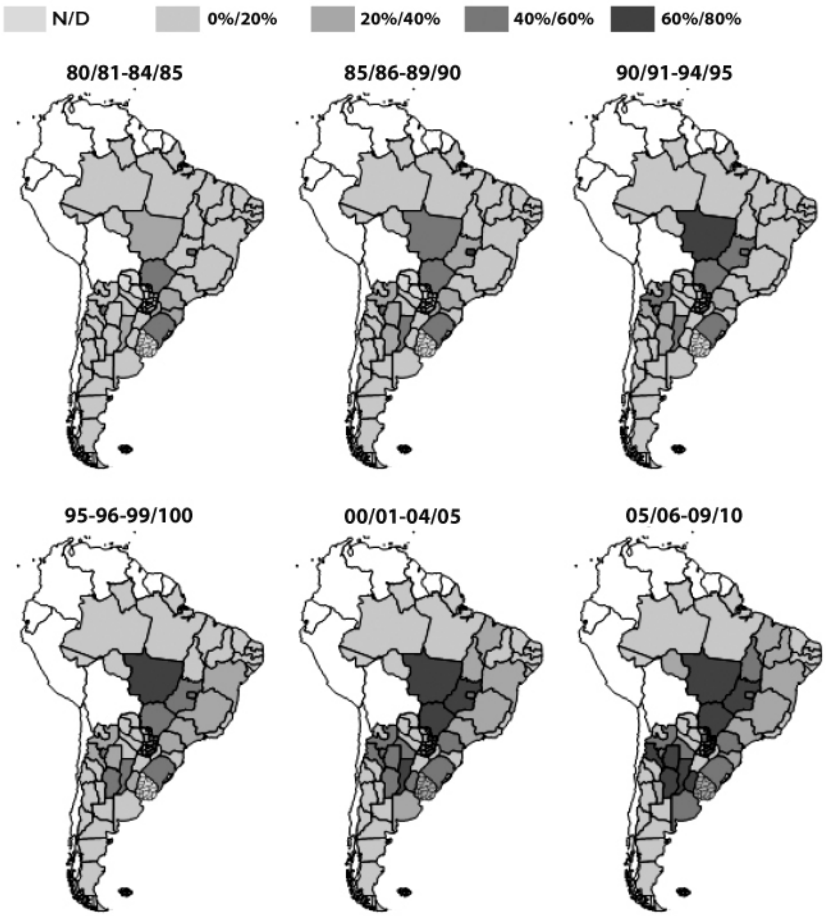
Chapter 6

Cost Analysis:

Comparison of the evolution of production and the costs of transgenic and conventional soybean cultivation

As already noted (Chapter 2), in the countries studied the area planted with soybean has increased steadily since the 1970s. The expansion of the area under cultivation in relation to other extensive agricultural crops also shows an increase in the use of this oilseed in crop rotations (Figure 6.1). This chapter compares the costs and production of soybean in the countries concerned.

Figura 6.1. Evolution of the area planted with soybean in relation to other extensive agricultural crops in Argentina, Brazil, Paraguay, and Uruguay, from the 1980-1981 to the 2009-2010 crop year



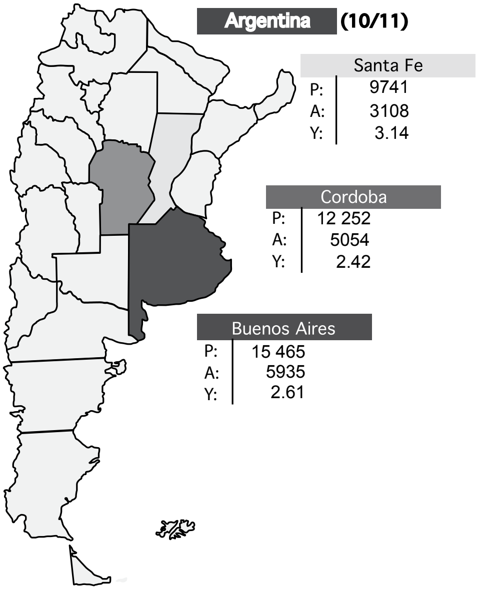
Note: The darker the color, the larger the area planted with soybean.

Source: Del Río 2012, based on reports from the *Companhia Nacional de Abastecimento* (CONAB) of Brazil, the Ministry of Livestock, Agriculture and Fisheries of Uruguay, the Ministry of Agriculture, Livestock and Fisheries of Argentina, the Ministry of Agriculture and Livestock of Paraguay, and the *Instituto de Biotecnología Agrícola* (Inbio) of Paraguay.

6.1. Argentina

In Argentina, the provinces of Buenos Aires, Santa Fe and Cordoba, which make up the central region referred to as the zona núcleo, account for most of the country's soybean production (Figure 6.2).

Figure 6.2. Soybean production in Argentina in the 2010-2011 crop year



P = Production (thousands of tons)
A = Area under cultivation (thousands of hectares)
Y = Yield (tons per hectare)

Source: MAGyP. Taken from Del Río 2012.

In the 2010-2011 crop year, the province of Buenos Aires led the country in area cultivated with soybean–5.9 million hectares–followed by Cordoba and Santa Fe (5 million and 3.1 million, respectively). The three provinces account for almost 75 per cent of soybean production in Argentina.

The Central Region is the most traditional farming area and has deep soils. Chemical fertilization of the crop in the region increases year after year, thanks to the excellent results achieved and because it is the area where the greatest amount of nutrients is extracted from the soil. Productivity in this region for the crop year under reference ranged from 2.4-3.1 tons per hectare, substantially higher than in the surrounding provinces.

In Argentina, rainfall decreases from east to west, with precipitation concentrated in the summer months. The isohyets range from 1100 mm in the east to 70 mm in the west. While the volume of rainfall in Argentina is far lower than in Brazil and Paraguay, the differences in soybean production have to do with soil quality and depth, and the fact that transpiration is less because of the latitude involved.

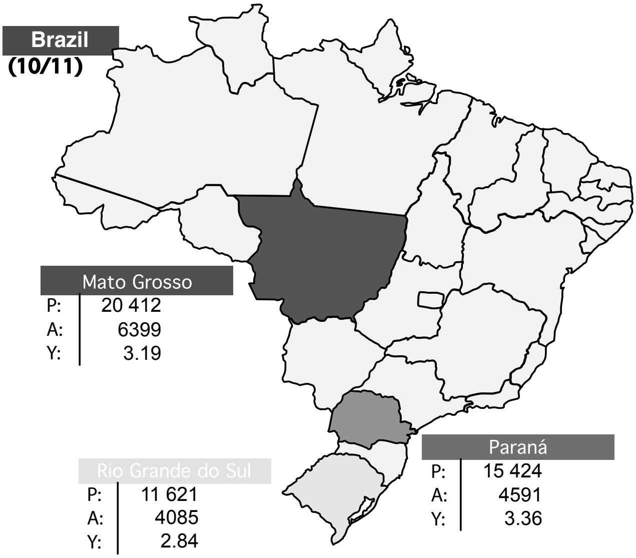
6.2. Brazil

Brazil is the biggest producer of soybean in the Southern Common Market (Mercosur). Mato Grosso is the largest soybean-producing state, followed by Paraná and Rio Grande do Sul (Figure 6.3). Mato Grosso has more stable yields than the other two states, because of the regularity of its rainy season, which starts in October and ends in April. Volume ranges from 2200-2400 mm per annum. This rainfall pattern makes production highly stable and allows farmers to plant a second crop (maize-II).

Precipitation in the states located in the south of the country, from Paraná to Rio Grande do Sul, is lower and more variable. It is for that reason that the latter state has lower yields (Figure 6.3).

The expansion of soybean growing in Brazil began in the southern states and gradually moved north, mostly driven by the migration of producers. At present, Brazil produces soybean in areas where rainfall is between 1400 mm and 2400 mm per year, although in many areas soil quality is a major constraint, and reflected in production costs and yields.

Figure 6.3. Soybean production in Brazil in the 2010-2011 crop year



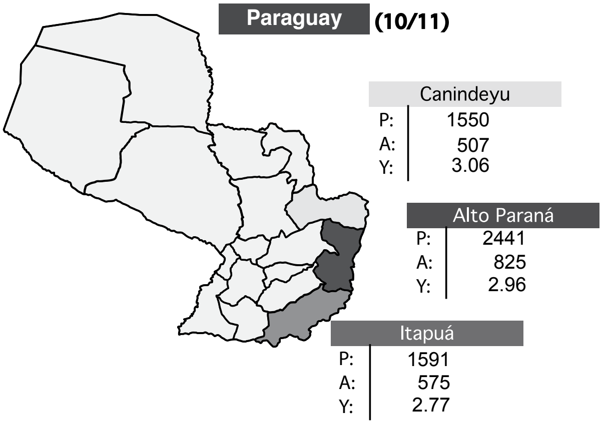
P = Production (thousands of tons)
A = Area under cultivation (thousands of hectares)
Y = Yield (tons per hectare)

Source: CONAB (Production estimates 2010-2011 crop year). Taken from Del Río (2012).

6.3. Paraguay

In Paraguay, the main soybean-producing area is in the southeast of the country, close to the Paraná River, a region known as the zona oriental (Figure 6.4). In this area, the soil is deep but chemically fragile, and water retention is low. As in Brazil, the soil needs to be corrected because of its acidity, and requires fertilizers to compensate for the chemical deficiencies of the soil. In Paraguay, soybean is produced in an area where rainfall ranges from 1600-2200 mm per year, although in some production areas annual rainfall is only 1200 mm.

Figure 6.4. Soybean production in Paraguay in the 2010-2011 crop year



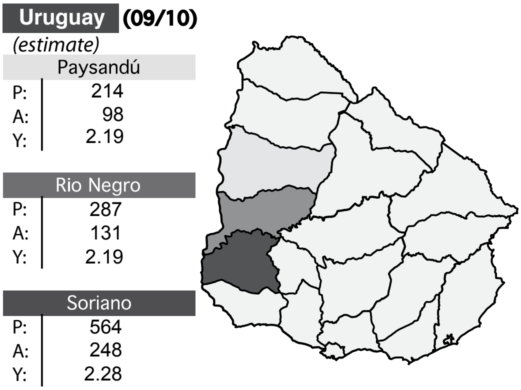
P = Production (thousands of tons)
A = Area under cultivation (thousands of hectares)
Y = Yield (tons per hectare)

Source: INBIO. Taken from Del Río (2012).

6.4. Uruguay

Soybean cultivation in Uruguay is a very recent development, although the crop area has grown exponentially and producers have gradually adapted the cultivation systems to current technology. The soybean-producing area par excellence is located to the east of the Uruguay River (Figure 6.5), where the soil is deep and of better quality than in the rest of the country. The quality of the soil decreases as you move east and the percentage of soil with stones or bedrock a few centimeters from the surface increases, making certain areas unproductive.

Figure 6.5. Soybean production in Uruguay in the 2010-2011 crop year



P = Production (thousands of tons)
A = Area under cultivation (thousands of hectares)
Y = Yield (tons per hectare)

Source: MGAP. Taken from Del Río (2012).

The main characteristics of Uruguay's soils are their clay to clay-loam texture, medium depth, low phosphorus content, and very marked potassium deficiencies. Notable physical characteristics include the low infiltration rate and the small quantity of water available for crops. Rainfall in the region where soybean is cultivated in Uruguay ranges from 900-1100 mm per year. The rainfall pattern is more uniform in winter than in summer, making winter crops a better option. In contrast, the erratic distribution of precipitation during the summer months and negative balances make the production of summer crops a risky undertaking.

The brief description of soybean production in the four countries shows that the environmental and edaphological conditions are a constraint in numerous regions. However, current technology, based on a technology package analyzed in this study, has made it possible to devise production strategies with results that range from acceptable to highly efficient (Table 6.1).

Table 6.1. Productive potential and agro-ecological characteristics of the countries

Country	Type of climate	Precipitation (mm per year)	Type of soil according to predominant texture	Depth at which water is available (in meters)	Effective depth of roots (m)
Argentina	Temperate	700-1100	Loam Silt loam Sandy loam Clay	High 120-180	High 1.5 a 2.5
Brazil	Tropical to subtropical	1400-2400	Sandy clay	Low 70-120	High 2 a 3
Paraguay	Tropical to subtropical	1600-2400	Sandy clay	Low 70-120	High 2 a 3
Uruguay	Temperate	900-1100	Clay loam Clay	Low 70-100	Low 0.7 a 1

Source: Rovea 2012.

6.5. Analysis of production costs among countries

Following is an analysis of the costs associated with soybean cultivation in the four countries (including those relating to agrochemicals, seeds, fertilizers and planting, applications and harvesting), as well as an analysis of marketing costs and a comparison of the costs of conventional and GM soybean cultivation.

6.5.1. Costs associated with soybean cultivation

The analysis of estimated production models for the 2010-2011 crop year, taking exchange rates into account,[2] shows marked regional differences in the direct production costs per

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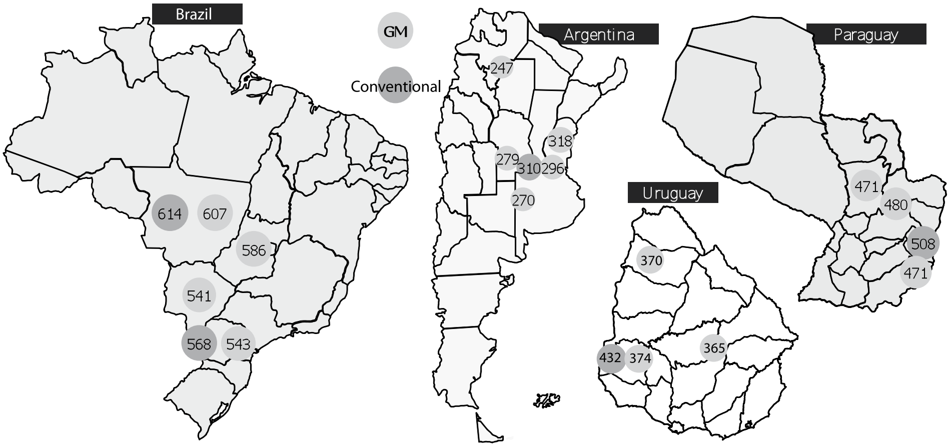
[2] Exchange rate for USD1: 4.05 pesos (Argentina), 1.67 reales (Brazil), 4350 guaranies (Paraguay), and 19.97 pesos (Uruguay).

hectare (seeds, agrochemicals, fertilizers and planting, applications and harvesting). Del Río (2012) analyzed 20 schematic presentations of production costs and concluded that they ranged from USD247 per hectare to USD614 per hectare (Figure 6.6, Del Río 2012).

Figure 6.6. Conventional and transgenic soybean production costs in the different production areas of the four countries



Note: The numbers inside the circles indicate the costs in USD/hectare, based on production models and information supplied by the *Companhia Nacional de Abastecimento* (CONAB) of Brazil, the *Empresa Brasileira de Pesquisa Agropecuária* (EMBRAPA), the *Instituto Mato Grossense de Economia Agropecuária* (IMEA), the Ministry of Livestock, Agriculture and Fisheries of Uruguay, the Ministry of Agriculture, Livestock and Fisheries of Argentina, the *Asociación Argentina de Consorcios Regionales de Experimentación Agrícola* (AACREA), the Ministry of Agriculture and Livestock of Paraguay, and the *Instituto de Biotecnología Agrícola* (Inbio) of Paraguay.

Source: Del Río 2012.

A comparison of transgenic soybean production costs among the countries shows that Argentina has the lowest direct costs (USD247 to USD318 per hectare), followed by Uruguay (USD365 to USD432 per hectare), Paraguay (USD471 to USD508 per hectare) and, lastly, Brazil, which has the highest costs (USD543 to USD614 per hectare).

The biggest differences in direct costs (establishment of the crop and cost of the harvest) are related to fertilizers. In Argentina, it is necessary to use fertilizers in some regions of the country. Uruguay has neutral soils but they are very deficient in P, K and S. Brazil and Paraguay have acid soils with very low P, K and S content. Hence, costs vary according to the volumes used and fertilizer prices in each country.

It is worth noting the contribution made to fertilization costs by technological developments. In the case of N, a nutrient in high demand, the crop is capable of assimilating 40-80 per cent through biological fixation. Consequently, the improvement of nitrogen-fixing bacteria was a major step forward in obtaining acceptable to high yields and reducing production costs, since average inoculation costs for the crop are only USD3 per hectare (or 0.5 to 1.5 per cent of direct costs; Del Río (2012).

Thus, differences in the application of fertilizers are the main reason for the variation in production costs among the different production areas in each country and among countries. In the case of agrochemicals, the biggest differences in cost also have to do with the types of inputs required and, of course, the quantities applied. Finally, the variation in cost is also influenced by differences in the outlay required for the establishment of the crop, maintenance, and harvesting. The existence or otherwise of a developed market for agricultural machinery services has a direct bearing on the type of production system used (amount of capital required for machinery). The operating costs and capital expenditures involved naturally affect production costs (Del Río 2012).

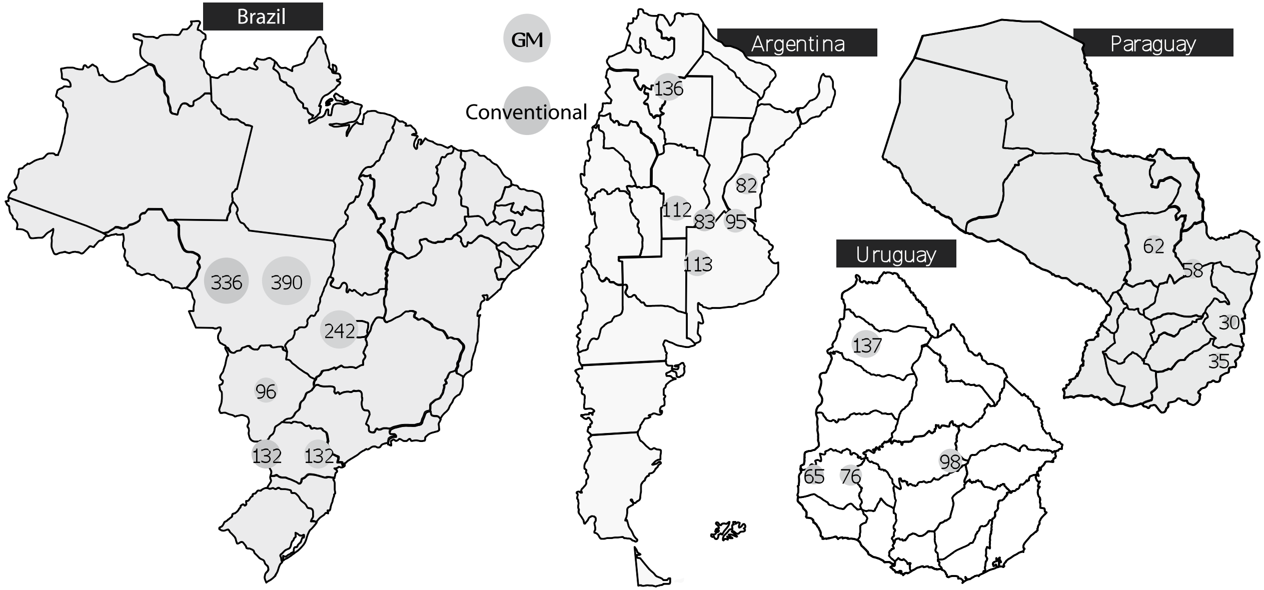
It should be noted that the difference in costs related to inputs has more to do with the volume than the price of the product. Generally speaking, the unit price of inputs is not an important factor in the differences in costs within and among countries. Cost differentials with respect to agrochemicals and fertilizers are mainly accounted for by the type of inputs used and the doses required (Del Río (2012). Although the prices of most inputs (measured in USD) do not vary greatly, there are certain exceptions, such as seed. For example the cost of seed in Argentina is USD0.50 to USD0.65/kg, in Brazil it is USD1.0 to 1.30/kg, in Paraguay it is USD1.0 to USD1.30/kg and in Uruguay, it is USD0.60 to US0.90/kg (Del Río 2012, Rovea 2012).

6.5.2. Marketing costs

In addition to direct production costs, there are also significant differences among the countries with respect to internal marketing costs (Figure 6.7), basically due to the costs involved in transporting soybean from the production area to the port of embarkation (Del Río 2012). Within the four countries, grains are mainly transported by road; only a small percentage is transported by train or boat. In Brazil, Paraguay, and Uruguay, the vast majority of soybean is exported as grain, whereas in Argentina more than 70 per cent of production is exported in the form of oil and pellets, which calls for a large milling and processing capacity.

The price of fuel is also a factor in the differences in transportation costs (Del Río 2012). However, given the different ways in which fuel is regulated and the fact that price variations are not always transferred to the domestic market in each country, an analysis of the issue is beyond the scope of this study.

Figure 6.7. Marketing costs among countries



Note: The numbers inside the circles indicate the marketing costs in USD/hectare.

Source: Del Río 2012, based on data from the United States Department of Agriculture (USDA), the *Companhia Nacional de Abastecimento* (CONAB), the E*mpresa Brasileira de Pesquisa Agropecuária* (EMBRAPA), the *Instituto Mato Grossense de Economia Agropecuária* (IMEA) and field surveys.

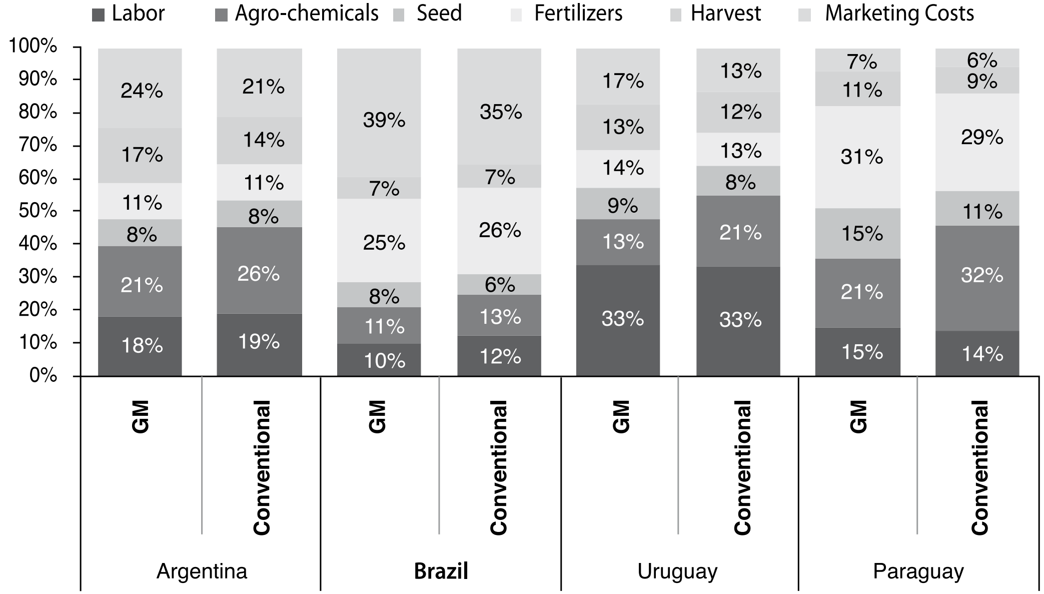
6.5.3. *Comparison of conventional and GM soybean costs*

The difference in direct production costs between conventional soybean and transgenic soybean ranges from USD7 to USD58 per hectare, which represents a maximum differential of 15 per cent (Figures 6.8 and 6.9).

It should be noted that, in terms of the cost per ton produced, these differentials increase considerably in certain regions, since the larger volumes of GM soybean produced leads to economies of scale. The percentage for conventional soybean in the region as a whole is put at 3 per cent (Del Río 2012), rising to 8-15 per cent in certain areas, such as the northern region of the state of Mato Grosso.

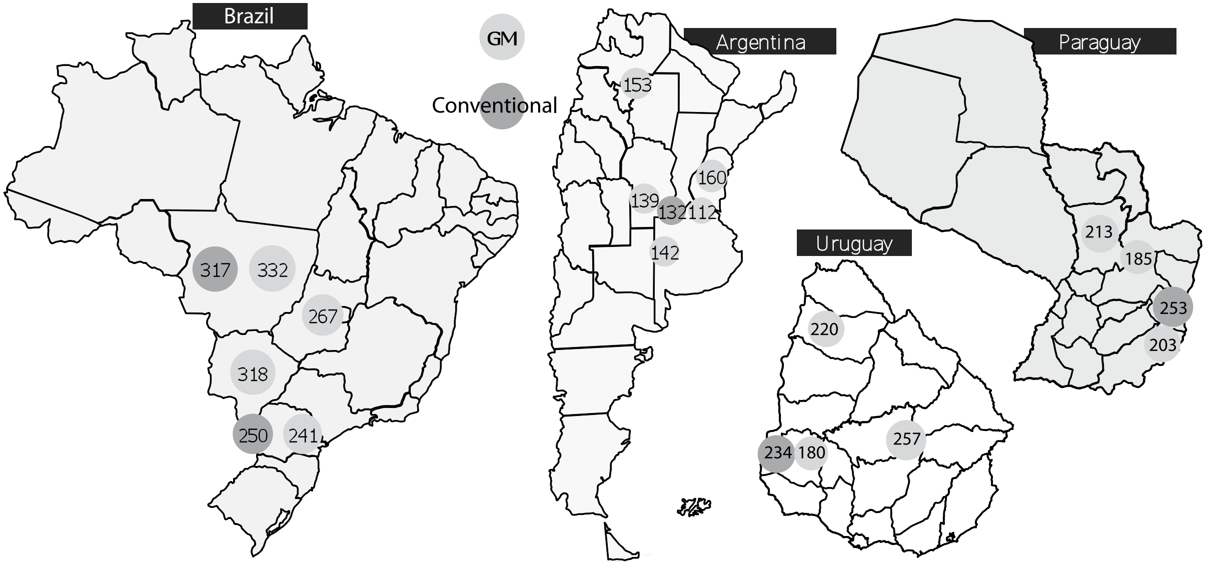
Conventional soybean is an attractive product for certain market niches where there is a specialized demand for it for human consumption (*e.g.*, Europe and Asia). Given the differential price in relation to GM soybean, it is an attractive business prospect for certain specific companies. However, this study has shown that in order for the conventional soybean production system to be profitable, a high degree of efficiency is required. Crop management needs to be much more specific, more applications of agrochemicals are required, and the producer has to be extremely alert to know when weed control should be done. As noted, GM soybean cultivation may require a maximum of three applications of herbicide, whereas conventional soybean may need four to five applications, which pushes up costs (Rovea 2012). Labor costs are also USD10-20 per hectare higher than in the case of GM soybean management. Added to the above is the need for a traceability process to avoid the adventitious presence of transgenic soybean, which also drives up costs (Del Río 2012).

Figure 6.8. Distribution of GM and conventional soybean costs in the different countries, expressed in percentage terms



Source: Del Río 2012, based on production models, with information from the *Companhia Nacional de Abastecimento* (CONAB) of Brazil, the *Empresa Brasileira de Pesquisa Agropecuária* (EMBRAPA), the *Instituto Mato Grossense de Economia Agropecuária* (IMEA), the Ministry of Livestock, Agriculture and Fisheries of Uruguay, the Ministry of Agriculture, Livestock and Fisheries of Argentina, the *Asociación Argentina de Consorcios Regionales de Experimentación Agrícola* (AACREA), the Ministry of Agriculture and Livestock of Paraguay, the *Instituto de Biotecnología Agrícola* (Inbio) of Paraguay, and his own estimates.

Figure 6.9. Total costs of conventional and transgenic soybean in the various countries



Nota: The numbers inside the circles indicate the total costs in USD per ton.

Source: Del Río 2012, based on production models, with information from the *Companhia Nacional de Abastecimento* (CONAB) of Brazil, the *Empresa Brasileira de Pesquisa Agropecuária* (EMBRAPA), the *Instituto Mato Grossense de Economia Agropecuária* (IMEA), the Ministry of Livestock, Agriculture and Fisheries of Uruguay, the Ministry of Agriculture, Livestock and Fisheries of Argentina, the Asociación *Argentina de Consorcios Regionales de Experimentación Agrícola* (AACREA), the Ministry of Agriculture and Livestock of Paraguay, and the *Instituto de Biotecnología Agrícola (Inbio) of Paraguay*.

In the interviews conducted with conventional soybean producers in each country (Rovea 2012), the farmers highlighted as important aspects such as the strict control measures required, with their corresponding traceability, and the specificity of the product with regard to the market. At least one conventional soybean-producing company was interviewed in each country. In every case, the interviewee stated that the company filled market niches and employed very strict control measures, including traceability.

In the case of Brazil, the state that produces most conventional soybean is Mato Grosso, mainly in the northern region, where the transition to the Amazon starts. This area, where restrictions on the expansion of the crop area exist (it cannot exceed 20 per cent), markets conventional soybean through the ports in the north of the country. Transgenic soybean, on the other hand, is transported to the ports in the south, which accounts for the difference in marketing costs between the two varieties. The price premium for conventional soybean, because of its specialized use in market niches, is around USD20 per ton, whereas in the state of Paraná, the price is around USD6 per ton higher. In the latter state, a negligible amount of conventional soybean is produced by smallholders.

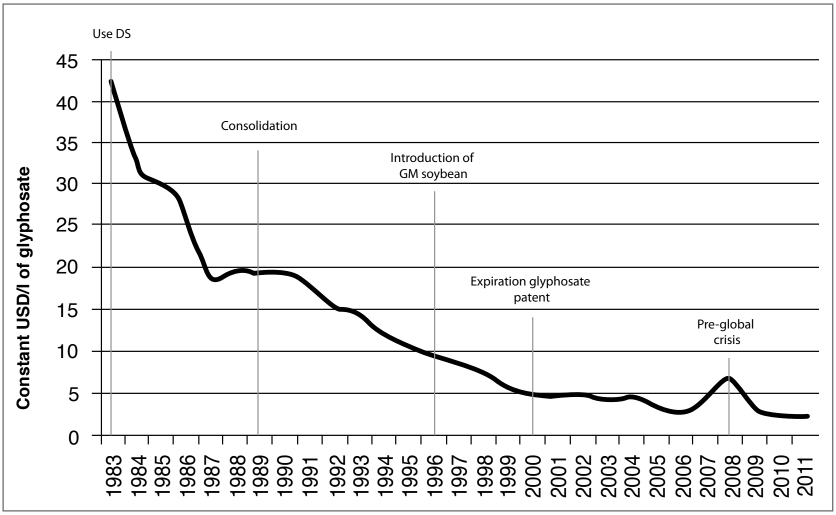
In Paraguay, there are also cases of conventional soybean being sold to markets with specific requirements. The Japanese Cooperative of Iguazu, which exports to Japan, is a case in point. For example, two varieties of conventional soybean with a high protein content (42 per cent) fetch USD200 per ton more than the price quoted on the Chicago commodities market. However, the soybean exported must meet size requirements, so 30-40 per cent of production is sold at the local price. In Argentina, the vast majority of conventional soybean production is processed and sold ready for human consumption on specialized markets (Del Río 2012).

Rovea interviewed producers for his study in 2012. The results highlight the differences associated with the product, how it is exported, and the type of business that each company conducts, which helps account for the differences in costs. Conventional soybean is not a commodity (Del Río 2012), and each case involving this kind of crop has a different, client-specific price system. In general, the markets where there is a demand for this product are in Europe and Asia.

As already noted, the difference in cost between conventional soybean and transgenic soybean is a maximum of 15 per cent, which is due mainly to two factors (Del Río 2012):

- The price of inputs for conventional soybean has not increased in recent years; in fact, the price has remained steady and, in some cases, fallen. One of the main reasons for this development is the fact that the patents of the active principles of herbicides for conventional soybean expired, triggering the manufacture of generic compounds in many parts of the world. Free competition made it possible to maintain or lower prices. One of the best examples of falling GM soybean costs is the reduction in the price of glyphosate (Figure 6.10).

Figure 6.10. Trend in the price of glyphosate in Argentina (Constant USD as at December 2011/liter of compound)



DS = Direct seeding.

Source: Based on Agroseries – AACREA.

While there are no consolidated statistics on the consumption of this product, increased use of the compound has gone hand in hand with the development of GM soybean and its expansion in the different territories.

- The production costs of transgenic soybean are currently experiencing an increase of USD25-45 per hectare because of the use of other herbicides in addition to glyphosate, and some species of weeds' resistance to or tolerance of the compound (Papa 2010). It has been suggested that the problems encountered in controlling certain weeds are due to poor use of the technology, i.e., the failure to rotate modes of action to prevent herbicide-resistance species from developing over time (Gazziero *et al.* 2001). The region should focus its policies on the crop imbalances that have developed in some areas of the countries.

Thus, the microeconomic analysis of 20 modal systems of soybean production in the countries studied shows the differences in production costs in the various regions. Given the characteristics of the soils and the marketing costs, fertilization needs largely account for the differences observed. It is also evident that, at present, the costs involved in producing GM and conventional soybean are similar (the maximum difference detected was 15 per cent), although the management of conventional soybean is more complex.

Recent studies conducted for Argentina (Trigo 2001) have estimated the aggregate impact of GM soybean. Based on a simulation model, it was estimated that the adoption of the technology generated an accumulated gross profit of USD65.435 billion during the period 1996-2011. The study also suggests that the estimated economic savings to consumers in the same period was approximately USD89 billion.

Chapter 7

Analysis of possible scenarios

What would happen if the four countries analyzed in this study were to cultivate only conventional soybean, produce only GM soybean, or continue to cultivate both types? Brazil, Argentina, Paraguay and Uruguay account for almost one half of world soybean production (FAO 2012), and GM soybean makes up roughly 90 per cent of what they produce (James 2011). A series of simulation exercises were carried out and the results are discussed below (Rovea 2012, Del Río 2012).

7.1. Effect of the absence of GM soybean cultivation in the four countries

If the countries were to continue to produce the current volumes of soybean and meet future demand for soybean without the technology package described in this study, what would the economic and environmental costs be?

If the region were to cultivate only conventional soybean, global production would decline by 15-25 per cent (Del Río

2012), basically due to less efficient weed control (Manning *et al.* 2003). In addition, the crop area would increase more slowly than at present because of the difficulty of controlling weeds in some areas (Papa 2010). Another factor would be the cost of production, which could rise by 7-15 per cent (Del Río 2012), without taking into account the operating opportunity cost involved in performing the work in a timely and efficient manner, or the environmental cost (Foloni 2001) associated with the release of various synthetic agrochemicals.

If the region were to cease producing GM soybean completely, the cost of not allowing the presence of other transgenic events in the future–such as drought tolerance–would also have to be taken into account. The droughts that occurred in the 2008-2009 and 2011-2012 crop years had a serious impact; the second of the two resulted in around 30 per cent of the GM-HR crop harvest being lost (Agrodigital 2012). If only conventional soybean were to be planted in a similar drought scenario, complete harvests would be lost, with the resulting economic and social consequences (Cristaldo 2012).

As noted in sections 3.2.2. and 5.4., drought resistance has been studied in soybean and in other species. However, the complexity of the characteristic (Mitra 2001) limits the capacity of conventional plant breeding to generate new varieties of soybean in a very short time. If a new, highly drought-tolerant soybean variety produced using conventional plant breeding methods were to be made available today, it would undoubtedly be used on a large percentage of the crop area.

7.2. Effect of the presence of only GM soybean in the four countries

This scenario is similar to the present situation, in which GM soybean accounts for nearly 90 per cent of production in the region. The use of transgenic soybean makes a bigger contribution to the sustainability of the crop than conventional soybean (Brindaban *et al.* 2009). The downside would be that people who wish to consume conventional soybean byproducts would not be able to do so. That would be a negative development, because niche market consumers–who pay a premium–would be denied the possibility of choosing the type of food they wish to consume, food produced using the methods they prefer, even though it is more expensive.

On the other hand, the region would continue to reap the benefits of GM-HR soybean highlighted throughout this document if only that variety were to be cultivated in the region. However, it would be advisable to conduct an analysis of that situation in a drought scenario, in which GM drought-tolerant soybean materials are indispensable. In a severe drought scenario, GM-HR soybean would not be very useful, as it would also be impacted by the low moisture levels. Consequently, it is imperative that GM soybean materials with several events be developed and incorporated simultaneously, especially herbicide resistance and drought tolerance. Events of this kind have been reported in soybean (Chan *et al.* 2010, Huang *et al.* 2010), but it is not clear when these events will be made commercially available in the Southern Cone countries. Furthermore, at present only drought-tolerant maize is commercially available for the next planting season in the United States (APHIS 2011).

7.3. Effect of the coexistence of GM and conventional soybean cultivation

This is the present situation: both GM-HR and conventional soybean are produced. Producers and consumers are free to choose the type of soybean they wish to plant and consume, respectively. The percentage of cropland used for each type of soybean will depend on economic considerations (demand, prices, and the rate of return for each type).

If the trend of severe drought events continues (Agrodigital 2012), the effect on conventional and GM-HR soybean will be the same, given the harshness of the phenomenon. As a result, coexistence will depend, in part, on the effects of the drought and on the introduction of the characteristic of tolerance to it, either through conventional plant breeding or transgenesis. As already noted, as far as herbicide resistance is concerned coexistence will depend on the price and market demand.

Chapter 8

Final considerations

The growth in the area planted with soybean in the countries of the southern region has been driven by the crop's economic value, the high demand for the product, and the adoption of innovative technology. This study was carried out in response to the expansion of soybean cultivation in the countries.

The use of a technology package that combines direct seeding, inorganic fertilization, proper use of biocides (fungicides, insecticides, and herbicides), genetically modified herbicide-resistant soybean, and efficient mechanical harvesting creates a synergy that simplifies the production system and makes it more efficient in technical, environmental, and economic terms.

The use of the system of direct seeding in soybean cultivation is an important means of reducing the crop's negative impact on the environment. Direct seeding is a production model that makes more efficient use of water, and reduces water and wind erosion and the amount of time during which agricultural machinery is employed. This reduces GHG emissions and generates savings for the producer. Without this technique, many areas could not be used for production as the soil would be degraded very rapidly. The efficient use of inorganic fertilization, based on technical criteria, is designed to maintain a balance between the environment and productivity. Knowledge of the soil nutrient balances required and their effective management are essential in maintaining productivity. Proper chemical fertilization not only increases yields in areas that have been degraded by many years of agricultural use, but also makes it possible to make adjustments in areas that are naturally deficient so they can produce good yields. The correction of acid soils that contain aluminum, such as those found in large swathes of Brazil and Paraguay, makes it possible to expand production by using land not suitable for crops in its natural state. However, the high cost of upgrading the soil pushes up production costs significantly in the two countries.

The genetic improvement of conventional materials and the incorporation of indeterminate growth habit into all maturity groups increased the plasticity of the soybean, reinforced its adaptation to various production systems, and increased productivity. Nonetheless, it was the introduction of GM soybean that drove cultivation in the region. Although yields of GM and conventional soybean are the same, since the genetic modification of herbicide resistance does not affect the yield components, GM cultivation shows clear advantages in terms of crop management, specifically cheaper and more efficient weed control, mainly as a result of the permanent drop in the price of glyphosate and the smaller number of applications required in the case of GM soybean. All the above translates into lower production costs.

Of course, because soybean (whether conventional or transgenic) is grown as a monoculture and chemical agents are used, it is bound to have an impact on the environment. The use of the technology package based on GM-HR soybean, which makes efficient weed control possible, is the key factor in reducing the negative impact on the environment, because there is less soil disturbance, a smaller amount of herbicide is used and fewer applications are required. Based on the information analyzed, GM-HR soybean has made cultivation more efficient, resulting in a reduced environmental impact without triggering any new negative environmental process.

Based on the results and impact achieved during more than 15 years in use, it is fair to say that GM-HR soybean cultivation is a clean technology.

Transgenic technology in soybean cultivation paves the way for the incorporation of new herbicide, insecticide, and fungicide molecules that counteract the negative effect of weeds, pests, and diseases in a more precise way and with less damage to the environment. In addition, due to the biology of the species, there is an opportunity to develop the bioinoculant industry and make biological nitrogen fixation more efficient.

In short, the comprehensive technology package of direct seeding, fertilization, herbicides, and GM soybean is more efficient than the application of any of its components separately. Moreover, the environmental and economic benefits of the technology package based on GM soybean are greater than those generated when the same package is applied to conventional soybean.

Today, we have a technology that makes it possible to produce with a minimum of environmental impact (less water used, smaller crop area, improvement of soils, and less contamination) and reverse the problem of degradation in places where it exists. However, a greater technological effort is needed to develop drought-tolerant soybean and make it available as quickly as possible. In the Southern Cone countries, the issue under discussion should not be conventional soybean vs. GM-HR soybean, but rather how to solve the problem of not being able to produce due to severe drought. In the face of this challenge, transgenic technology is called upon to provide an urgent and efficient response.

Conclusions

- The expansion of GM soybean cultivation in Argentina, Brazil, Paraguay, and Uruguay, and its global importance in environmental, economic, technological, and social terms, were the reasons for carrying out this study, which was amply justified.

- GM soybean seed boosts the technology package associated with direct seeding and fertilization used to grow conventional soybean. Because it is easy to manage, GM soybean has been widely accepted and used by producers. During 2011, approximately 40 million hectares were planted with GM soybean in the four countries.

- GM soybean cultivation and the technology package associated with it have had a more positive environmental impact than conventional soybean cultivation. To obtain current yields, conventional soybean would require a larger crop area and more tillage than GM soybean. Moreover, conventional soybean causes more water, air, and soil contamination, due to the use of various agrochemicals, and generates more GHG emissions.

- The cultivation of GM soybean has generated a positive economic impact for producers and countries alike. At present, the direct economic costs of cultivating GM soybean using the technology package analyzed in this document are 15 per cent lower than those of conventional soybean.

- The regulatory biosafety frameworks in the four countries created the conditions required to ensure that the relevant study of the potential risks of this technology for human and animal health and for the environment were carried out.

- Although the genetic modifications of soybean used in the countries under review have been based fundamentally on the introduction of herbicide resistance, in the near future the contribution of this technology will make it possible to adapt this crop to climate change, thanks to the availability of GM drought-tolerant soybean.

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