Storing soybeans (*Glycine max*) in silo bags: economic outcomes and grain loss risk

Almacenamiento de soja (*Glycine max*) en silo bolsa: resultados económicos y riesgo de pérdida de granos

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Abstract

Silo bags have the potential to increase grain marketing efficiency and to give farmers additional bargaining power. However, silo bags are prone to tearing that can cause grain losses. This article assesses the economic outcomes of storing soybeans in silo bags, as compared to grain commercial storage facilities, considering the risk of grain losses. A bio-economic model of soybean storage is developed and calibrated for Southeastern Argentina. The soybean loss modelling is based on empirical measurements of silo bag losses. Results indicate that both silo bag and grain storage facility profits break-even, with 2% soybean losses. When soybean losses range between 0% and 5%, optimal storage time varies from 8.5 to 9.6 months, respectively. Results show that silo bag storage may not be optimal with 10% losses, and that a 3% price premium can compensate losses of up to 5%. Silo bags constitute a feasible storage alternative that can provided more flexibility to argentine agro industrial system in situations of limited storage capacity or of logistic problems.

Keywords
soybean storage • silo bag • economic outcomes • soybean loss risk • bargaining power

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Resumen

El silo bolsa tiene el potencial de incrementar la eficiencia del comercio de granos y de dar a los productores un mayor poder de negociación, pero es propenso a sufrir roturas que pueden causar pérdidas de grano. Este artículo evalúa los resultados económicos del almacenamiento de soja en silo bolsa considerando el riesgo de pérdida de granos en comparación con el almacenamiento de soja en un acopio comercial. Se desarrolló y calibró un modelo bioeconómico de almacenamiento y comercialización de soja para el sudeste de Argentina. El proceso de pérdidas de soja modelado se basa en mediciones de las pérdidas experimentadas por silos bolsa reales. Los resultados indican que las ganancias obtenidas utilizando el silo bolsa y el acopio se igualan con 2% de pérdidas de la soja almacenada. Cuando las pérdidas de soja oscilan entre el 0% y el 5%, resulta óptimo almacenar entre 8,5 y 9,6 meses, respectivamente. Los resultados indican que con un 10% de pérdidas, no es óptimo almacenar en el Sb, y que la obtención de un diferencial de precio del 3% puede compensar pérdidas de soja de hasta 5%. Por lo tanto, el Sb constituye una alternativa económicamente factible que puede dotar de mayor flexibilidad al sistema agroalimentario en situaciones de falta de capacidad de almacenaje o de problemas de logística.

Palabras clave

almacenamiento de soja • silo bolsa • resultados económicos • riesgo de pérdida • poder de negociación

Introduction

Silo bags (Sb) have several advantages that can improve the efficiency of the grain storage and marketing sector, and potentially help farmers to obtain better margins. This higher efficiency can contribute to increase the added value of the soybean value chain (6). The silo bag is a hermetic system widely used in Argentina to make silage (corn and sorghum), but mainly to store dry grains (3, 7). Farmers in Argentina and in Australia have argued that storing in Sb puts them in a better position to negotiate grain prices, broker commissions or grain handling charges with grain buyers (4, 13). On-farm bins provide the same incentives, but at a much higher cost. Such an increased bargaining power arises because marketing agreements for farmers using Sb are different from the agreements for farmers using commercial grain storage facilities. Farmers not using Sb would haul grain right after harvest and store it at one of the local grain storage facilities. However, once decided for one particular storage facility, the farmer is limited to the price bids from that facility, resigning bids from other potential buyers, such as other grain storage facilities, soybean crushing plants, and direct bids from exporting companies. Typically, farmers not using Sb would wait until prices are convenient enough and sell grains through the commercial grain storage facilities. Marketing agreements for producers using Sb are rather different. Once the silo bag is set at the farm, producers would wait for bids from several potential buyers, thus having more freedom to negotiate transaction conditions, such as commercial commissions and conditioning fees.

In spite of the described advantages, the Sb plastic liner may be damaged through tears and ruptures which might generate varying levels of grain losses (both in terms of quantity and quality). A series of agronomic practices are recommended to minimize the risk of grain losses. Such practices include selecting a clear and leveled site to set the bag, bagging clean and dry grain, periodically monitoring the integrity of the plastic liner and the carbon dioxide concentration inside the bag, and repairing perforations with adhesive patches when needed (1). However, in spite of these efforts, some level of grain spoilage is still likely to occur -increasing risks for Sb users (14).

In Argentina, the traditional marketing channel for cereals and oilseeds has been dominated by commercial grain storage facilities and farmer cooperatives. By marketing grain through a commercial storage facility or a cooperative the farmer has no risk of losing either quality or quantity of his grain.

Even though the use of sb storage technology is spreading around the world, the economic mechanisms that triggered its impressive adoption rates in Argentina have not been adequately studied. The objective of this article is to evaluate the economic performance of storing and marketing soybeans using silo bags, as compared to commercial grain storage facilities, considering the risk of grain losses. Our hypothesis is that, despite the risk of grain spoilage (losses), the storage of soybeans in Sb offers a similar or higher economic return than using commercial grain storage facilities, depending on whether a grain price premium can be obtained. A better understanding of the relative economic performance of Sb and grain storage facilities will help producers better evaluate the advantages and risks of using each storage alternative. The article is organized as follows: First, a soybean storage model is developed. Second, model outcomes for a range of parameters that represent the typical conditions of Argentine farmers are presented and discussed. Finally, conclusions are drawn about the economic performance of each storage alternative, and further research lines are suggested.

MATERIALS AND METHODS

In this section, a bio-economic model of soybean storage is developed and used to determine optimal storage strategies, through a dynamic programming algorithm. Additionally, profits for fixed storage strategies were computed. The model was calibrated for the County of Balcarce in the Southeast of the Buenos Aires province, which is representative of the Humid Pampas region, regarding storage practices. The model considers a risk-averse farmer who has to decide his grain sales in a finite time horizon of $T + 1$ periods after harvesting a known stock of grains, s_1 at $t = 1$. The farmer can choose one of two storage alternatives: a) Sb or b) commercial grain storage facility. The selling decision is made once a month (12 decision nodes). Harvest time is set on April, $t = 1$ (*i.e.*, the month when most of the soybean is harvested in the County of Balcarce), and $t = T$ is March, therefore the next harvest occurs on $t = T + 1$.

The farmer formulates his sale plan knowing that selling q_t units of grain at price p_t generates revenues by $p_t q_t$ along with sale related costs. The price p_t is specified both for the Sb and for the commercial grain storage facility as $p_t \varepsilon \left\{ p^t_s, p^\varepsilon_s \right\}$. For a producer storing and selling though the commercial grain facility, the

soybean price, p_{s}^{ε}, represents the average monthly cash price taken from the Rosario Board of Trade. Average prices for each of the 12 months are computed from a cash soybean price series starting in January 2006 and ending in April 2018. Before computing monthly averages, the series is deflated and expressed as constant April 2018 prices using the Consumer Price Index (IPIM) (8). Finally, the price series is centered at a mean price equal to 240 $/t. The sign $ denotes US dollars.

Previous studies indicate that Sb have the potential to increase the bargaining capacity of producers, by allowing them to negotiate lower marketing costs or higher product prices (4, 13). For Sb users, such an effect is modeled as a price premium that farmers might be able to obtain via bilateral bargaining with different buyers. For each decision node, Sb price is defined as,

$$p_t^s = p_t^e * (1 + \frac{\psi}{100}),$$

where the parameter ψ is the percentage price premium that farmers might obtain when storing soybeans in Sb in their farms. Plausible values for parameter ψ are identified through a survey carried out with farmers and commercial representatives of grain storage facilities in the County of Balcarce. Fifty surveyed farmers and four grain commercial facilities' representatives indicated that price premiums for Sb users usually range from zero to 3%.

With the sale of q_t units of grains, the farmer faces sale-related costs common to both storage alternatives, namely, a commission charged by the buyer, γ_1, proportional to the sale value and a long freight, γ_2, per unit transported from the storage facility to the port located one hundred kilometers away (Quequen port). If the farmer chooses Sb, he must then pay handling charges, γ_3^s in addition to several storage costs: the bagging service fee, the cost of the bag, κ, and the cost of taking the grain out of the Sb, λ. If the farmer chooses a grain storage facility, he faces a short freight from the field to the facilities in addition to handling charges, γ_3^s; storage cost corresponds to a monthly fee per quantity of grain stored, δ, and it normally includes up to 3 months of free storage (table 1, page 271). For both storage alternatives, values for cost and freight parameters are taken from local grain storage facilities and Sb service providers and represent the prevalent rates for April 2018 in the County of Balcarce.

The soybean loss process

The soybean stock evolves according to for $s_{t+1} = s_t - \tilde{w}_t - q_t$ for $1 \leq t \leq T$, where $\tilde{w}_t$ represents the random number of tons of soybeans becoming spoiled and non-marketable in a month t. The monthly loss was estimated from a previous study in which grain losses were measured in 13 silo bags under field conditions in the County of Balcarce (14). In such study, the quantity of soybean lost in each Sb at the end of storage was measured by weighing all grain before and after storage. All silo bags presented variable amounts of localized portions of the grain that had become spoiled and that could not be marketed, but none of the Sb exhibited an extensive spoilage through the mass of grain. The portions of spoiled grain ranged from 0.12% to 11.25%, with an average of 2.03%, (14). It is assumed that at the beginning of storage, grain quality can be described by the following parameters: total amount of green and damaged grains -including sprouted, fermented, burned or rotten grains- below 5% and without odors. Such quality parameters represent the usual grain status achieved by farms of the County of Balcarce.

Table 1. Parameter values and definitions.
Tabla 1. Valores y definiciones de los parámetros.

Parameter	Unit	Value	Meaning
S_1	ton	60	Initial grain stock
$\overline{w}$	ton	{0, 1.2, 3, 6}	Expected total soybean losses
γ_1	%	2.5	Buyer's commission
γ_2	$/t	17	Long freight to port
γ_3^s	$/t	6.0	Sb handling charges
γ_3^e	$/t	6.9 + 6.0	Storage facility short freight + handling charges
κ	$/t	3.0 + 2.3	Bagging fee + cost of the bag
λ	$/t	3.0	Grain extraction fee
δ	$/t/month	1.0	Storage facility storage fee
π_t	$/t	-	Period t contribution to profit
γ	%	3	Annual real interest rate
σ	-	{0.0001, 2, 6}	Risk aversion coefficient
ψ	%	{0, 3}	Sb price premium

Based on the finding of a previous study (14), it is assumed that the portion of lost grain $\tilde{w}_t$ cannot be sold, but the remaining mass of grain maintains the initial quality and can thus be sold without price penalties.

The results of Taher *et al.* (2019b), were used to estimate the probability distribution of grain loss. The authors showed an inverse relation between the amount of soybean lost in Sb storage and the number of recommended management practices implemented by farmers. Therefore, the risk of soybean loss is represented here as a function of the number of recommended management practices employed. As a result, farmers are exposed to different loss probability density functions whose parameters are determined by the Sb management that they perform. In our model, as the number of management

practices employed by the farmer decrease, the soybean loss probability density functions are located more to the right (*i.e.*, with increasingly higher means). The soybean loss density function estimated with the data from Taher *et al.* (2019b), is parameterized to represent different scenarios of soybean loss. The occurrence of grain loss is assumed to be independent from one month to the next: that is, the occurrence of loss in a given month has no effect on the occurrence of loss in the following month. Therefore, soybean loss process is modeled as a first order discrete Markov process. The overall dynamics of soybean loss process is consistent with the theoretical foundations of the evolution of stored grain conditions (3).

Maximum likelihood estimations of several potential distributions were fitted to the data of Taher *et al.* (2019b),

using R (2016) and R package Fitdistrplus (5). The overall fit of the distributions was evaluated and a lognormal distribution was selected as it provided the best representation of the observed data, presenting low values for the AIC and BIC criteria. The selected distribution of soybean loss had a mean of 2.07% and a standard deviation of 0.29%. Once the distribution was selected, 5000 independent random samples were drawn from the distribution and used to estimate the transition probability matrix, P. According to the estimated stochastic process, the probability density function for soybean loss at node t is represented by an ergodic transition probability matrix **P** whose row i, column j element, $\mathbf{P}_{ij}$, is the probability of jumping from state i in period t to state j in period t +1. Given the transition probability matrix **P** and a known initial loss state, w_1, it is possible to simulate representative loss paths by Monte Carlo simulation. This simulation starts from an initial loss state $w_1 = i$ and simulates a jump to w_{t+1} by randomly picking a new state j with probability $\mathbf{P}_{ij}$ (10).

Individual probability estimates, $\mathbf{P}_{ij}$, are obtained denoting as the number of times that a grain loss observation changes from state i to state j, according to

$$\mathbf{P}_{ij} = \frac{n_{ij}}{\Sigma_{j=1}^{J} n_{ij}} \, ,$$

where the denominator is the sum of entries in jth row. Such procedure constitutes the maximum likelihood estimation proposed by Anderson and Goodman (1957).

Grain losses are calculated as t of grain spoiled in month t, but they are reported as a percentage of the total stock in the Results section, to allow for wider generality. The distribution of losses was parameterized by increasing its mean to represent different scenarios of expected total soybean loss, from 0% to 10% of the total stock in a 12 month period (table 1, page 271). Expected total losses are obtained by summing the random monthly losses over the 12 decision nodes $(\overline{w} = \sum \widetilde{w}_t)$. The mean of each distribution represents the expected total grain loss that a given farmer can experience on average and each individual realization of $\widetilde{w}_t$ are the actual monthly losses. While losses for any given year cannot be known in advance, farmers can estimate their expected grain loss from their own records of using Sb, from neighbors or colleagues with a similar agronomic management or from technical publications, in case the farmer has no history of Sb use. Optimal storage strategies using Sb will adjust storage length according to expected total soybean losses, to maximize profits from grain sales. Note that expected total grain losses (reported in the results section) are different from total actual grain losses. However, as each storage strategy may differ in storage length, total actual losses may or may not be equal to expected total losses.

Computation of soybean sale profits

The stock state space is defined to take one of 60 possible values, $q_t \in \{0, 1, 2, \dots, 60\}$. The discrete stock state space is viewed as an approximation to an underlying continuous interval where each loss level represents the mid-point to an underlying continuous interval. Note that each of these mid-points is separated from its previous and following level by 1.67% of the total grain stock, thus leading to small approximation errors. Since short sales are not allowed in any period, q_t is restricted to satisfy

$$0 \leq q_t \leq s_t - \widetilde{w}_t.$$

Thus, for Sb storage the contribution to profit for period t is:

(1)

$$\pi_t^s = \left[p_t^s (1 - \gamma_1) - \gamma_2 - \gamma_3^s - \lambda \, \iota_{1\{t=0\}} \right] q_t - (s_1 - q_t) \kappa \, \iota_{2\{t=1\}} \qquad 1 \leq t \leq T$$

where is $\iota_{1\{t=0\}}$ $(\iota_{2\{t=1\}})$ a binary indicator variable that equals one (zero) in every period except for period 1, when it equals zero (one). The binary indicator variable $\iota_{1\{t=0\}}$ activates the fee for unloading the bag whenever a sale occurs, only if time t is greater than one, while $\iota_{1\{t=0\}}$ activates both the bagging fee and cost of the bag only if time t equals one. As for storage in the grain storage facility, the contribution to profit for period t is: (2)

$$\pi_t^e = [p_t^e(1-\gamma_1) - \gamma_2 - \gamma_3^e - \delta \max(t-4; 0)] \, q_t \qquad 1 \leq t \leq T$$

In order to identify optimal storage strategies, this problem is solved to determine the sale policy that maximizes the expected utility of the sum of the discounted profits generated over a 12 month horizon,

$$max_{\pi_t \, q_t} \; E_1 \sum_{t=1}^{T} \beta^t \left[\frac{\pi_t^{1-\sigma} - 1}{1-\sigma} \right] \qquad (3)$$

where $\beta \in (0.1)$ is the per-period discount factor calculated as $1/((1+r)^{1/12})$, and r is the annual real interest rate. The expression between brackets represents an isoelastic utility function where, $\sigma > 0$, represents the constant relative risk aversion (CRRA) coefficient. The operator $E_1[\cdot]$ is the expectation operator conditional on period t = 1 information. The CRRA utility function is not defined under exact risk neutrality. Therefore, following Lai *et al.* (2003) parameter σ is set equal to 0.0001 (near risk neutrality) to approximate the optimal risk-neutral strategy. Hereafter, this case is referred to as risk neutral. This model is solved as a dynamic programming problem (10), through the following Bellman equation for $1 \leq t \leq T$,

$$v_t(s_t, p_t) = \max_{\pi_t, q_t}\{u(\pi_t) + \beta E[v_{t+1}(s_{t+1}, p_{t+1})]\} \, (4)$$

subject to $\pi_t \geq 0, \qquad 0 \leq q_t \leq s_t - \widetilde{w}_t$ (5)

$$s_{t+1} = s_t - \widetilde{w}_t - q_t \qquad (6)$$

$$v_{T+1}(s_{T+1}, p_{T+1}) = -infinity \qquad (7)$$

p_t is as defined above   (8)

s_1 is given.   (9)

In the above equation, the function in (7) is arbitrarily set to make the farmer sell everything before $t = T + 1$, since grains not sold at or before T become unmarketable (because fresh grain from the new harvest is available). Thus, this means that the model will force $S_{T+1} = 0$.

The model is programmed in Matlab, using the Compecon toolbox (10).

Table 1 (page 271) shows the parameter values used. Each storage alternative is required to be self-financed; thus, when resorting to Sb, farmers are required to sell some grain at harvest time to cover both the bagging fee and the cost of the bag.

Both Sb and commercial grain storage facility alternatives are also compared under three non-optimal selling policies: (i) selling all grains at harvest time, named "selling at harvest" (Note that when selling at harvest, the marketing costs are identical for both the Sb and the storage facility, since there is no storage. Therefore, both alternatives yield the same profits), (ii) selling the same amount every month (*i.e.*, 8.33% of the harvest each month), named "equal monthly sales", and (iii) selling all stored grain (*i.e.*, 96.67% of the harvest for the Sb and 100% of the harvest for the storage facility) in the month with the highest expected price (*i.e.*, December), regardless of soybean

losses, named "December sale". Note that while storage length is adjusted to maximize profits under optimal policies, storage length is fixed under non-optimal policies the storage length is fixed.
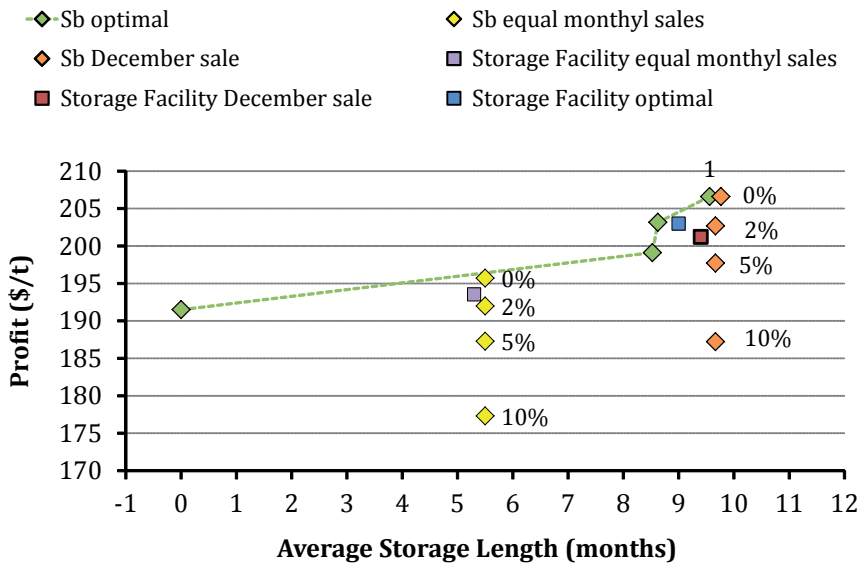
In addition to selling policies, Sb and grain storage facility alternatives are compared considering different values for the main model parameters: (i) soybean losses, (ii) price premiums and (iii) risk aversion levels (table 1, page 271). Once the model is solved, 500 Monte Carlo simulations are run to represent all possible soybean loss paths, according to the random occurrence of grain spoiling. In agreement with Lai *et al.* (2003), the sum of discounted

profits (named simply as profits, hereafter) as well as the average storage length (asl), - the average time that each ton is held in storage is reported for each sale policy.

RESULTS AND DISCUSSION

Figure 1 shows soybean profits and the asl for optimal and non-optimal sale policies, for risk neutral farmers.

Results for risk-averse farmers are presented later in this section. Following the optimal policy, if no losses occur, Sb yields 4 $/t more profits than grain storage facility.

Legend:
- ◆ Sb optimal
- ◆ Sb December sale
- ■ Storage Facility December sale
- ◆ Sb equal monthyl sales
- ■ Storage Facility equal monthyl sales
- ■ Storage Facility optimal

(¹) These points have been slightly displaced horizontally to allow visualization.
(¹) Estos puntos han sido levemente desplazados horizontalmente para facilitar su visualización.
Percentages indicate the proportion of grain spoiled.
Los porcentajes indican la proporción de grano no comercializable.

Figure 1. Optimal and non-optimal storage strategies for the silo bag (diamonds) and the grain facility (squares) for four levels of silo bag's grain losses.

Figura 1. Estrategias de almacenamiento óptimas y no óptimas para el silo bolsa (diamantes) y el acopio (cuadrados) para 4 niveles de pérdida de grano.

This is, in part, because the short freight fee is waived when using Sb, but also because the distribution of sales affects its average price. Optimal storage length without grain losses is 9.7 months for the Sb and of 9.0 months for the commercial grain facility.

However, Sb profits and the optimal storage time gradually decreases with increasing grain losses. With a 2% expected loss, both the Sb and the grain facility yield similar profits (203.1 and 202.4 $/t, respectively). Sb profits are further reduced with increasing expected losses. For such storage alternative, with a 10% loss it is optimal to sell all the grain at harvest, obtaining profits of 191.50 $/t. Along the same line, in a scenario of 10% soybean loss farmers will obtain higher profit storing in the commercial grain facility rather than selling at harvest. Because grain facility has zero losses, following an optimal sale policy, profits are constant at 202.4 $/t.

Results indicate that storing soybean in Sb and experiencing losses of 0%, 2%, and 5%, increases profits by 7.9%, 6.1% and 4.0%, respectively, as compared with selling grains right at harvest. Similarly, storing soybean in grain facility increases profits by 5.7% with respect to selling it at harvest.

Although, Moreno Ferro and Paturlanne (2015) argued that storing soybeans is not economically convenient in 95% of the years, these authors used a historic time series from the period 1994 to 2014 to estimate the soybean price seasonal pattern, which is different than the price series used in our study. The use of a different price series can generate a different seasonality patterns.

Furthermore, these authors considered in their calculations the average cost of the bag and of the bagging service from 2004 to 2014; such average cost is likely higher than the one considered in our study. The different price series and costs considered can account for the differences obtained.

Figure 1 (page 274) also shows non-optimal sale policies. The Sb December sale policy generates profits ranging from 206.6 $/t to 187.2$/t, for grain losses ranging between 0% and 10%, respectively. For this policy, the asl is 9.7 months. Finally, the Sb equal monthly sales policy yields profits from 195.7 $/t to 177.3$/t, with grain losses ranging from 0% to 10%, respectively. For this policy, the asl is 5.5 months. As for the grain facility, its optimal policy and December sale policy generate profits which are close to the Sb equal monthly sales with a 2% soybean loss.

According to these results, soybeans can be optimally stored in Sb for up to 9.7 months, provided no grain is to be lost. However, with expected total losses between 2% and 5%, optimal storage time is 8.5 months, on average. Finally, Sb is not an optimal storage alternative with an expected 10% grain loss; in such scenario, it would be advisable to sell soybeans at harvest. The grain facility represents a better alternative with such level of expected loss. Because non-optimal policies cannot adjust storage length, substantial reductions in profits result from increasing level of soybean loss.

Risk and return profiles of different soybean marketing policies for risk neutral farmers are presented below. In figure 2 (page 276), the dotted line depicts an efficient frontier in terms of profits and variability of such profits. The inclusion of increasingly higher soybean losses determines a downward sloping risk-return efficiency frontier.
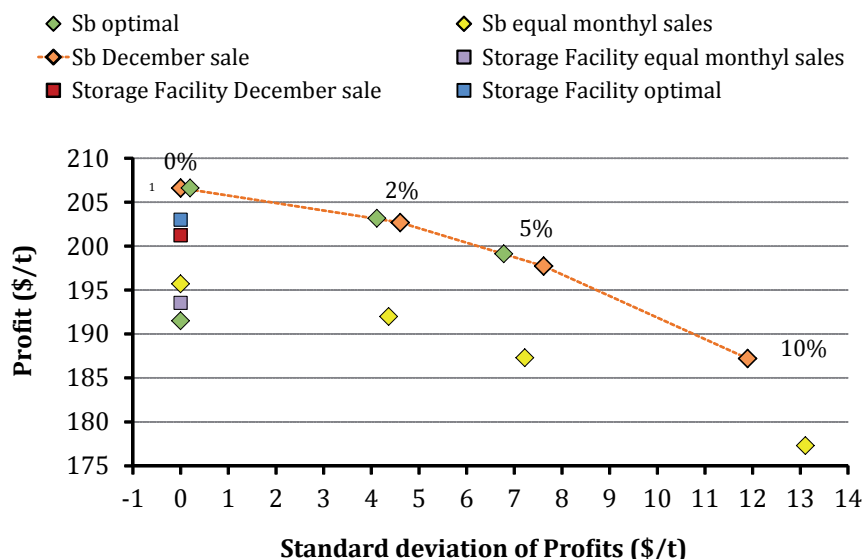
[1] These points have been slightly displaced horizontally to allow visualization.

[1] Estos puntos han sido levemente desplazados horizontalmente para facilitar su visualización.

Percentages indicate the proportion of grain spoiled.

Los porcentajes indican la proporción de grano no comercializable.

Figure 2. Mean and standard deviation of profits for optimal and non-optimal storage strategies for the silo bag (diamonds) and the grain storage facility (squares) for four levels of silo bag's grain losses.

Figura 2. Promedio y desvío standard de las ganancias para estrategias de almacenamiento óptimas y no óptimas para el silo bolsa (diamantes) y el acopio (cuadrados) para 4 niveles de pérdidas de grano.

The optimal Sb sale is the most efficient policy as it yields the highest profits and the smallest standard deviation of profits for each level of total expected losses. The December sale policy has a risk-return profile similar to the optimal Sb policy for grain losses between 0% and 5%.

However, when losses of 10% are expected, selling in December leads to profits of 187 $/t. Because the optimal Sb policy can adjust storage length according to the level of expected losses, it obtains a small advantage over the Sb December sale policy.

The risk and return analysis also shows that grain facility sales, the Sb sales with 0% soybean loss, and selling at harvest imply no risk of losing grain and, therefore, all these policies have a zero standard deviation of profits. Note that selling at harvest becomes the optimal Sb policy when total expected soybean losses reach 10%, yielding a profit of 191.5 $/t.

Finally, the equal monthly sale policy is the least efficient in terms of profit and risk, since it yields lower profits than other policies, for comparable levels of expected losses.

Optimal sale policies for farmers with different risk aversion profiles using the Sb (Panel A) and grain facility (Panel B) are shown in figure 3 (page 278). As the charts show, the optimal sale policy is similar, whether the farmer uses the Sb or the grain storage facility.

For the three risk aversion profiles, the asl, the quantity sold each month and the profits obtained are similar for both storage alternatives.

For risk-neutral farmers using any storage alternative, it is optimal to sell all grain after 9 months of storage, since this storage length provides the best trade-off between a higher income generated by higher prices and the opportunity cost of storing. Risk-neutral farmers using Sb need to sell 3.33% of their soybeans at harvest to cover bagging expenses, which slightly shortens their asl. Risk-averse farmers (*i.e.*, those with σ ≥ 2) value income stability more than risk-neutral farmers; thus, they spread sales over several months to maintain a more stable income flow throughout the year.

Profits for optimal and non-optimal sale policies considering a 3% price advantage for the Sb are shown in figure 4. Such figure also includes profits for the optimal Sb sale policy without the price advantage and profits for the optimal grain storage facility sale policy as references.

Results show that using Sb under an optimal sale policy and obtaining a 3% price advantage can increase Sb profits by 5.6%, 3.8% and 1.8%, for grain losses of 0%, 2% and 5%, respectively, when compared with the optimal storage facility sale policy. Obtaining a price premium increases Sb profits but does not change the asl substantially. Figure 4 (page 279) also shows that a 3% price premiums cannot compensate for a 10% soybean loss, in which case it is optimal not to store in the Sb but rather sell all the grain at harvest, which makes the price advantage disappear.

Results presented show the level of trade-off between grain losses and price premiums. The Sb December sale policy, obtaining 3% price premium and with a 2% grain loss, yields profits which are 4.3% higher than the equivalent storage facility policy (*i.e.*, 209.8 $/t *versus* 201.2 $/t, figure 4, page 279). Therefore, under such a sale policy, a 3% price increase can more than compensate a 2% grain loss. Similarly, the Sb equal monthly sale policy, obtaining 3% price premium and with a 2% grain loss, yields profits 2.7% higher than the equivalent grain storage facility policy (*i.e.*, 198.8 $/t *versus* 193.5$/t). Results indicate that with losses of up to 2% and obtaining a price premium of 3%, Sb can generate profits 2.7% to 4.2% higher than those obtained with grain storage facility.
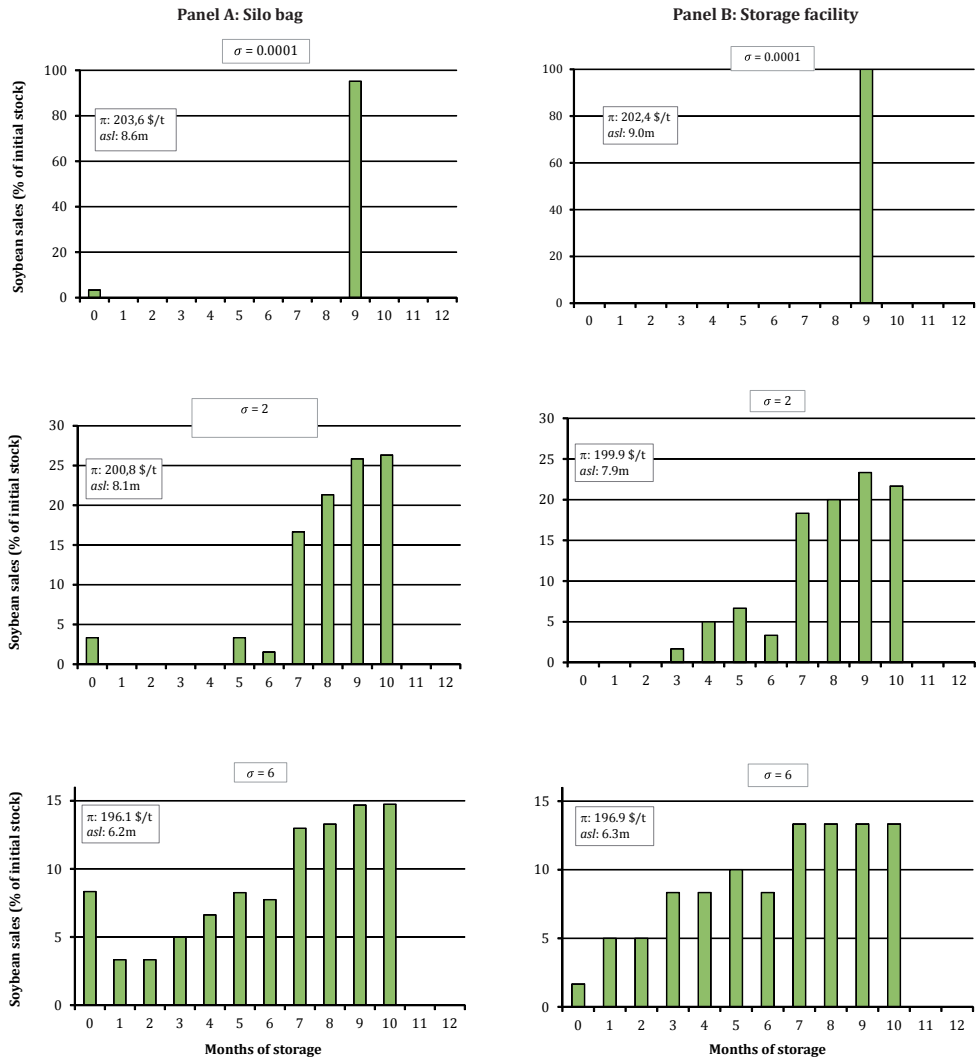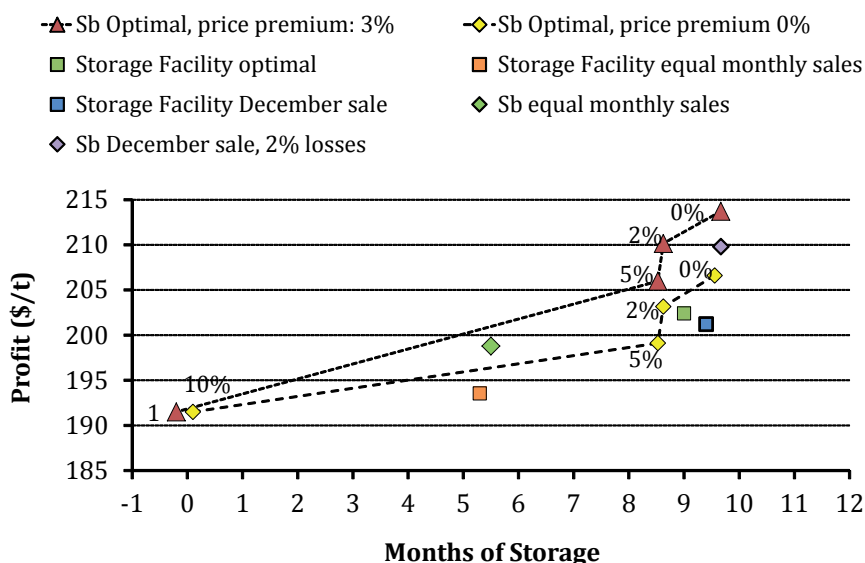
In the charts, π denotes profit and asl denotes the average storage length, in months.

En los gráficos, π indica ganancias y asl indica tiempo de almacenaje promedio, en meses.

Figure 3. Optimal monthly sales for the silo bag, with 2% losses, and for the grain storage facility, for farmers with three risk aversion profiles.

Figura 3. Ventas mensuales óptimas para el silo bolsa con 2% de pérdidas de grano y para el almacenaje en acopio para productores con 3 niveles de aversión al riesgo.

Legend:
- Sb Optimal, price premium: 3%
- Sb Optimal, price premium 0%
- Storage Facility optimal
- Storage Facility equal monthly sales
- Storage Facility December sale
- Sb equal monthly sales
- Sb December sale, 2% losses

(¹) These points have been slightly displaced horizontally to allow visualization.

(¹) Estos puntos han sido levemente desplazados horizontalmente para facilitar su visualización.

Figure 4. Profits for optimal and non-optimal sale policies for the silo bag with and without a 3% price advantage and for the storage facility. Percentages indicate the proportion of grain spoiled. Non-optimal silo bag sales include a 2% grain loss.

Figura 4. Ganancias para estrategias de almacenamiento óptimas y no óptimas para el silo bolsa con y sin un diferencial de precio del 3% y para el acopio. Los porcentajes indican la proporción de grano no comercializable.

Conclusions

The bio-economic model developed here is the first to optimize soybean storage management, taking into account Sb grain losses. Storing soybean in Sb increased profits by 4% to 7.9%, and storing it in a grain storage facility, increased profits by 5.7%, with respect to selling the soybeans at harvest. Under an optimal sale policy, storage length was adjusted given the expected level of total grain loss. When losses ranged between 0% and 5% of the total stock of soybeans, it was optimal to store soybeans during 9.6 to 8.5 months,

respectively. With 10% soybean losses, it was optimal not to store any grain in the Sb. The optimal storage length using the grain facility was of 9 months. The Sb and the grain storage facility profits broke-even when soybean losses were at 2%.

Given these results, it is important that farmers try to reduce grain losses by following the suggested management practices (1), and that farmers take the time to carefully measure their grain losses when storing in Sb in order to adjust storage length. Maintaining the

same storage length with increasing levels of losses can reduce profits substantially. For risk-averse farmers, the Sb created more incentives for them to sell more soybeans at harvest than the storage facility, since this strategy eliminates the risk of grain spoiling, it reduces income variability and it saves costs. Finally, this study showed that obtaining a relatively small price premium (*i.e.*, a 3% price increase) could compensate up to 5% of grain losses. Results presented support the hypothesis that Sb offers economic returns which are similar to, or slightly higher than, the commercial grain storage facility. Therefore, Sb constitutes a feasible storage alternative. Given the limitations of Argentina in terms of permanent storage facilities, silo bags are a valuable tool that can provided increased flexibility to the argentine agro industrial system, especially in years of bountiful harvests or of logistic problems. Beyond our results, this conclusion is also supported by the rapid and widespread adoption of Sb in Argentina and across the world. Finally, two caveats are worth noting. First, our work estimated the loss process with data from one year only, so further research should investigate this process under more general conditions. Second, it is possible that the prevalent seasonal pattern in soybean price can be modified if one selling policy is adopted extensively by many farmers. However, in such a case, farmers can adapt their selling policies to follow the new seasonal pattern and maximize their economic results from the grain sale. The model developed in this article is able to work with different price distributions, including customized distributions.

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