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11.1 The Adoption of RR Soybeans

11.1.1 Soybeans in Argentina: The Crop of the 1990s

Soybean cultivation was introduced in the Pampean region of Argentina in the 1970s, and has been characterized by an incredible rate of adoption and growth. In 1970-71, soybean production amounted to 59,000 tons, with a crop area of approximately 38,000 hectares. Only ten years later, in the 1980-81 season, production increased to 4 million tons and the crop area to over 2 million hectares. In the 2000-01[2] season, the planted area exceeded 10 million hectares and the output was estimated to be 23-25 million tons. As for utilization, soybeans and related products (oil and flour) represent 15% of Argentina's total exports. Argentina is the world's largest exporter of soybean oil (30% of the world exports) and the second largest exporter of soybean flour (27% of the world exports). These figures allude to the rising importance of soybeans to Argentina.

Due in part to genetic improvements, the average yield surpasses 2.6 tons/hectare, making it possible to extend the agricultural border into marginal regions where edaphic and climatic conditions are less favorable.

The soybean area comprises a wide zone stretching from the northern tip of the country to the south of the Pampean region. The primary soybean belt, however, is concentrated in central and southern Córdoba, Santa Fe, and

1. *The authors wish to express their gratitude to Eugenio Corradini Jr. for collecting, processing, and analyzing data related to this study, and Fernando Mousegnes and Ramon Sobral, both from INTA, for their valuable comments and suggestions.*

2. *Soybeans are planted in November/December and harvested in April/May.*

northern Buenos Aires. This area accounts for almost 90% of the country's soybean-sown area as well as production.

The conditions in the soybean belt allow for the practice of double-cropped soybean cultivation (S-II), which consists of sowing short-cycle soybean varieties later than usual, immediately following the wheat harvest. This practice allows farmers a double source of yearly income (wheat and soybeans). However, it must be noted that the soybean yield tends to be approximately 25-35% lower than through single-cropping methods (S-I). At the end of the 1980s, double cropping (wheat/S-II) had reached 60% of the soybean area, but at present only represents 30%. The decrease is associated with a reduction of wheat acreage, lower production costs of S-I, and a decrease in the sunflower crop area, which has been replaced with S-I.

The rapid soybean adoption during the 1970s was due to its high gross margin relative to other crop production and ranching. For instance, by the mid 1970s the gross margin (per hectare) of soybeans was double that of corn (Peretti et al., 1995).

11.1.2 The Rapid Adoption of RR Soybeans

The emergence of Roundup Ready® (RR) soybean varieties that are resistant to glyphosate has become an extremely important genetic breakthrough for the Pampean region. Table 11.1 shows the level of adoption of different genetically modified seeds in Argentina. In crops such as cotton or corn, biotechnology traits have not been widely incorporated to the most used varieties, thereby limiting farmer adoption. Moreover, the higher costs associated with Bt cotton have slowed its diffusion relative to soybeans.

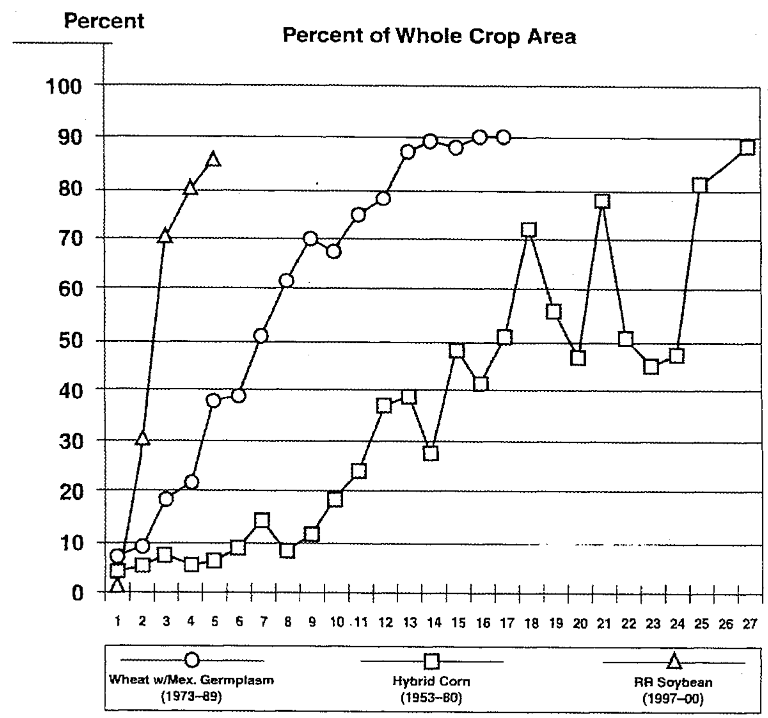
The rate of RR soybean adoption is unprecedented, however. Figure 11.1 shows the evolution of RR soybean adoption compared to two other key genetic innovations in Argentina: wheat varieties with Mexican germplasm and hybrid corn. The wheat varieties began to be developed by the National Institute of Agricultural Technology (INTA) at the beginning of the 1970s, with the purpose of achieving varieties adapted to the local conditions and to increase yields. Penna et al. (1983) report that the gross margin associated with these wheat varieties had stochastic dominance (of first or second degree) over the gross margins of traditional varieties, which stimulated their adoption. Hybrid corn was introduced in Argentina in 1953—its growth was slow relative to the US We can see that reaching 80% of the sown area took about 13 years for wheat and 20 years for hybrid corn. As for RR soybean, its rate of diffusion has been much higher than either wheat or hybrid corn. A similar comparative analysis by Kalaitzandonakes (1999) has yielded similar results in the US

Table 11.1 *Area in Argentina sown with genetically modified seeds.*

	1996-97		1997-98		1998-99		1999-00		2000-01	
	ha	%	ha	%	ha	%	ha	%	ha	%
RR Soybeans	50,000	0.7	1,756,000	25	5,600,000	70	6,800,000	80	8,500,000	85
Bt Corn					30,000	0.9	192,000	5	N/A	
Bt Cotton					5.000	0.7	8.000	1	N/A	

Source: Own elaboration, based on CONABIA-ASA. (% means over total sowing hectares).

Figure 11.1 *Adoption of new seeds in Argentina.*



The unprecedented adoption of RR soybeans in Argentina seems to be driven by economic and agronomic advantages. In Argentina, the prevailing weed spectrum, especially in the Pampa Húmeda (humid pampa) region, has caused glyphosate to be readily adopted by farmers, helping to increase the acceptance of RR soybean seeds. Furthermore, the rise of RR soybeans has allowed synergies with other improved agronomic methods, such as no-till practices. Since 1995-96 there has been a significant acceleration in no-till area, as shown in Table 11.2. Between 1995-96 and 1998-99, such area

Table 11.2 No-till area in Argentina.

	1995/96 (thousand ha)	1998/99 (thousand ha)	Increment (thousand ha)
Soybean I	338	2,039	1,701
Soybean II	620	1,650	1,030
Corn	210	1,011	801
Wheat	230	1,359	1,129
Sunflower	338	690	352
Total	**1,736**	**6,749**	**5,013**

Source: Own elaboration, based upon data from SAGPyA and AAPRESID.

increased by 2.7 million hectares in the case of soybean, whereas for the other crops (wheat, corn, sunflower), it increased by 2.3 million hectares. The adoption of RR soybeans has facilitated an increase in the practice of no-till by simplifying weed control. This also indirectly affected cropping practices of wheat and corn, because no-till is a system that has to be sustainable over different crop rotations and hence farmers must integrate it into their overall management practice.

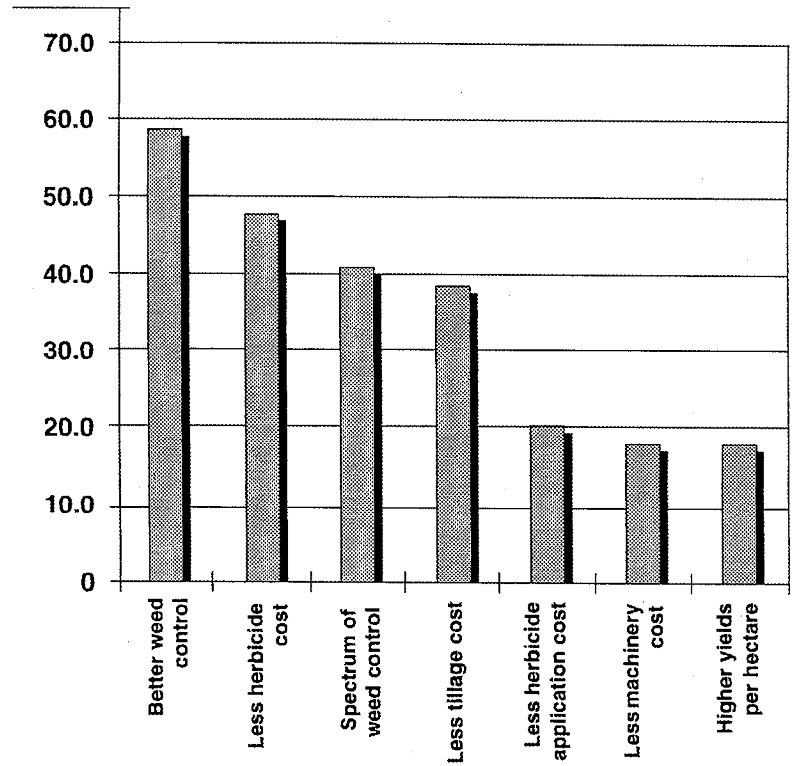
11.1.3 Farmers' Perception of RR Soybean Advantages

The commercial launch of RR soybeans in Argentina took place in 1997. One year prior, a private company surveyed 400 soybean farmers in the humid pampa region. The farmers were asked their opinions of the potential advantages of transgenic soybeans over traditional varieties. The main results are shown in Figure 11.2. Among the advantages perceived by the farmers were improved weed control (mentioned by 58% of the farmers) and lower costs associated with lower herbicide expenses. Only 17% believed that RR soybeans would offer increased yields.

According to the survey, 84% of the farmers were willing to adopt the new technology. In comparison, a similar 1995 survey in the US showed roughly 50% of American farmers were willing to adopt RR technology. The survey also showed that farmer decisions were influenced by outside information providers, including private consultants and extension agents of the INTA (30%), seed and agrochemical suppliers/agents of the input companies (26%), and visits to experimental plots organized by input companies (17%). Hence, technical advice from experts has been key to the diffusion of soybean technology to Argentina.

In June 1999, a second survey was conducted in the Pampean region to reassess farmers' opinions about RR soybean. The 338 farmers were asked "how would you rate the general performance of RR I and RR II soybean?"

Figure 11.2 Farmers' perception of RR advantages prior to introduction.



Source: White, 1997.

The respondents rated RR I as excellent (22%), very good (50%), good (27%), and "so-so" (2%). As for RR II, the sample consisted of 200 farmers, who rated it as excellent (19%), very good (55%), and good (24%) (White, 1999).

Another survey was also conducted in 1999 by the INTA experiment station at Marcos Juarez, regarding transgenic soybean adoption of 80 farms in the Northern Pampean region, an area where adoption of transgenic soybeans rose from 23% in 1998 to 80% in 1999. The advantages mentioned by farmers were lower costs (93%) and time saving (71%). Twenty-nine percent of the farmers tested RR soybeans on a test plot before fully adopting. Only 5% of the farmers considered RR soybeans offer improved yields (Aguirre & Segura, 1999).

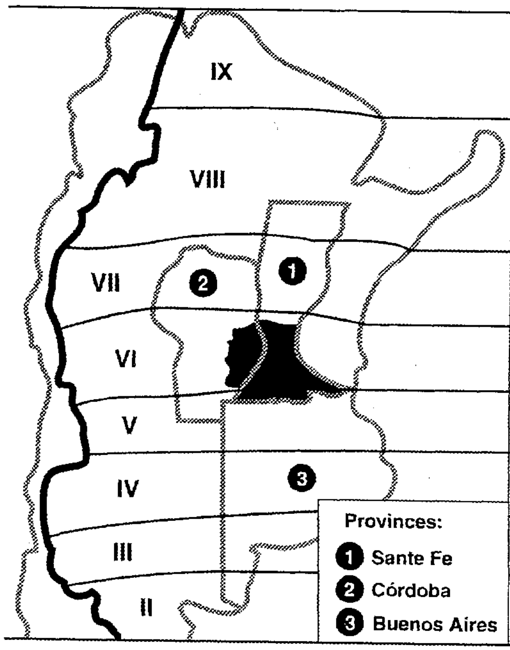
The surveys indicate that the perceptions of Argentinian farmers on the benefits of RR soybeans have changed little after several years of experimentation with the technology. Perceived benefits, centered around cost and improved weed control, seem to account for the rapid adoption. We attempt to measure such economic and agronomic benefits in the next section.

11.2 Agronomic Considerations and Economic Impacts

11.2.1 Agronomic Considerations

Figure 11.3 shows northern Argentina's eight soybean maturity groups. The majority of RR soybean production is concentrated in the darkly shaded area of the map, located in the VI growing region. Hence, we focus on the agronomic and economic aspects of RR soybeans in the northern subregion of the Pampean region, which can be considered as the soybean belt. In this area, no-till has been widely used for years, especially in loam or sand loam soils. No-till is strongly recommended for erosion control due to better coverage of the soil, improved organic matter, less water run-off, and decreased compaction.

Figure 11.3 *Soybean maturity groups in Argentina.*



Maturity Group Identified as Medium Cycle	MG that can be used	N° of MG
IX	IV AL IX	6
VIII	IV AL IX	6
VII	IV AL VIII	5
VI	IV AL VII	4
V	III AL VII	5
IV	III AL V	3
III	II AL IV	3
II	I AL III	3

Source: INTA, "El Cultivo de la Soja en Argentina," 1997.

RR soybeans have facilitated no-till practices by requiring less machinery. For instance, a larger area can be cultivated in a shorter time by sowing and spraying simultaneously with one tractor, direct-drill seeding equipment, and a sprayer. Two applications of herbicide make it possible to eradicate perennial weeds, such as johnsongrass and bermudagrass. Glyphosate is effective in controlling these weeds.

Other benefits of RR soybeans are greater flexibility of sowing time, lower herbicide-related costs, and shorter distance between rows. This is what Carpenter and Gianessi (1999) call "simplicity and flexibility" because of the possibility of eliminating a broad spectrum of weeds with an herbicide that can be applied at any stage of the crop growth.

In Argentina, RR soybeans also have an important impact on the suitability of double-crop production (Wheat/Soybean II). The use of Roundup has greatly improved burndown of weeds when preparing the field for the (late season) second cropping of soybeans.

Unlike traditional herbicides, which can have negative carryovers, glyphosate does not entail residual effects that might harm successor crops (Carpenter & Gianessi, 1999). For instance, if the sowing of soybeans in November was complemented with the application of a highly residual herbicide (e.g. PIVOT), planting of sunflowers in order to eliminate any negative residual effects would require 400mm of rain. However, annual rainfall in the Pampas typically exceeds 400mm.

Farm size does not effect the adoption of RR soybeans in Argentina, because plant genetics is a "divisible technology," which can be applied regardless of the size of the farm—especially when equipment services can be hired from contractors. Small soybean farmers, who account for 90% of farmers using RR soybean (Cazenave and Associates, 2000), can now implement a crop-after-crop rotation pattern that allows them to maintain soil fertility. Prior to the introduction of RR and no-till, the rotation patterns demanded alternating cropping and cattle raising in order to restore soil nutrients, preserve its structure, and maintain adequate levels of organic matter. Many small farms had found double cropping infeasible, while large farms have been more effective in implementing a crop-cattle raising pattern. RR soybeans and glyphosate have made it possible for thousands of small farmers to continue a crop-after-crop pattern, and improve their comparative economics.

11.2.2 Analysis of the Short-Term Profitability of RR Soybeans

The adoption of RR soybeans in Argentina affords a common hypothesis to technology adoption: "If the expected gross margin from the introduction of RR soybeans is greater than that from traditional varieties, while decreasing the risk, then there will be enough stimulus for adopting such technology, and the adoption rate should be high."[3]

Higher gross margins, due to the adoption of RR soybeans, may be caused by yield increases and/or by the decrease in production costs. The gross margin may also be influenced by the price that consumers would be willing to pay for RR soybeans. Should international consumer resistance against GMOs continue to increase, RR soybean price could decrease to a level lower than that of conventional soybeans. In such a case, farmers' gross margins would be affected regardless of farm-level impacts.

Yields could also increase due to more rows per hectare, more efficient management of the water in the soil, or decreased crop damage. However, tests carried out by INTA do not show immediate differences between the yields of RR and traditional varieties when using no-till practices.[4] The results of the tests performed in the northern area of Buenos Aires province in 2000 are shown in Table 11.3.

These results confirm what other researchers have observed: the main contribution of RR soybeans lies in more efficient control of weeds, rather than in the increase of the yield per hectare.

Table 11.4 shows the gross margins of the three common tillage systems for Soybean II and I:[5] conventional tillage/traditional varieties (CT), no-till/traditional varieties (NT), and no-till/RR varieties (NTR). For Soybean I, the difference in the gross margin in favor of the NTR system over the NT system was $14.73 in 1998/99, $16.85 in 1999/2000 and $17.42 in 2000/01, per hectare. These differences are an increase between 4.48% and 6.76%.

Table 11.3 *NTA no-till survey results, 2000.*

	RR Soybean (no-till) (tons/ha)	Traditional Varieties (no-till) (tons/ha)
Under Water Land	2.5	2.4
Under Irrigation	3.6	3.5

Source: Engineer Fernando Mousagnes, INTA San Antonio de Areco (personal communication, 2000).

Table 11.4 *Gross margin of soybean S I and S II.*

S I		**1998**			**1999**			**2000**		
Data	**Unit**	**CT**	**NT**	**NT/R**	**CT**	**NT**	**NT/R**	**CT**	**NT**	**NT/R**
Yield	Tons/h	2.6	2.9	2.9	2.6	2.9	2.9	2.6	2.9	2.9
Price	US$/ton	204.0	204.0	204.0	166.5	166.5	166.5	160.0	160.0	160.0
Gross Revenue	**US$/ton**	**367.2**	**510.0**	**510.0**	**299.7**	**416.2**	**416.2**	**288.0**	**400.0**	**400.0**
Subtotal Tillage	**US$/ton**	**46.3**	**24.5**	**24.5**	**43.5**	**27.2**	**27.2**	**47.8**	**32.4**	**32.4**
Seed	US$/h	23.2	26.1	56.7	18.0	20.2	35.1	18.4	20.7	27.0
Herbicide	U$ S/h	22.1	44.5	19.0	18.0	40.4	15.9	15.5	31.7	13.6
Insecticide	US$/h	5.1	5.1	5.1	5.0	5.0	5.0	4.7	4.7	4.7
Subtotal	**US$/h**	**50.5**	**75.7**	**80.9**	**41.0**	**65.6**	**56.0**	**38.7**	**57.1**	**45.5**
Direct	**US$/h**	**96.8**	**100.2**	**105.4**	**84.5**	**92.9**	**83.3**	**86.5**	**89.6**	**77.8**
Administrative	3.50	12.8	17.8	17.8	10.4	14.5	14.5	10.0	14.0	14.0
Short	1.90	6.9	9.6	9.6	5.6	7.9	7.9	5.4	7.6	7.6
Long	5.80	21.3	29.5	29.5	17.3	24.1	24.1	16.7	23.2	23.2
Loading/Unload.	2.00	7.3	10.2	10.2	5.9	8.3	8.3	5.7	8.0	8.0
Marketing	**13.10**	**48.4**	**67.3**	**67.3**	**39.5**	**54.9**	**54.9**	**38.0**	**52.8**	**52.8**
Harvest	**10.00**	**36.7**	**51.0**	**51.0**	**29.9**	**41.6**	**41.6**	**28.8**	**40.0**	**40.0**
Total	**US$/h**	**182.0**	**218.5**	**223.7**	**154.0**	**189.5**	**179.8**	**153.3**	**182.4**	**170.6**
Gross Profit	**US$/h**	**185.1**	**291.4**	**286.2**	**145.6**	**226.7**	**236.3**	**134.6**	**217.5**	**229.3**
S II		**1998**			**1999**			**2000**		
Data	**Unit**	**CT**	**NT**	**NT/R**	**CT**	**NT**	**NT/R**	**CT**	**NT**	**NT/R**
Yield	Tons/h	1.8	2.5	2.5	1.8	2.5	2.5	1.8	2.5	2.5
Price	US$/ton	204.0	204.0	204.5	166.5	166.5	166.5	160.0	160.0	160.0
Gross Revenue	**US$/ton**	**530.4**	**591.6**	**591.6**	**432.9**	**482.8**	**482.8**	**416.0**	**464.0**	**464.0**
Subtotal Tillage	**US$/ton**	**66.5**	**24.5**	**24.5**	**63.2**	**27.2**	**27.2**	**70.0**	**32.4**	**32.4**
Seed	US$/h	20.3	23.2	50.4	15.7	18.0	31.2	16.1	18.4	24.0
Herbicide	US$/h	35.7	72.9	31.0	32.2	53.7	23.7	27.2	43.3	20.3
Insecticide	US$/h	5.1	5.1	5.1	5.0	5.0	5.0	4.7	4.7	4.7
Subtotal	**US$/h**	**61.2**	**101.3**	**86.5**	**52.9**	**76.7**	**59.9**	**48.1**	**66.5**	**49.1**
Direct	**US$/h**	**127.8**	**125.8**	**111.0**	**116.2**	**140.0**	**87.1**	**118.1**	**99.0**	**81.5**
Administrative	3.50	18.5	20.7	20.7	15.1	16.9	16.9	14.5	16.2	16.2
Short	1.90	10.0	11.2	11.2	8.2	9.1	9.1	7.89	8.8	8.8
Long	5.80	30.7	34.3	34.3	25.1	28.0	28.0	24.1	26.9	26.9
Loading/Unload.	2.00	10.6	11.8	11.8	8.6	9.6	9.6	8.3	9.2	9.2
Marketing	**13.10**	**70.0**	**78.0**	**78.0**	**57.1**	**63.7**	**63.7**	**54.9**	**61.2**	**61.2**
Harvest	**10.00**	**53.0**	**59.1**	**59.1**	**43.2**	**48.2**	**48.2**	**41.6**	**46.4**	**46.4**
Total	**US$/h**	**250.8**	**23.0**	**248.3**	**216.6**	**216.0**	**199.1**	**214.6**	**206.6**	**189.2**
Gross Profit	**US$/h**	**279.5**	**328.5**	**342.2**	**216.2**	**266.8**	**283.6**	**201.3**	**257.3**	**274.7**

The costs of labor, machinery services and other inputs are included in the gross margin calculation. Depreciation and opportunity cost of capital are not included. "Short" and "Long" are transportation costs. Short: less than 63 miles; Long: more than 63 miles. Short plus Long equals the total transportation cost paid by the farmer.

3. There could also be a case where the expected net margin is the same but the risk is lower, which would be preferable to the former situation. The new technology could show a more leptocurtic distribution of the yield than the preceding one.

4. No-till does not improve the yield in the short term. Long-run effects depend on the soil condition of the plot. If the soil is in good condition, yields are likely to be retained and then increase. If the soil is poor, yields will decrease, stabilize, and then increase after time.

5. An equal price and yield per hectare for both commodities is assumed.

In 1998/99, when the area planted with RR soybeans increased dramatically, the production costs of the NTR practice were only 10% lower than the NT practice. Regardless of the small benefit, farmers were still willing to plant RR soybeans.

Varying production costs are the main cause of differences in gross margin. Table 11.4 compares these costs, showing that during the last three years of soybean production in Argentina, the production costs decreased under all three systems, especially in the case of NT and NTR. Direct expenditures for seed and herbicides account for much of the differential.

The cost of RR seeds was significantly higher than traditional seeds, as shown in Table 11.5. After full-scale introduction in 1998/99, RR seed prices decreased at a much faster rate than traditional varieties. In the 2000/01 growing season, RR seeds retained only 48% of their 1998/99 value, while traditional seeds retained almost 80%.

Table 11.5 *Soybean seed prices (US$/kg).*

Year	Traditional Seed	% of 1998-99 Value	Seed RR	% of 1998-99 Value
1998-99	0.29	100	0.63	100
1999-00	0.22	76	0.39	62
2000-01	0.23	79	0.30	48

Source: INTA (Marcos Juarez), Report for Agricultural Extension, N° 54, 59 and 63.

Conversely, the costs of no-till herbicide bundles were 54-56% lower than herbicides used in traditional no-till systems (Table 11.6). This suggests that the cost of the herbicide program was responsible for much of the cost differences between traditional no-till practices and RR/no-till practices. It should be noted that the decrease in production costs for RR/no-till is much more significant when compared to conventional tillage. In sum, the decrease in production costs for the three patterns has not been determined by the actual tilling component, which has been showing a steady cost increase over the last three years.

11.2.3 The Impact on Soybean II

Differences in production costs of Soybean II (double cropped) between the three tillage/seed systems (in absolute values) are lower than those observed for Soybean I (see Table 11.2). In the 1998/99 season, the direct cost of the conventional system was lower than the no-till and the no-till/RR system. In 1999/00, the difference was greater with respect to the no-till system and practically equal to the no-till/RR system. This is due to the lower costs of conventional tilling compared to those of Soybean I. In 2000/01, the direct

Table 11.6 *Herbicide prices for soybean I and II (US$/liter).*

For Soybean I

	Direct Sowing								Direct Sowing with RR			
Year	Round Up	(*)	Misil		Pivot		Select		Round Up		Misil	
1996-97	5.85	100	48.00	100	44.7	100	37.90	100	5.85	100	48.00	100
1997-98	4.80	82	57.00	119	39.00	87	30.25	80	4.80	82	57.00	119
1998-99	4.20	72	46.06	96	34.22	77	31.70	84	4.20	72	46.06	96
1999-00	3.50	60	41.80	87	23.48	53	29.50	78	3.50	60	41.80	87
2000-01	2.95	50	37.00	77	21.62	48	23.50	62	2.95	50	37.00	77

For Soybean II

	Direct Sowing								Direct Sowing with RR			
Year	Round Up	(*)	2,4-D		Senecorex		Galant		Round Up		2,4-D	
1996-97	5.85	100	5.47	100	18.49	100	36.5	100	5.85	100	5.47	100
1997-98	4.80	82	4.60	84	17.40	94	30.00	82	4.80	82	4.60	84
1998-99	4.20	72	4.50	82	19.00	103	30.00	82	4.20	72	4.50	82
1999-00	3.50	60	3.90	71	20.40	110	27.00	74	3.50	60	3.90	71
2000-01	2.95	50	3.70	68	16.00	87	19.50	53	2.95	50	3.70	68

**1996/97 Base year (August equal to 100.) Source: Revista Margenes Agropecuarios, August of each year. Note: Prices do not include V.A.T.*

cost of no-till/RR dropped substantially with respect to no-till. The higher cost of seed under the no-till/RR pattern was offset by the decreased cost of herbicides.

The difference in the absolute value of the gross margin between no-till/RR and the traditional no-till system was lower than for Soybean I. This situation makes the adoption of RR Soybean II more vulnerable to changes in relative input and output price than Soybean I. Any increase in the price of RR seed or glyphosate could discourage farmers from adopting the system.

11.2.4 Risk Analysis: Stochastic Gross Margin Simulation

In the previous sections, the costs and benefits associated with the cultivation of soybeans under different technologies (RR seeds, no-till, etc.) were described. In all cases, analysis was done for average values; the results confirm the advantage of RR soybeans under no-till. This section introduces uncertainty into the calculation of the gross margin for the alternatives available to farmers in the Northern Pampean region.

The stochastic nature of yields and prices is introduced to the analysis by specifying relevant probability distributions. We use a Monte Carlo sampling procedure to evaluate the gross margins for different scenarios and to obtain their respective associated probability distribution, expressed as a Cumulative Distribution Function (CDF).

Six different primary cultivation alternatives in the Northern Pampean region are analyzed:

1. Soybean I RR no-till (SI RR NT)
2. Soybean I no-till (SI NT)
3. Soybean I RR conventional till (SI RR CT)
4. Soybean I conventional till (S I CT)
5. Wheat/Soybean II RR in no-till (W/SII RR NT)
6. Wheat/Soybean II no-till (W/SII NT)

The evaluation of soybean and wheat yield uncertainty can be described through triangular distributions. The parameters used (maximum, minimum, and modal values) were elicited from an interview with a qualified source.[6] The values obtained are presented in Table 11.7.

Another important source of uncertainty is price. The triangular distributions (with the parametric values) representing the uncertainty in prices for soybean and wheat is presented in Table 11.8.

Under these assumptions, a stochastic simulation for gross margins can be carried out. A synthesis of the variables used and the resulting gross margins per hectare are presented in Table 11.9.

Table 11.7 *Triangular distributions of yields (tons/ha).*

Cultivation	Minimum Value	Modal Value	Maximum Value
SI RR NT	2.0	3.5	5.5
SI NT	2.0	3.5	5.0
SI RR CT	1.7	3.5	5.5
SI CT	1.7	3.5	5.0
SII RR NT	1.5	2.0	2.7
SII NT	1.2	2.0	2.7
WHEAT NT	2.0	3.0	5.0

Table 11.8 *Triangular distributions of prices ($/ton).*

Crop	Minimum Value	Modal Value	Maximum Value
Soybean	120	160	220
Wheat	85	110	150

6. *Fernando Mousegnes, Extension Service INTA San Antonio de Areco, Buenos Aires Province.*

Table 11.9 *Gross margins (variables are set at mean values).*

	Yield (ton/ha)	Price ($/ton)	Gross Revenue ($/ha)	Costs ($/ha)	Gross Margin ($/ha)
SI RR NT	3.6	166.7	611.11	230.43	380.68
SI NT	3.5	166.7	583.33	241.11	342.22
SI RR CT	3.5	166.7	594.44	260.12	334.32
SI SC	3.4	166.7	566.66	256.22	310.44
WHEAT NT	3.3	115.0	383.33	310.00	73.33 (1)
SII RR NT	2.0	166.7	344.44	165.12	179.32 (2)
SII NT	1.9	166.7	327.77	157.21	170.56 (3)
W/SII RR NT	—	—	—	—	252.65 (4)
W/SII NT	—	—	—	—	243.90 (5)

Source: Own elaboration (4)=(1)+(2); (5)=(1)+(3).

By running a Monte Carlo simulation with the data (1,000 iterations using @Risk software) a cumulative distribution function (CDF) for each gross margin was estimated. The results were interpreted using the concept of stochastic dominance, which ranks two actions, A and B, each with a probability distribution of outcomes (x) defined by cumulative distribution functions $F_A(x)$ and $F_B(x)$, respectively. A has first-degree stochastic dominance (FSD) over B if $F_A(x) \leq F_B(x)$ for all x. Graphically this means that the CDF of A should always lie below and to the right of the CDF of B (Hardaker et al., 1997). In this example, for a given level of accumulated probability, the farmer will have a larger gross margin with action A than with action B.

If the two CDFs cross, there is no dominance in terms of FSD, and the concept of second-degree stochastic dominance (SSD) is used. In formal terms, second-degree stochastic dominance A is preferred to B if:[7]

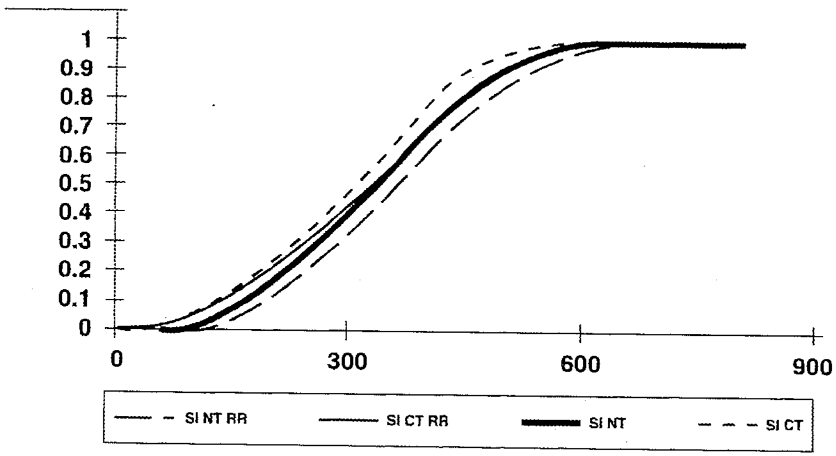
$$\int_{-\infty}^{x^*} F_A(x)dx \leq \int_{-\infty}^{x^*} F_B(x)dx$$

Graphically, this approach means that we have to compare the surface below the two CDFs. If the area below $F_A(x)$ is smaller than the area under $F_B(x)$ then it follows that A dominates B in the sense of SSD (Hardaker et al., 1997).

Figure 11.4 shows the CDF for the gross margin of the four alternatives (SI NT RR, SI NT, SI CT RR, SI CT) previously mentioned, smoothed through the fractile values obtained from the simulation. As can be seen among the

7. *For all values of x^*, with at least one strong inequality.*

Figure 11.4 *CDFs of gross margin—Soybean 1 ($/ha).*



four CDFs, the no-till with RR varieties (SI NT RR) is below and more to the right than the other three, and thus dominates in the FSD sense. At the same time, the alternative of no-till with no RR soybean (SI NT) dominates conventional till with no RR soybean in the FSD sense. The alternative SI NT also presents stochastic dominance in the second-degree sense over the conventional till with RR soybean (SI CT RR). Lastly, the conventional till with RR soybean (SI CT RR) dominates the conventional till with no RR seed (SI CT) in the FSD sense.

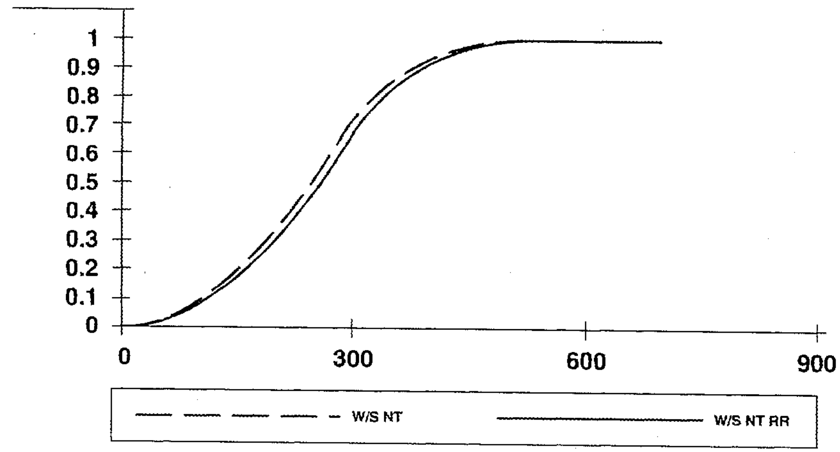
Figure 11.5 portrays the CDF for gross margin of the two combinations of wheat-soybean: SII NT RR and SII NT. It suggests that the no-till alternative with RR soybean dominates in the first-degree sense.

If the assumptions used for this simulation are representative of costs and farmers' perceptions over yields and prices, then the results suggest that for the expected margin:

- No-till is a technique that, once implemented and stabilized, is superior to the conventional till.
- The RR seed is a superior technology compared to common seeds.
- There is a strong complementarity between no-till and RR seeds, because the combination is more efficient, and is the dominant alternative.

These conclusions are consistent with the actual trends observed in the Pampean region. As mentioned previously, the accelerated adoption of RR soybean varieties was accompanied (and probably fueled) by a rise in no-till practices from 1996. Both innovations spread together reducing costs and, at the same time, offered more stable yields. Farmers perceived this situation as highly profitable, which supported the rapid adoption.

Figure 11.5 *CDFs of gross margin—Wheat/Soybean II ($/ha).*



11.2.5 Impact Sensitivity to Input Prices

Clearly, the impact of RR technology adoption on the economic profitability of soybean production is sensitive to changes in input prices. For instance, if the fee for the use of the technology were $17/hectare (as in the US), the difference between the gross margin under the no-till/RR and conventional systems would disappear. In such case, Argentine farmers would have a decreased stimulus to employ the no-till/RR system. Retrospectively, it would be difficult for biotechnology and seed companies to require a technology fee due to the inadequate patent legislation protecting the breeders of transgenic varieties. The lack of patent protection in Argentina compels farmers not to buy original seed every year. An estimate suggests that approximately 40% of the RR soybean area in Argentina is planted with seeds produced and sold directly by farmers.

Partly to counteract the lack of patent protection in biotechnology traits, companies have an incentive to raise the price of herbicides—specifically, the price of Roundup or Misil. These increases affect the cost of RR/no-till, because traditional no-till also utilizes Roundup and Misil. Yet the price of Roundup has decreased by almost 50% in the last five years. This decrease paralleled an increase in the no-till (without RR seed) area cropped. The price decrease of Roundup may have been correlated to the growth of market volume. Some have hypothesized that the price decrease was due to Monsanto's strategy of targeting an increase in use of RR soybean varieties. The price of Roundup could then presumably be increased once farmers became accustomed to using RR soybeans and the company attained a monopoly over the glyphosate market (Albin et al., 2000). However, Monsanto's glyphosate patent has already expired, which has opened the door for competition from other suppliers. In addition, a glyphosate plant is due to open in Argentina, which may further reduce manufacturing/transportation costs.

11.3 The Expected Long-Term Impact of RR Soybean

The introduction of RR soybeans has significantly spread the implementation of no-till (without RR seed) in Argentina. The long-term benefits resulting from the combination of both technologies are as follows:

Better weed control: Better not only for soybeans, but other crops as well. For example, Roundup is especially effective against weeds such as johnsongrass and bermudagrass, which significantly impact corn yields. Corn follows Wheat/Soybean II in the most common rotation pattern: Corn–Soybean I–Wheat/Soybean II–Corn.[8] It should be noted that new herbicides for wheat leave less stubble on the ground (owing to their residual effect), which increases the ease of planting Soybean II, improving the profitability of the series Wheat/Soy II. In sum, RR soybeans, as well as no-till (without RR seed), increased the long-run yield of all crops that make up the rotation pattern, owing to a better management of water and efficient control of weeds. This is important in those areas where weeds have reached high levels of invasion, because glyphosate has no side effects on the soil microflora. Nevertheless, the continuous application of glyphosate could cause weeds to become resistant to it in the long term, making it necessary to use another pre-emergent herbicide.

Control of hydric erosion: The loss of the topsoil has been an increasing problem in Argentina over the last years. For instance, in San Antonio de Areco (one of the districts of the soybean belt), serious potential yield deterioration has occurred because of a loss of topsoil, increased compaction, and decreased water retention capacity. The potential production loss for soybeans was 8% between 1965 and 2000 (Sobral et al., 2001). Soils tilled conventionally lose 10 tons of topsoil per hectare yearly. This loss can be three times as great in soils prone to erosion. However, in cases where non-till/no-till is implemented, such loss is limited to 2.5 tons per hectare per year (Cazenave and Associates, 2000).

8. Technological advances in agricultural machinery are also helping increase the efficiency of production. For instance, new "stripper" cutterbars for harvesting wheat leave the stubble standing, simplifying no-till of Soybean II. Additionally, new sowing equipment for no-till bury and cover the seed better than conventional machinery (Mousegne, personal communication).

Environmental control: The no-till (without RR seed) method prevents agrochemicals from contaminating rivers due to diminished water drainage. It also helps decrease environmental pollution from decreased use of solid fuels. It is estimated that in 10 years the organic matter will have increased from 2.5 to 3.5%. Organic matter absorbs carbon dioxide from the air and releases oxygen, which helps reduce the greenhouse effect (Cazenave and Associates, 2000).

11.4 Conclusion

RR soybean adoption in Argentina, in the past five years, can be predominantly attributed to a greater relative profitability compared to traditional varieties, as well as lower risk. Improved profitability is a result of decreased herbicide costs, and is especially significant when compared to soybean production utilizing conventional tillage practices and traditional seed. Although the cost of the RR seed is greater than traditional seed, the cost is offset by lower herbicide expenditures.

The yields of RR soybeans are not significantly different from those of traditional varieties, and the international price paid for this grain has also remained comparable. However, if international consumers eventually pay a 6% premium for nontransgenic soybeans, the direct cost benefits obtained by the producer would disappear, and could create adequate incentive for increased production of traditional varieties. This situation is even more likely in the case of Soybean II, where the difference in gross margins is smaller than that of Soybean I.

In the medium term, Argentinean prices of RR seed and/or glyphosate are unlikely to rise at the same rate as prices of agrochemicals used by the direct tillage systems (without RR). The imminent increase in Argentina's industrial capacity in glyphosate production is expected to increase competitive pressure. Therefore, future prospects of NT/RR systems providing greater profitability are likely to prevail in the coming years.

The relative profitability of RR soybeans could also be significantly affected by a change in input prices. Beyond gains in gross margins, the "ease" of work provided by RR soybeans could account for some producer value, and is likely to further strengthen continuing interest in RR soybeans.

In addition, RR soybeans have also brought indirect benefits to Argentina, including enhanced use of no-till technology, which along with glyphosate has provided a more effective and efficient weed control treatment. It has also aided in increasing the productivity of the entire crop rotation system in the Pampa Húmeda, especially in corn. The combination of no-till with RR varieties allows small producers to continue this rotation and produce soybeans without the need to integrate cattle operations in the rotation. RR soybeans, together with no-till, have also contributed to a reduction of hydric erosion of Pampean soils, as well as the maintenance of beneficial microflora.

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