HEDGING AGRIBUSINESS PRICE RISK WITH CROP ROTATION IN BRAZIL: A REAL OPTIONS APPROACH

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ABSTRACT

This paper uses the Real Options Theory in the Brazilian agricultural sector to value the financial effect of crop, or cultivation, rotation. To this end, four different annual crops commonly grown in Brazil were selected: Soybeans, Corn, Cotton and Wheat. Then the stochastic process that best suits the uncertain behavior of the historical prices of these crops was determined through several statistical approaches. Monte Carlo simulation modeling is then applied to estimate the financial value of the possibility of cultivation rotation by the Real Options Theory over a projected 10-year planting period. For the Real Options valuation, the Operational Profit of a production in an area of 500 hectares is used. The results show that the actual annual crop rotation option adds significant value to the producer as well as a significant risk reduction. It is also apparent that the lower the price correlation between assets, the greater is the effect of the actual crop rotation options.

Keywords: Real Options; Crop Rotation; Mean Reversion; Monte Carlo Simulation.

1 INTRODUCTION

Over the past 40 years, Brazil evolved from being a net food importer to a major global supplier and a major player in world agribusiness industry Klein & Luna (2018).. In 1960 the per capita production was 376 kg of grains, 26 kg of meat and 70 liters of milk. By 2015 this had increased to 1,004 kg, 118 kg and 171 liters, respectively, even though the population grew from 70 million to 205 million in this same period. Coffee accounted for half of all the country´s exports from 1840 to 1960, but by 2016 represented only 3% of all Brazilian exports, while soybeans accounted for 30% of the total.

Agriculture has always been one of the strengths of Brazil´s economy, and has evolved from extensive monocultures during the colonial period to a diversified portfolio of products in the 21st century. Since the 1990s, Brazilian producers have become major world-wide suppliers of products such as soy, meats, sugar, orange juice, corn, cocoa, cotton and tobacco (KLEIN & LUNA, 2018). Major technological advances in agricultural production due to scientific research mainly led by the Brazilian Agricultural Research Corporation (Embrapa, 2019), have allowed Brazilian agribusiness to reach competitive levels of productivity with other world producers. In addition, new systems for planting and land use have also brought gains in productivity and helped reduce environmental impacts.

Agribusiness is recognized as an industry subject to significant risks arising uncertainty over commodity process, cost of production inputs and harvest yields due to climatic effects. In addition, farmers have the flexibility to switch annual crops between harvests, in a process known as crop rotation, depending on the variation in prices of each crop. Thus, crop planning, which involves the choice of which product to cultivate, must take into consideration the return and financial risks associated with this decision. This involves the use of analysis tools to assist the producer in the decision making process. As shown by Bastian-Pinto, Ramos, Ozorio, & Brandão (2015), the majority of Brazilian agricultural producers are small to medium sized and generally operate with small margins of return. In these cases, a bad decision can generate significant losses for the producer.

The most commonly used valuation tool is the Discounted Cash Flow method, which assumes that future cash flows will occur as predicted and does not capture the uncertainties and flexibility that may be associated with an investment opportunity (DIXIT & PINDICK, 1994; TRIGEORGIS, 1995). Given that agribusiness investment projects typically present significant managerial flexibilities, the Real Options Approach (ROA) is better suited for evaluating this class of projects and it is able to determine the value derived from any options that may be embedded in the project (DIXIT & PINDYCK, 1994; COPELAND & ANTIKAROV, 2002).

The main objective of this paper is to analyze the financial return derived from the flexibility to rotate crops between harvests and compare the results obtained with plantation of the same selected crops in mono-cultivation. This will allow determining if there are any financial gains derived from this flexibility. Annual crops, in contrast to perennial crops, can be changed at each harvest without the need to respect the growth period of the species considered (SANGUINO et al., 2007).

We model the flexibility to choose the optimal product to cultivate in each harvest period as an European switch option over a period of 10 years. The most appropriate stochastic process to simulated product price behavior is based on historical price series, which is then modeled with Monte Carlo Simulation. The results indicate that there is a significant increase in financial return when considering a greater number of different crops for rotation, as well as a reduction in the risk associated with a loss in mono-cultivation. This work contributes to the literature by showing how ROA can be applied in the Agribusiness sector and assist producers in making the optimal crop choice decision.

This paper is organized as follows: after this introduction, it covers the literature on Brazil´s agriculture and the flexibilities available to producers as well as Real Options, Stochastic process issues and Monte Carlo Simulation in the field. The model utilized is them described with pertinent data source and treatment. Results are listed and explained, followed by a discussion on these. Finally, we conclude.

2 LITERATURE REVIEW

2.1 UNCERTAINTY AND FLEXIBILITY IN AGRIBUSINESS

Franchini et al. (2011) argue that the rotation of crops in annual plantings in Paraná State bring several productivity and even environmental advantages and allow to maximize the return of the producer, subject to the price fluctuations of the products of the used crops.

Mohan (2007), on the other hand, found that among the uncertainties associated with coffee production, the price volatility of coffee is the one that mostly affects the return of producers, even when considering the volatility of the exchange rate between coffee producing countries. Due to this relative importance among all the risk factors that affect the farmer's return, the author suggests the use of derivatives by producer cooperatives.

Hart, Lence, Hayes, & Jin (2015), verify that agricultural prices in the United States, have a mean reversal behavior due to productions cycles. They model prices by a process similar to the Schwartz (1997) mean reversion model, to estimate the necessary hedge level to adequately protect soy producers in that country. Hauer, Luckert, Yemshanov, & Unterschultz (2017) apply the ROA to assess the real options present in the conversion of land use between agriculture and forest production in the Alberta region of Canada. It is worth remembering that this country is one of the main pulp producers in the world.

Livingston, Roberts, & Zhang (2014) study the optimal sequence of alternation between soybean and corn planting in the United States using real options and compare the result with monoculture, in a work very similar to that developed in this paper, yet limited to these two cultures. Di Corato & Brady (2019) verify that by using a real options model, the value of the land increases when considering future flexibilities and uncertainties regarding passive or non-alternating culture. Song, Zhao, & Swinton (2011) also study the effects of uncertainty and the irreversible cost of switching between soybean and switchgrass rotation and the flexibility to choose only energy crops. They compare results by net present value and the optimal decision to consider the uncertainty of crop returns.

Musshoff (2012) uses Real Options to estimate the value of investment timing delay for short rotation coppices for energy production of wood chips in norther Germany, an area with low agricultural output since the area is mostly sandy with little water-storing capacity. This author finds that farmers should not convert until the present value of the investment returns exceeds the investment costs considerably.

Wolbert-Haverkamp & Musshoff (2014) assess the effect of planting fast-growing forests using real options in Sweden. Ehmke, Golub, Harbor, & Boehlje (2004) uses TOR to measure the value of investment in organic wheat production using precision agricultural technology. The results reveal that the option to wait until the market uncertainty is resolved is very valuable. Irene & Konstadinos (2009) in their study attempt to assess the optimal investment price trigger for a new producer in the organic dairy sheep farming system in Greece and secondly, to assess the profitability of an organic farmer's investment in an attempt to improve production. The results indicate that ROA is a more adequate form of analysis if the issue of investment profitability is examined in an environment of risk and uncertainty.

Junior, Dantas, Baldissera, & Bertolini (2019) verify the contribution of using the Real Options Approach (ROA) in the analysis of investments in the diversification of rural production in the state of Paraná in Brazil. Its results point out that the Theory of Real Options is a more accurate method to calculate the present value in rural production diversification projects, as it better captures managerial flexibility and the movement of NPV considering the project's volatility.The concept of crop rotation, or cultivation, implies making the decision to alternate, without costs associated with that decision, or with reduced costs, the agricultural culture of an area with some objective of gain, be it financial or productivity (LIVINGSTON, ROBERTS, & ZHANG. 2014, CORATO & BRADY, 2019; SONG, et. Al. 2011; FRANCHINI et. Al., 2011; FICK, 2011; SANGUINO et al., 2007). To have this flexibility, the producer needs to be considering only crops of annual planting, that is, whose decision to produce in the next harvest does not depend on the one currently being produced.

2.2 Important Non Perennial Crops in Brazil

Brazilian agriculture has proved to be among the most diversified in the world, and a leader in the production and export of some crops. Brazil is the main world producer of soy (recently overtaking the United States), sugar (often competing for the first place with India), in addition to coffee, orange and cocoa, among others (KLEIN & LUNA, 2018). Some products of world consumption, are still little present in Brazil, but increasing in production. Among these we can highlight corn, wheat, cotton and rice. In addition to fruit and tropical products such as açaí and palm, the latter is often known in Brazil as palm oil.

Listed below are the products that are the subject of this study: soy, corn, wheat and cotton. The choice of these crops is due to being the most appropriate annual planting crops for crop rotation as suggested by Franchini, Debiasi and Torres (2011), in addition to having daily price series in the CEPEA / ESALQ / USP database (2019). Another annual crop common in Brazil but which was not included in the scope of this study was rice. The reason for this is that this crop needs flat areas and extensive irrigation due to its own production characteristics. This fact prevents it from being a culture conducive to the rotation of annual crops such as those selected for this study (KLEIN & LUNA, 2018).

2.2.1 Soybeans

Soybeans are one of the main products of world agriculture, due to the wide range of uses of their by-products and derivatives. Among these, soybean oil is produced through the crushing process and has soybean bran as a by-product. About 12% of the weight in grains is transformed into oil, the remainder being transformed into bran, which has its greatest use in the production of animal feed. Brazil is currently the world's largest exporter of soybeans, and often disputing this position with the United States. With regard to world production, and having an internal production of 125 million tons in 2019, it once again surpassed the United States, which produced 97 million tons in 2019 (INDEXMUNDI, 2020). The production of the 10 main producing countries can be seen in

Figure 1. It is interesting to note that until 1977 Brazil did not appear among the world producers. Since then, most of the other competitors have remained stagnant, while Brazil and Argentina (currently the world's third largest producer with 53 million tons produced in 2019) started growing soy production leading to what was called in the 2000s from Brazil- Argentina Soy Boom.

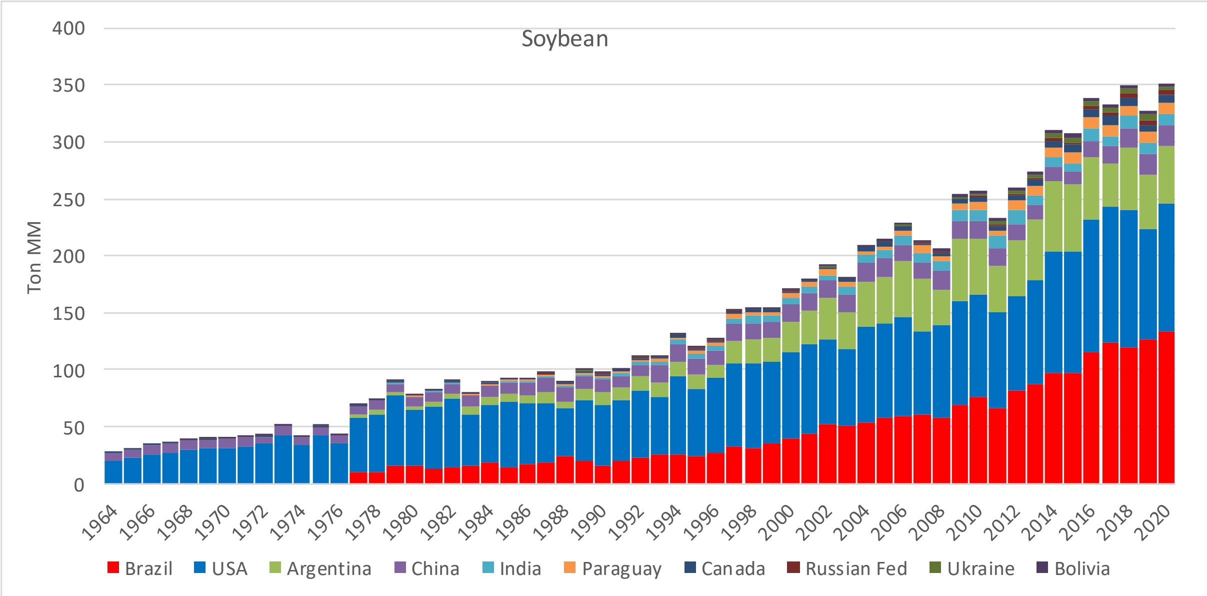

Figure 1 – Major Soybean Producers.
Source: Indexmundi (2021)

2.2.2 Corn

Extensively used as human food or animal feed because of its nutritional composition, corn is a cereal grown in much of the world. Brazil is the third largest world producer (SLC AGRICOLA, 2019; INDEXMUNDI, 2019), with its production growing rapidly compared to other producers. Corn plays a key role in crop rotation, as it produces a large amount of straw that helps protect the soil and recycle nutrients. It is the main crop used with crop rotation, along with Soy, both in Brazil and in the United States (FRANCHINI et al., 2011; LIVINGSTON et al., 2014). Despite not being a major exporter of the product, this is still due to the growing domestic demand even for ethanol production, its prices are based on the international quotation multiplied by the exchange rate. The 12 largest current corn producers in the world can have their historical production monitored in Figure 2.

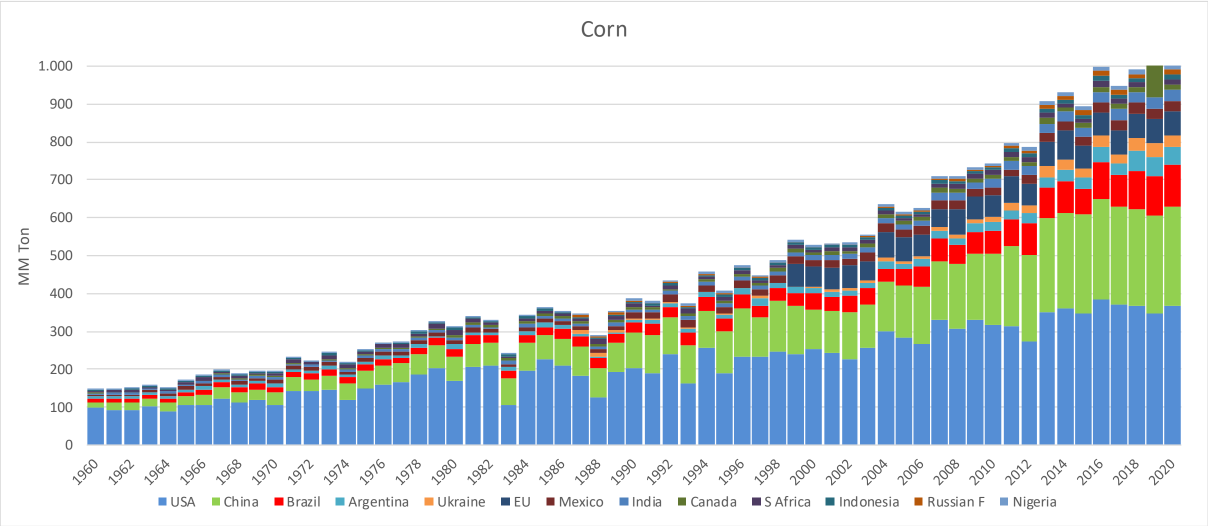

Figure 2 – Major Corn Producers.
Source: Indexmundi (2021)

2.2.3 Wheat

Wheat is the cereal whose crop ranks second in production in the world, second only to rice (INDEXMUNDI, 2020). Its grains are staple foods used to make flour, bread and are an ingredient in brewing. In 2013 Brazil was the second largest importer of wheat in the world (7.3 Million Tons) according to FAOSTAT data (2019), and appears as the 15th world producer (INDEXMUNDI, 2020). Wheat is the main agricultural product imported from Brazil. Despite having grown, this production does not reach the productivity of other major world producers such as the European Union, China, India and the Russian Federation, largely due to the climatic conditions of Brazil, which are not very suitable for wheat (KLEIN & LUNA, 2018). Even Argentina neighboring Brazil, has significantly higher production. This importance, as well as the country's deficiency, make wheat an interesting crop to be included in the study of crop rotation. Its domestic price is strongly related to the international quotation and the exchange rate despite having important government subsidies due to its internal demand (KLEIN & LUNA, 2018).

2.2.4 Cotton

It is a white fiber that grows around its seeds. Brazil, despite being a major producer, is not considered a significant exporter of cotton lint, but rather processed cotton textile products (MDIC, 2019). In recent years, Brazil has remained among the top five world producers, alongside countries such as China, India, USA and Pakistan (ABRAPA, 2019). The 8 largest current cotton producers are listed in Figure 3. As the main agricultural source of a textile-based product, it is also an important crop for inclusion in the present crop rotation study.

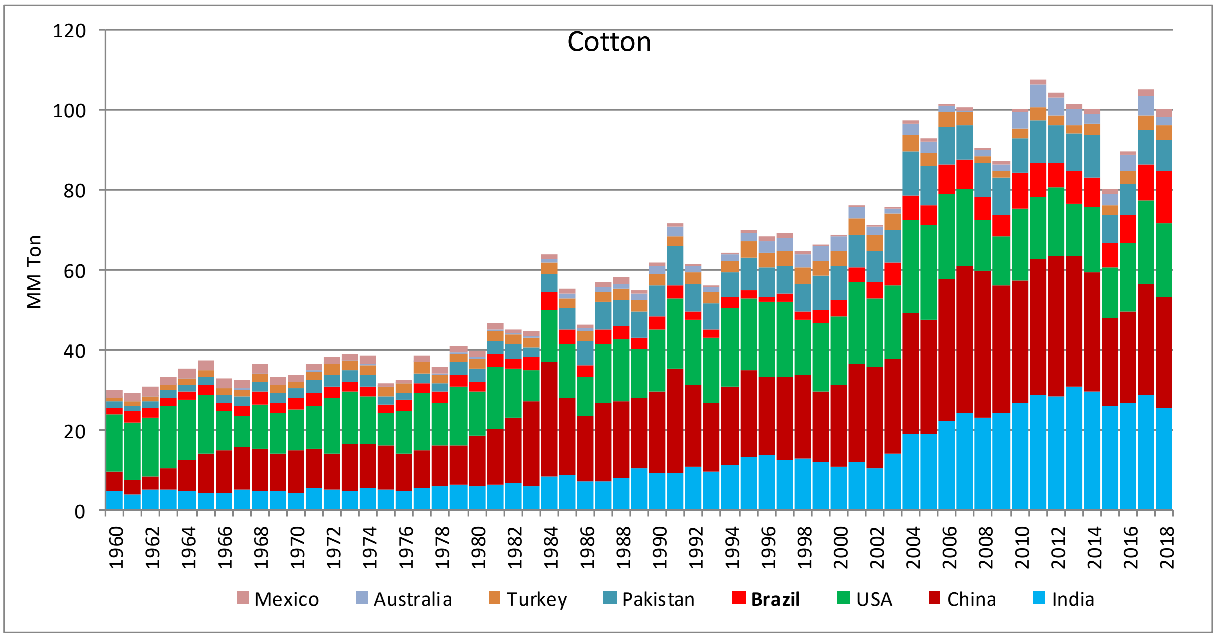

Figure 3 – Major Cotton Producer.
Source: Indexmundi (2021)

3 MODEL

The modeling of the present study considers the stochastic treatment of time series of agricultural prices and applies the theory of real options to estimate the value arising from the option of alternating crops for each harvest. In this chapter, both the model parameters and the stochastic process to be used and the form of evaluation used are estimated and determined.

3.1 Stochastic Processes

Most studies using ROA consider stochastic processes in their models. A stochastic process is a variable that develops in time in a partially random way, with little known basis for its prediction. The Black & Scholes (1973) models are based on a stochastic process model known as Brownian Geometric Movement (MGB).

$$dS = \alpha S dt + \sigma S dz \tag{1}$$

Although MGB is widely used according to Dixit & Pindyck (1994), due to its variance growing indefinitely over time, it can be considered unsuitable for modeling uncertainties that have an equilibrium level defined by microeconomics. According to this, when the prices of a product are very high, this will cause an over-supply, which will lead to their fall, thus generating a cycle of oscillation around an equilibrium price level. The stochastic model that represents this behavior is called the Mean Reversion Model (MRM).

MRM is often recognized as most suitable for modeling commodity prices (BASTIAN-PINTO, BRANDÃO, HAHN, 2009). MRM is also a Markov process where the intensity of the standard deviation as well as the direction are dependent on the current price level and revert to an equilibrium average that is assumed to be the average price in the long run (BASTIAN-PINTO, BRANDÃO, 2007).

Schwartz (1997) proposes a versatile and easy to apply geometric mean reversion (MRM) model described by equation (2):

$$dS = \eta\left[\ln\bar{S} - \ln S\right]Sdt + \sigma Sdz \tag{2}$$

Where S is the price of the asset; η is the mean reversion speed parameter; σ is a volatility parameter; $\bar{S}$ is the price equilibrium level (or average), dt is the time increment; and dz is Wiener's increment. According to Bastian-Pinto (2018), the expected value equations, simulation and parameter determination of the single factor reversal factor model of Schwartz (1997) are:

The value expected by equation (3):

$$E\left[S_t\right] = \exp\left\{\ln\left(S_{t_0}\right)e^{-\eta(t-t_0)} + \left[\ln\left(\bar{S}\right) - \frac{\sigma^2}{2\eta}\right]\left(1-e^{-\eta(t-t_0)}\right) + \frac{\sigma^2}{4\eta}\left(1-e^{-2\eta(t-t_0)}\right)\right\} \tag{3}$$

The simulation equation for this process can be written as (4).

$$S_t = \exp\left\{\ln\left[S_{t-1}\right]e^{-\eta\Delta t} + \left[\ln\left(\bar{S}\right) - \frac{\sigma^2}{2\eta}\right]\left(1-e^{-\eta\Delta t}\right) + \sigma\sqrt{\frac{1-e^{-2\eta\Delta t}}{2\eta}}N\left(0,1\right)\right\} \tag{4}$$

Also according to Bastian-Pinto (2018), to calibrate the parameters of the MRM model by Schwartz (1997) from time series St, a simple linear regression can be performed. From this the parameters are obtained by the following equations.

$$\eta = -\ln(b)/\Delta t \tag{5}$$

$$\sigma = \sigma_\varepsilon\sqrt{\frac{2\ln b}{(b^2-1)\Delta t}} \tag{6}$$

$$\bar{S}' = \exp\left[\left(a + \frac{\sigma_\varepsilon{}^2}{2\left(1+b\right)}\right)\Big/\left(1-b\right)\right] \tag{7}$$

3.2 Data Collection

In addition to the information and concepts described in the theoretical framework, it was necessary to obtain data on the price series for the sale of the products under study. One of the main sources of information on historical prices of agricultural products produced in the Brazilian territory is the Center for Advanced Studies in Applied Economics at the Luiz de Queiros Higher School of Agriculture at the University of São Paulo - CEPEA / ESALQ / USP (2019). This collection collects daily and publishes on its website, price series both in *Reais* (R $) and in American dollars (US$) due to international competition being an important factor in the agricultural products market. The CEPEA / ESALQ / USP (2019) price survey with an already established methodology makes this institution one of the main information centers related to Brazilian agribusiness. These data reflect the effective remuneration of producers in the surveyed regions. As the work proposes to evaluate the financial return of producers, national prices converted into US$ on the same day were considered, for possible comparison with other international studies. As explained in the theoretical framework, among the crops considered in the study, only soy is a product predominantly intended for export, with Brazil even being a net importer of wheat (MDIC, 2019).

3.2.1 Agricultural Prices Series

For the present work, the spot prices (SPOT) of the chosen products and their calculated monthly averages were raised, on a daily basis and in US $. The data collected goes from March 2006, the oldest date from which there are values for all four cultures object of the study, until December 2020, obtaining series of 178 months. The series are plotted in figure 4.

The availability of the time series surveyed by established methodology and widely disseminated on the CEPEA website is one of the reasons for choosing the four cultures in this study. Other sources do not have Brazilian price series for so many products and with such frequency. Only these products, in addition to rice, have series with this time span at the time of this study. For the reason explained in Chapter 2, rice was not the subject of this study. Series of commodity prices traded on commodity exchanges are available from several sources, but the interest of this study is to verify the financial remuneration of the Brazilian producer and his financial risk in agricultural production. The series of spot commodity prices refer to the first contracts to expire on future prices, compared to the prices used which are raised by the CEPEA / ESALQ / USP methodology directly with the Brazilian agricultural producer, therefore more aligned with the objectives of the present study.

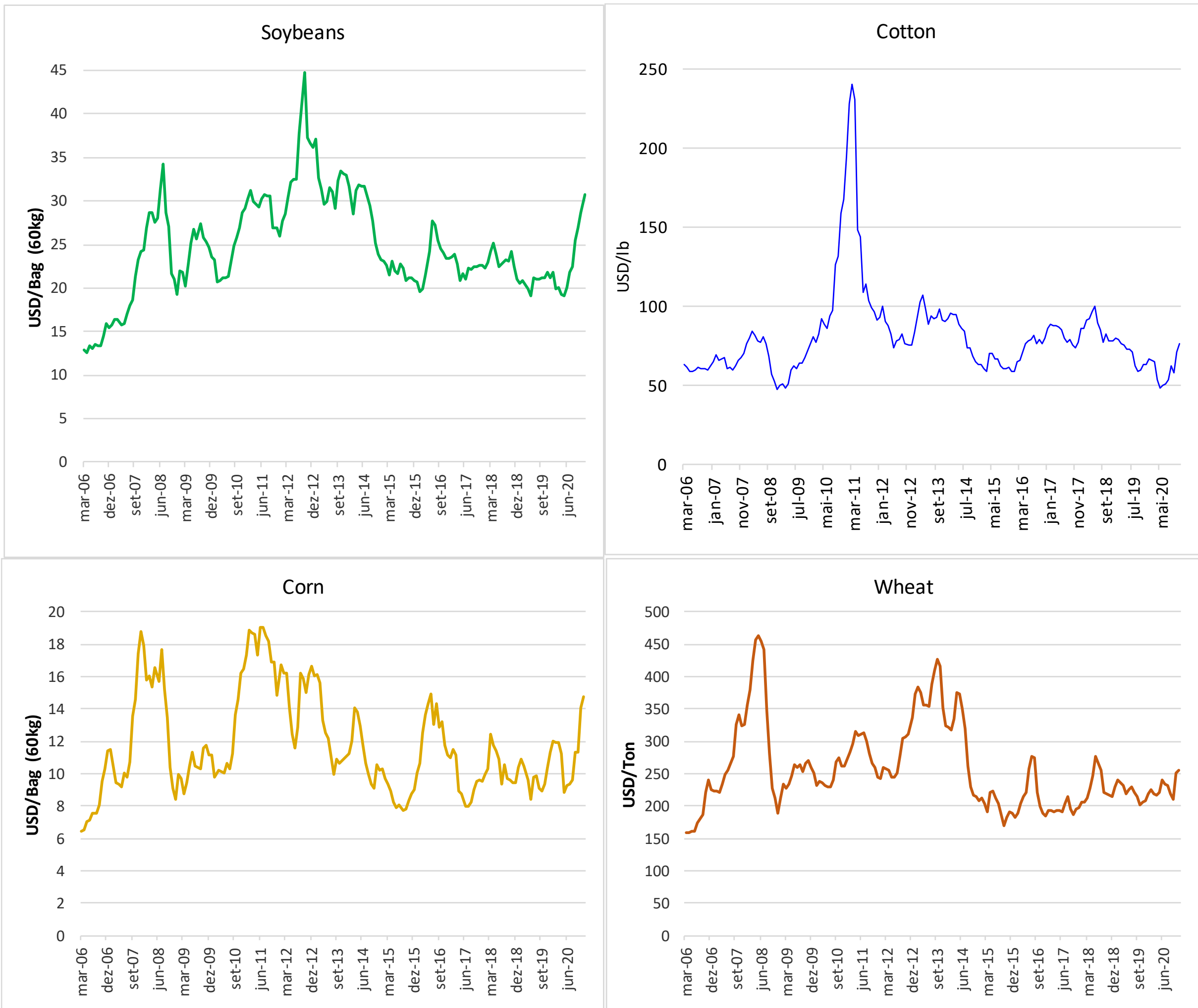

Figure 4 – Price series Soy, Cotton, Corn and Wheat– Monthly average
Source: CEPEA/ESALQ/USP (2021)

3.2.2 Production and Productivity Costs

In addition to the price series of the analyzed products, data related to productivity and production cost of the crops object of this study were also researched. These were collected from different sources and sources. The main ones for total production costs per Hectare (HA) were the websites of IMEA (2019), Syngenta (2019) and CEPEA / ESALQ (2019) itself. The values, both of productivity and production costs, vary depending on the production location, harvest and variety within the analyzed product. However, in this work, mean values of these variables were considered for the Monte Carlo simulation, assuming that only prices change every year. This simplification is in line with the literature, especially Mohan (2007), who suggests that prices are the factor of uncertainty that most affects the return and risk of agricultural producers. It is also consistent to assume that climatic variations, such as droughts and droughts, affect different crops in a uniform manner, therefore not having as significant an effect as prices on the producer rotation option. The values used can be seen in the Error! Reference source not found, in both R $ and US $. The conversion rate between the two currencies used is 4.00 R $ / US $ since this corresponds approximately to the average quotation of the American currency in Brazil in the last year (2019).

	Productivity		**Fixed Cost**
	Value	/ Hectare	USD/HA
Soybeans	58.87	bag 60 kg / Ha	946.00
Cotton	3,313.8	lb/ Ha	2,077.86
Corn	121.49	bag 60 kg / Ha	801.,66
Wheat	4.44	Ton /Ha	705.00

Table 1 – Productivity and Production Fixed Costs for the cultures studied
Source: IMEA – CEPEA – Syngenta (2020)

3.3 Data Treatment

3.3.1 Statistical tests for Stochastic Process Determination

For the verification of the most suitable stochastic process to be used in the modeling of the price series for Monte Carlo Simulation, these were converted to Natural Logarithm (LN) and seasonally adjusted using the EViews® software (option Census X12 which returns the LN series) price without seasonal effects). The seasonality effect can generate biased reading, both of the statistical tests and of the parameters of the modeled stochastic process. Therefore, this treatment is of fundamental importance before the following analyzes. These series were then subjected to the following unit root tests: Augmented Dickey-Fuller (ADF.

The unit root tests seek to verify the persistence of the time series of prices, which would be proof of the possibility of modeling this by a MGB. In the case of the ADF test (Augmented Dickey – Fuller), the null hypothesis H0 seeks to confirm the presence of a unit root, indicating the persistence of the analyzed series, and thus pointing to a typical MGB behavior. In the opposite case, if H0 is rejected, the persistence of the series cannot be confirmed, thus inferring its stationarity, opposite characteristic of persistence and indication of the presence of Reversion to the Average. The reading of the test t statistic (negative value) is compared with the critical values of the test for various levels of accuracy: 10%, 5% and 1%. The lower the value of the rejection level of the test, the greater the certainty of rejection of the H0 and, therefore, the greater the confirmation of the possibility of modeling by Reversion to the Average. The critical values of the ADF test can be seen in the listings in the results tables of the EViews® software in Appendix 2.

The summary of the ADF tests applied to the series of the study is shown in Table 2. It can be seen that by ADF only the Wheat confirms the rejection of Single Root with an accuracy of 1%. The other three series confirm the rejection of Root Unit between 5% and 1%, which would confirm the non-persistence of all series. In other words, the ADF test points to the Reversion to Average behavior in the series, especially in Wheat, but with strong indications in the other three.

	Soybeans	**Cotton**	**Corn**	**Wheat**
ADF				
T-Stat	-3.0317**	-3.3820**	-3.5350***	-3.,7400***
Prob (T-Stat)	0.34%	1.29%	0.82%	0.43%

Statistical significance: ***: 1%; **: 5%; *: 10%

Table 2 – Unit Root tests for price series

3.3.2 Stochastic Process Parameter Estimation

The annual mean reversion modeling parameters were estimated by equations (5), (6) and (7) of chapter 3.1. These are listed in annual values for use in the Monte Carlo simulation model, in Table 3. The values of the parameters of η (mean reversion speed in annual values), σ (volatility in annual values) and $\bar{S}$ (equilibrium level in USD), thus obtained are used in equations (3) and (4) of expected value and simulation for Monte Carlo simulation modeling that are used in the deterministic evaluation and crop rotation options according to the projection of these prices agricultural products.

	Soybeans	Cotton	Corn	Wheat
η (reversion speed) eq (7)	0.614	0.520	0.942	0.666
σ (volatility) eq (8)	21.18%	27.77%	31.30%	24.52%
$\overline{S}$ (equilibrium level) eq (9)	27.4	85.44	12.78	273.58
	USD/bag (60kg)	USD/lb	USD/bag (60kg))	USD/Ton

Table 3 –MRM Model parameters for Monte Carlo Simulation (annual values)

It can be observed that among the products of the study, corn has the highest volatility (σ) and mean reversion speed (η), indicating a characteristic behavior of agricultural commodity. Cotton, on the other hand, despite having strong volatility, has a lower reversal speed among those analyzed. The opposite occurs with soy: lower volatility and high speed of reversion. Wheat is among the other products in these two parameters. It is important to remember that the value of options is always related to the volatility of the underlying assets, but in the case of average reversal models, the speed of reversal also has a strong influence on the value of options (BASTIAN-PINTO, 2018).

3.3.3 Price Series Correlation

Also for the Monte Carlo simulation, the correlations between the series of log returns of product prices used were estimated, shown in Table 4. These correlation parameters, calculated for each pair of price series, are estimated from the series of log price returns and are also used in Monte Carlo Simulation for stochastic projection of these.

	Soybeans	Cotton	Corn	Wheat
Soybeans	1.000			
Cotton	0.3342	1.000		
Corn	0.5271	0.4279	1.000	
Wheat	0.4698	0.4312	0.4159	1.000

Table 4 – Price series correlation

It can also be observed that the pairs of products analyzed have a significant correlation of their returns. These can be classified as strong (above 0.5): Soy / Corn; medium (from 0.4 to 0.5): Wheat / Cotton and Wheat / Corn; Wheat / Soy; and weak (below 0.4): Soy / Cotton. This classification is based only on the observation in Table 4. The correlations between the pairs of products, as well as the parameters of the stochastic process, have a strong influence on the value of the options evaluated at work.

3.3.4 Price Series Adjustment for Risk Neutral Approach

One of the important characteristics of financial derivatives and real options is that they need to be discounted at a risk-free rate. For this, the operating profit (OP) must be adjusted to an equivalent value neutral to the risk, to obtain the same Present Value that results from the risk-adjusted valuation. An approach similar to that of Freitas & Brandão (2009) was used, which describes the procedure to perform this adjustment in the case of stochastic processes of the MGB type. But in the present case with averaging reversal modeling, the price level of the stochastic variable St to which prices converge is estimated (see Table 3): (S ^ *)¯ by the risk-neutral approach. This is done by a numerical approach in such a way that the projection of Operating Profit (equation (10)) obtained, using the expected value of the stochastic price variable E [St] of equation (10), when discounting the free rate of risk Rf = 3.2% (nominal in US $), this returns the same present value as when discounted using the risk-adjusted rate and the original equilibrium value S¯. The initial values for the price simulation correspond to the average of the series prices during the year 2018. The initial prices, equilibrium levels and risk-neutral equilibrium levels can be seen in Table 5.

Product	Unit	S_0	$\bar{S}$	$\bar{S}^*$
Soybeans	USD/bags 60 kg	29.68	27.40	26.91
Cotton	USD/lb	73.45	85.44	82.33
Corn	USD/bags 60 kg	15.17	12.78	12.45
Wheat	USD/Ton	253.28	273.58	267.48

Table 5 – Starting prices, equilibrium and Risk Neutral equilibrium prices

It can be observed in Table 5, that at the time of the survey of prices for the study, the current prices in US $ for the four products studied are below the long-term equilibrium levels, with Cotton and Wheat being the most distant percentages. In Appendix 4, price developments over the 10 annual periods of the projection, the Operating Profit (LO) and the Present Value of the latter for each of the 4 cultures analyzed can be followed, in this case estimated using the risk-adjusted rate of eq (12).

3.4 PRODUCTION TYPE AND CHARACTERISTICS OF CULTURES OF THE STUDY

As previously mentioned, agribusiness is recognized as a sector subject to a significant degree of uncertainty and risk, where the prices of its products, usually commodities, are highly volatile and suffer competition from not only domestic but also international producers. Its production inputs, such as fertilizers and agrochemicals, also suffer frequent fluctuations and are supplied by large companies. In addition, the producer is always subject to fluctuations in production due to different impacts such as eventual pests, but mainly due to climatic effects such as droughts, droughts or excessive and prolonged rains. This high price volatility, in addition to the other exogenous and endogenous uncertainties mentioned above, makes the agricultural producer look for operational ways to reduce his production and revenue risks (FRANCHINI et al., 2011). The sector is also recognized for the variety of possible products that can be grown, as well as the possibility of exchanging production between them (SANGUINO et al., 2007). This production flexibility, associated with the high degree of price and revenue uncertainty, make this sector highly conducive to the application of Real Options valuation.

Due to the primary information gathered, the scope, type and dimension of the work to be modeled were defined. This study contemplates the theoretical modeling of a hypothetical farm (or field) of 500 Hectares (or 5 Km^2). It was estimated that this area is large enough to be considered a production unit focused on an activity for the purpose of capital remuneration. A larger area, such as 1,000 hectares, could have production problems due to low pest control or even logistical bottlenecks in harvesting and marketing. On the other hand, a smaller area, such as 100 hectares, does not have enough production to be competitive, and would be more suitable for a production laboratory or for cultivating products to support the activity of making, such as beans and cassava.

On this hypothetical farm there may be several crops. In order to consider the exchange options in the model, only non-perennial crops or annual crops are treated. In order to be able to choose what to plant before each harvest, and after harvest, easily change crops, crops such as cotton, soy, corn, wheat and even rice can be contemplated. In this way, it is possible to compare how the financial return would be over a 10-year time horizon in a crop without exchanges (mono-cultivation) where the highest present value is chosen, and the model with the built-in exchange. In this model, in each period the expectation of the future price of that year will be observed and the choice of whether to switch production or not, always aiming at maximizing its financial result. The region to be considered must necessarily have the capacity, or be adequate, to receive a diversity of cultures, and have a logistical structure to care for and dispose of the plantation of these chosen cultures (KLEIN, LUNA, 2018). The cultures chosen in this work are:

1. Soybeans: for being the main Brazilian agricultural crop, extensively cultivated in several biomes and regions of the country (EMBRAPA SOJA; 2020, LIVINGSTON et al., 2014).

Soy in grains is the main current product on the Brazilian export basket according to data from the MDIC (2020).

2. Corn: because it is one of the fastest growing crops, has a large international market and is frequently used in alternating planting with soybeans, both in Brazil and in the United States (EMBRAPA MILHO AND SORGH; 2020, LIVINGSTON et al., 2014). Corn production in the country has grown significantly to the point that it is even used, even on a small scale, for the production of corn ethanol (CANAL, 2019). This production is strongly driven by the winter harvest in the producing regions (FRANCHINI et al., 2011).
3. Cotton: also with high growth and market, and annual planting (EMBRAPA ALGODÃO, 2019; CONAB, 2019).
4. Wheat: despite having low productivity in Brazil when compared to other countries, the market is assured by the product deficit in the country (EMBRAPA TRIGO; 2019). A significant part of Brazilian wheat consumption is imported (KLEIN, LUNA, 2018; MDIC, 2019).

The area defined for the typical farm in the present study can be characterized in a wide area of the Brazilian territory, which accepts the crops object of this. Some of these crops are better suited to a specific area, such as cotton in western Bahia, Mato Gross and Goiás, while wheat is more suitable for Rio Grande do Sul and Paraná. Soy and corn are produced in all these areas as well as São Paulo, Minas Gerais and Mato Grosso do Sul. We will therefore consider a farm of 500 hectares (area of 5 km2) considered large in the region and located in the West of the State of SP, Minas Gerais or Paraná wide and flat areas, conducive to the selected crops (FRANCHINI et al., 2011). Other possible ones are, for example, the agricultural borders of Bahia and Minas Gerais (EMBRAPA, 2019; CONAB, 2019; IMEA, 2019).

3.5 CULTURE ROTATION MODEL WITH MONTE CARLO SIMULATION

We considered a farm for exchange or alternation of culture among those selected in the study, of medium to large size (500 Hectares), between the west of the State of São Paulo, the State of Paraná or the east of the State of Mato Grosso do Sul. The medium to large size suggests a professional management that should study the best rotation approach due to the financially optimum result to be obtained by the farm. This means that if one culture points to a better financial result than another, in an expected harvest, it will be chosen over what is in production in the previous (harvest) period.

The exchange option was estimated based on the Present Value (PV) of the Operating Profit (OP) of 10 years of production, without considering Income Tax (IR), as this applies equally to the revenue of all crops regardless of choice of the producer. The OP would correspond to the EBIT (Earnings Before Interest and Taxes) of a company with financial statements. Investment in land also does not generate depreciation, so it does not affect income tax in each period. The 10-year term has been determined, as it is sufficiently long for the prices of the products considered, in expected value, to have practically reached their long-term average with a difference of less than 1%. Thus, the Present Value obtained from the 10 years of OP of each culture, or each exchange option, reflects well, especially for comparison between the alternatives, the remuneration value derived from the real options studied.

It is considered that the farm project also uses only equity, therefore having no financial leverage effect. The Operating Profit (OP) formula for each crop is eq (8).

$$OP_t = [S_t \times Prod\ - Cost\ ] \times Area \tag{8}$$

where:

- S_t is the price in USD (for: *Kg* (Soybeans and Corn), Pounds (Cotton) or Ton (Wheat);
- *Prod:* is the productivity in weight per HA;
- *Cost* is the total production cost per area (USD/HA),and
- *Area*: Is the area considered – in this study a 500 HA area is considered
- The Present Value (PV) for each culture is estimated with eq (9).

$$PV_0 = \sum_{t=1}^{t=10} \frac{OP_t}{(1+k)^t} \tag{9}$$

In eq (8) and (9) parameters are: S_t product price in *t*, and *k* risk adjusted discount rate for agriculture producer which will be used for the model without options. As prices are already in USD, parameters are estimated for nominal US rates. The model used for the cost of capital k is the CAPM, with eq (10).

$$k = R_f + \beta_U \times MRP_{us} \tag{10}$$

Where: *Rf* is the risk free rate, MRP_{us} the Market Risk Premium for US stock market, and β_U the unlevered sector beta factor (we are estimating no financial leverage in this study). We used the 10-year Treasury note with com R_f = 3.2%, and the MRP_{us} = 5.6%. These values are available from

Bloomberg systems. The β_U sector was obtained from the Stern Business School of Damodaran (2020), and corresponds to β_U (Farm/Agriculture) = 0.50. Therefore the risk adjusted discount factor used is: k = 3.,2% + 0.5 x 5.6% = 6.0%, in nominal USD rate.

To estimate the value of the options of crop change (or Switch Options) we assume that at every beginning of a period (year) the producer will choose the crop that, according to the current prices, will provide the greater Operational Profit (OP). Therefore, he will exercise an option of OP maximization according to eq. (11).

$$OP_t^{max} = \max\left[OP_t^1; OP_t^2; ...; OP_t^n \right] \tag{11}$$

Where OP_t^{max} is the *OP* already maximized through the exercise of the switch option, and OP_t^1 ... OP_t^n represent the values of *OP* of all the crops considered in the forecasted period.

It is still worth mentioning that the work is not evaluating the return on capital investment made by the producer. This investment would be the value of the land acquired for production. And this is the same for all evaluated crops, since they will be produced on the same land unit, or farm. Therefore, the Net Present Value (NPV) of the investment in the crops was not calculated, but the financial remuneration derived from the net production of the direct costs of the crops.

4 RESULTS

The PV distributions for each product considering their respective volatilities are in Figure 5, made by Monte Carlo Simulation (MCS) using the Palisade Decision Tools® Sotfware @ Risk®. 100,000 (one hundred thousand) interactions were carried out to obtain the results of the frequency distributions of the Present Value of Operating Profit (eq. 9 and 10). The distributions show the average value of the Present Value (PV) of the Operating Profit (OP) of the four cultures analyzed. This value is used as a result of the VP, already incorporating the value of the Real Culture Exchange Options. In the distribution of MCS results, the probability (%) of a culture, or exchange of cultures, to obtain a PV of negative value and the estimate of the product of the negative value by the probability of its occurrence (US $) can be observed.

In the distributions of Figure 5, it can be observed that the Wheat has the lowest Present Value (average). However, also the distribution with lower probability of negative result, therefore less risk between the analyzed cultures. In all the Figures that describe the individual cultures, for easy reading and visualization, uniform colors were used to describe each of the cultures: Soy in Green, Maize in Yellow, Cotton in Blue and Wheat in Orange.

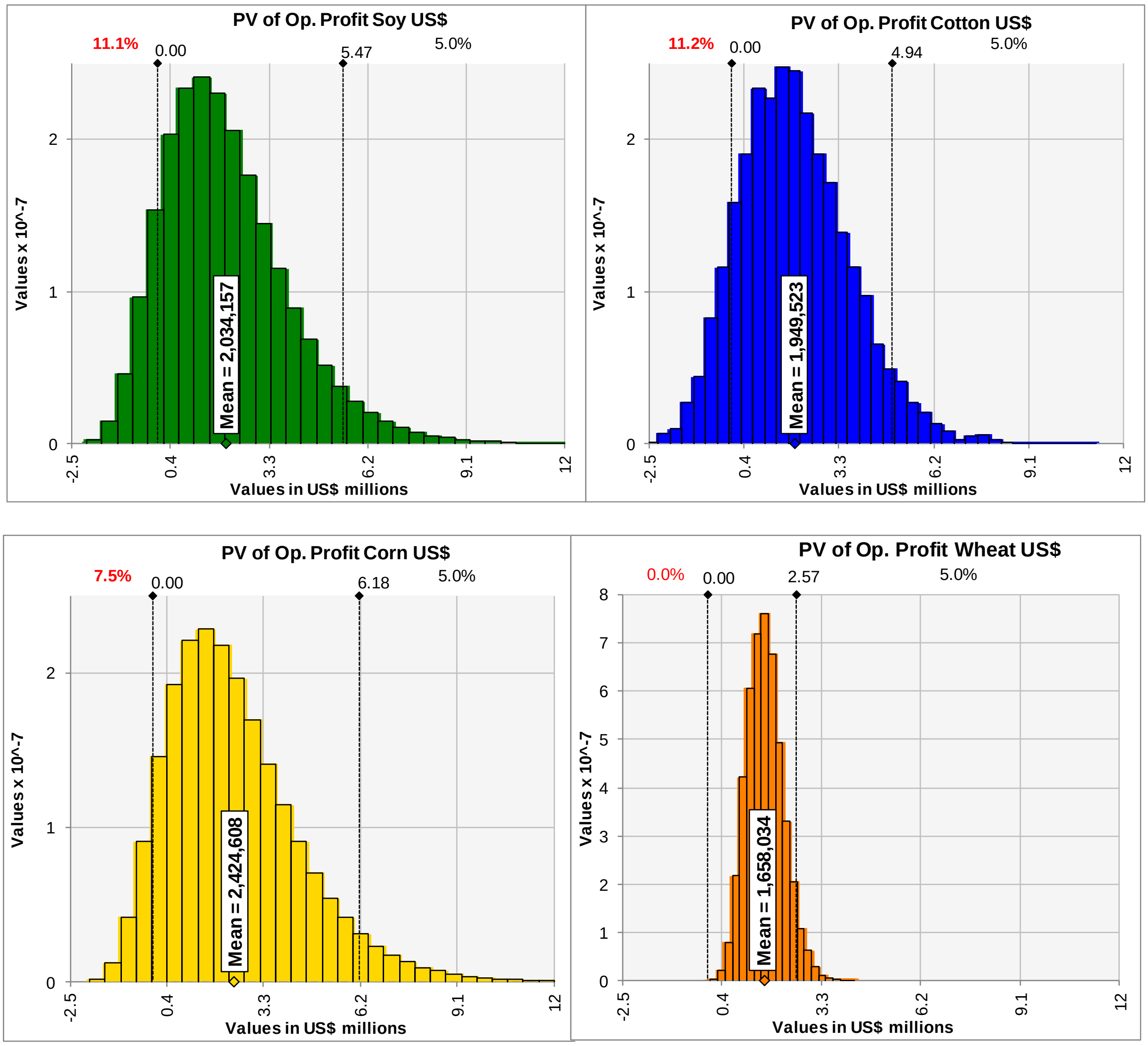

Figure 5 – Probability distribution of OP for Soybeans, Cotton, Corn and Wheat production

The summary of the analysis of the four cultures in mono-cultivation for 10 years is shown in Table 6. In this the mean PV is practically that of the deterministic approach and is the value that can be observed in Figure 5, as the average of the simulations obtained. The 3rd column of Table 6 also lists the probabilities of obtaining negative PV values, which is directly observed in the probability distribution figures, in the upper axis, on the left in red. And this value is a very intuitive risk measure regarding the planting of the crop under analysis.

Crop	Mean of PV (USD)	Prob of PV <0
Soybeans	2,034,157	11.10%
Cotton	1,949,523	11.20%
Corn	2,424,608	7.50%
Wheat	1,658,034	0.00%

Table 6 – Results for Mono-cultivation for each Crop

It can be seen in Table 6, that Wheat has the lowest present value and the lowest risk of PV <0, therefore also lower risk. The opposite is not fully confirmed, that is, greater return and greater risk.

4.1 VALUE OF THE CROP ROTATION FOR PAIRS OF CROPS

Monte Carlo Simulation is now applied to calculate the alternation or rotation option between different pairs of the studied cultures. This is done by maximizing the Operating Profit of the selected crops in each period. The principle is that the producer at each beginning of the planting season will choose the crop that projects (based on the expected price for the next harvest period) the maximum LO among the alternatives considered. As it is the most produced crop in the country, soy will be considered one of the reference crops in the options below. The first Rotation alternative analyzed is the most common both in Brazil and in the United States because they are the main crops: rotation between Soy and Corn. The result of the analysis is in Figure 6.

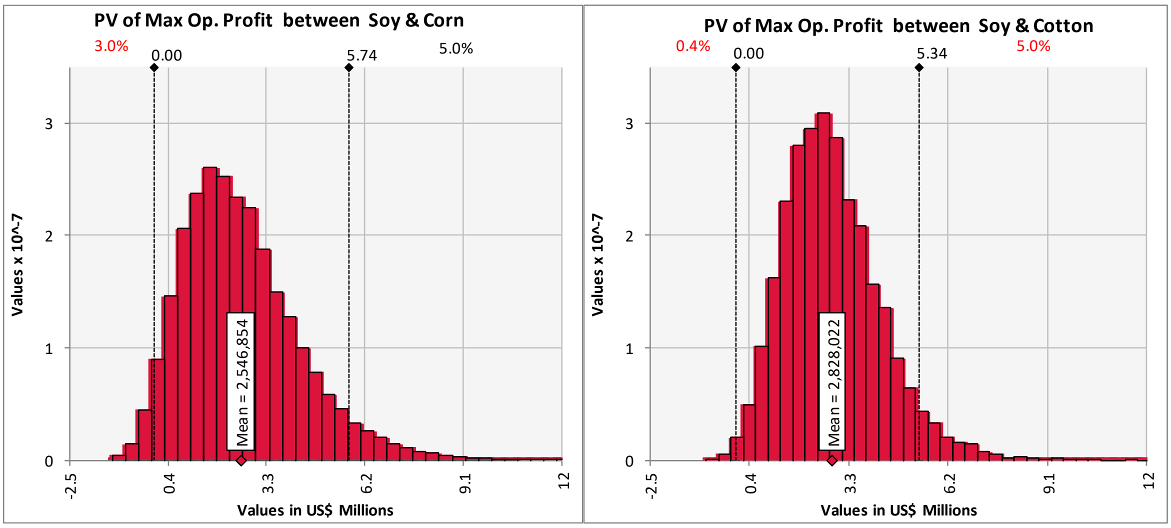

Figure 6 - Probability distribution for VP of OP for Soybeans and Corn rotation (left), and for Soybeans and Cotton rotation (right)

It can be seen that this rotation option adds a small value to the highest value crop (corn): 2,546,854 - 2,424,7608 = US $ 122,246, that is, 5.0% over corn. The main explanation for this low value seems to be the high correlation (0.538, the highest among the pairs of products analyzed, according to Table 4) between the prices of the two products: when one of the prices is high or low, the strong correlation with the another will cause it to have a similar variation (with high probability), making the possibility of rotation add little value to this rotation alternative.

Then, the same option values were calculated for other pairs of products: Soy and Cotton, Soy and Wheat, and Maize and Cotton. The results are in Figure 6 and Figure 7.

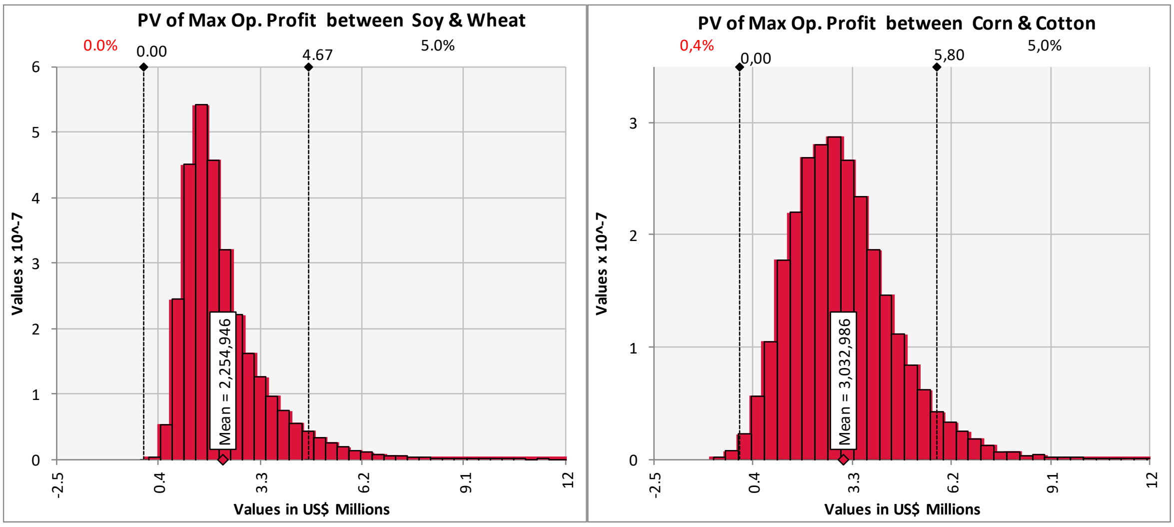

Figure 7 - Probability distribution for VP of OP for Soybeans and Wheat rotation (left), and Cotton and Corn rotation (right)

It can be observed that the pair of crops that provide the greatest return is the alternation of Soy and Cotton, with an increase of US $ 768,346, that is, 37.4% over the soybean single-crop alternative. And in this case, it is probably the result of the lowest correlation (0.318, Table 4) among all the pairs of cultures analyzed. But the pair of crops that presents the least risk is the soybean and wheat rotation, with zero probability of negative value.

4.2 VALUE OF THE CROP ROTATION FOR 3 AND 4 CROPS

5 DISCUSSION

6 CONCLUSIONS

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