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ARTICLE

Portfolio theory approach to plan areas for growing cotton, soybean, and corn in Mato Grosso, Brazil

Abordagem da teoria do portfólio no planejamento de área de cultivo de algodão, soja e milho em Mato Grosso, Brasil

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Abstract: This study aims to describe how cotton farms in the state of Mato Grosso in Brazil are configured by building a model that optimizes income and risk for a combination of crops (cotton [first and second crop], soybean, and corn second crop). Two regions were defined: North and East Central Aggregate. The first region comprises the production of soybean in the summer and cotton and corn in the second harvest, while the second is restricted to the cultivation of cotton and soybean in the summer and corn in the second harvest. An optimization model was used to build a production efficiente frontier of crop combinations by analyzing the return-risk ratio. The model shows that the use of soybean crops in the summer season provides greater gains in profitability. Revenue is maximized in the area by an increase in the cotton crop during the first harvest; however, this exposes the farm to greater production risks. The use of second crops helps mitigate this production risk for farms.

Keywords: Markowitz, efficiente frontier, production system, risk management, agricultural planning.

Resumo: Este trabalho teve como objetivo descrever como as propriedades de algodão no Estado de Mato Grosso se configuraram, construindo um modelo que otimize a renda e risco da combinação dos cultivos (soja, algodão safra, algodão 2ª safra e milho 2ª safra). Foram delimitadas duas regiões: Agregado Norte e Centro Leste. A primeira compreende a produção de soja no verão e algodão e milho na segunda safra, enquanto a segunda se restringe ao cultivo de algodão e soja no verão e milho na 2ª safra. O modelo de otimização foi utilizado para construir uma fronteira de eficiência produtiva de combinações de culturas, analisando a relação retorno-risco. O modelo mostra que o uso da safra de soja no verão proporciona maiores ganhos em rentabilidade. A receita é maximizada com um aumento da área para a cultura do algodão na primeira colheita, o que, no entanto, expõe a fazenda a maiores riscos de produção. O uso da segunda safra atenua os riscos de produção da fazenda. A diversificação de culturas se mostrou o melhor caminho para gerir o risco, dado que a utilização do maior número de cultivos resultou nas melhores relação entre retorno e risco.

Palavras-chave: Markowitz, fronteira eficiente, sistema de produção, gestão de riscos, planejamento agrícola.

1 Introduction

Brazil is recognized worldwide as a major producer of grains and cotton with Mato Grosso being one of the areas with the highest production. Between the 2013-2014 and 2017-2018 harvests, Mato Grosso accounted for a national total production average of 28% for soybeans, 27% for corn, and 63% for cotton (Alves et al., 2021; Companhia Nacional de Abastecimento, 2019).

Moreover, Brazil relies on a double-crop production system, producing two crops in the same area in one agricultural season, which allows them to remain one of the world's largest

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agricultural producers. In Mato Grosso, soybeans are the largest harvest, followed by second-crop corn. Recently, cotton farmers in this region also have invested in soybean systems, followed by second-crop cotton, a unique system in terms of world agriculture (Alves et al., 2018). The second-crop system has gained popularity in agricultural production in Mato Grosso. Between the 2013-2014 and 2017-2018 crops, an average of 84% of the cotton area (Instituto Mato-grossense de Economia Agropecuária, 2018) and 99% of the corn volume was produced in the second crop (Companhia Nacional de Abastecimento, 2019).

The second-crop model arose due to a desire for increased land use, diluted capital investment costs, and a need for improved distribution of the producer's cash flow. The introduction of a second crop also brought several agronomic benefits, such as better physical and chemical soil conditioning and more efficient use of fertilizers (Rosolem & Calonego, 2013; Tsunechiro & Godoy, 2001).

The double cropping system allows for crop diversification during the farming season, which mitigates risks because it allows the producer to choose different activities and avoid dependence on only one product (Kay et al., 2014; Olson, 2010).

Several studies have conducted risk analyses on agricultural production systems and some have considered a double-crop system in the model (Barros et al., 2019; Esperancini, 2006); however, there are no studies addressing second-crop cotton, possibly because this system gained expressiveness during the 2012-2013 harvest (Instituto Mato-grossense de Economia Agropecuária, 2018).

This study evaluated risk management of agricultural farms in Mato Grosso, Brazil, which have soybean, corn, and cotton crops in their systems. We also aimed to understand the composition of land use regarding diversification of crops to reduce risk. Thus, we used risk analysis tools, such as the Monte Carlo simulation and portfolio theory.

2 Farm risks

Agricultural activity is considered one of the investments with the highest risk levels and final production depends on the use of inputs and processes with uncertain characteristics, mainly related to climatic and price conditions (Barros et al., 2019; Howden et al., 2007; Kay et al., 2014; Osaki & Batalha, 2014; Pereira et al., 2007; Rodriguez et al., 2011).

Moreover, agricultural activity demands a long production period, which requires a significant period between the decisions and the results (Kay et al., 2014; Olson, 2010). For instance, producers are typically affected by market uncertainties during the decision-making process, such as input purchases and marketing prices. Besides, globalization has further exposed agribusiness to the complex international market and political risks, forcing producers to devise even more sophisticated business strategies (Kay et al., 2014).

Farming activities have several risk sources and are aggregated into five main areas: production, marketing, finance, legal/institutional, and personnel (Hardaker et al., 2015; Kay et al., 2014). Several studies have reported that production and market risks have the greatest impact on mitigating uncertainties in farming activities. Some of these mention yield, technical production coefficients, and market prices as the main quantifiable risk sources (Carvalho et al., 2014; Dill et al., 2010; Esperancini, 2006; Figueiredo et al., 2014; Luo et al., 2017; Nalley & Barkley, 2010; Osaki et al., 2019; Ponciano et al., 2004; Souza et al., 2008).

Theories on risks and uncertainties start from the premise that most people, often intuitively, are risk averse. Therefore, an individual would be willing to give up an expected return for risk reduction (Dill et al., 2010; Hardaker et al., 2015; Koumou, 2020; Vale et al., 2007). This risk aversion is observed in the willingness of rural producers to adopt various instruments to mitigate uncertainties, such as insurance, hedging, futures contracts, and crop diversification, by inserting new planning strategies, such as adding value to products, verticalization, and certifications.

Diversification is one of the most popular tools in the rural risk management literature as the selection of agricultural activities is one of the producer's most important decisions (Guiducci & Hirakuri, 2020; Hanson et al., 2007; Kay et al., 2014; Moss, 2010; Paut et al., 2019; Rădulescu et al., 2014; Rodriguez & Sadras, 2011).

Studies that surveyed producers or used the United States Census of Agriculture as a data base found that, regardless of farm size, producers adopt production diversification to protect against highly variable production environments, such as weather and price levels (Hanson et al., 2007; O'Donoghue et al., 2005; Rodriguez & Sadras, 2011).

3 Agricultural risks and crop diversification

The literature includes the use of several analytical applications to study the relationship between risks and farming activities. These studies mainly focus on the relationship between returns and economic risks to assist with the decision-making process of production systems for a specific region or farm. Furthermore, there are risk-related studies on the conscientious use of chemicals (Rădulescu et al., 2014; Sanglestsawai et al., 2017), environmental and economic risks related to fertilizer and mulch management (Boyer et al., 2018; Gabriel et al., 2013; Paut et al., 2020; Stott et al., 2016), investment analysis as a function of risk (Carvalho et al., 2014), machine operating capacity associated with economic risk (Osaki & Batalha, 2014), marketing contract structure and risk (Simões et al., 2015), and risks associated with water use in agricultural production (Burbano-Figueroa et al., 2022; Kumar et al., 2022; Luo et al., 2017; Power & Cacho, 2014).

In general, a risk component was introduced to assist in choosing the combination of various farming activities with the best economic return. Markowitz (1952) highlighted that risk perception is an idiosyncrasy of individuals, where each has a particular way of assuming risk. Based on this premise, choices are made based on the risk of losses, rather than on activities that have better returns (Hardaker et al., 2015). Therefore, these risk studies show discrimination among a range of efficient alternatives, empowering investors to choose the best returns within an acceptable risk level.

Freund (1956) and Hazell (1971) were the first ones to adapt stochastic mathematical models associating risks to the selection of activities for a rural property. Several programming models have been widely used in the academic literature on rural risk, with some of the most notable being portfolio theory (Markowitz, 1952), total absolute deviation minimization (MOTAD) (Hazell, 1971), and the Monte Carlo simulation (Hertz, 1979).

Although the three models have been used to evaluate risks associated with crop diversification on a farm, portfolio theory and MOTAD are models that seek the optimal set of activities to maximize the return of certain conditions on farm resources. The Monte Carlo simulation, on the other hand, is more efficient in evaluating the individual performance of crops and production systems.

One literature review revealed a positive relationship between agricultural diversification and risk mitigation, while other studies have shown that succession crops (double cropping) yields better results than monocultures (Esperancini, 2006; Osaki et al., 2019; Ribas et al., 2021). Other studies have found higher returns and reduced risks with a combination and succession of different crops during the same season (Coelho Junior et al., 2008; Dill et al., 2010; Gaydon et al., 2012; Ladenburger, 2020; Luo et al., 2017; Osaki et al., 2019; Paut et al., 2019; Power et al., 2011; Souza et al., 2008). Combining agriculture and livestock has also proven efficient for mitigating risks and increasing revenue (Figueiredo et al., 2014; Rădulescu et al., 2014).

However, diversification increases production risks without implying gains in profitability, especially for crop succession. For example, introducing second-crop corn as a winter crop in succession to soybean cropping increases risks and reduces returns compared to oilseed monocropping (Esperancini, 2006; Osaki et al., 2019; Osaki & Batalha, 2014). Higher risks have also been found for cotton succeeded by winter wheat or vetch than for monocropping without cover (Boyer et al., 2018).

Several rural activities are the basis for risk management of cropping farms, such as fruit, grains, fiber, forestry, livestock, or a combination of these farming types. However, analyses on cotton are scarce (Salassi, Deliberto, & Guidry 2013; Boyer et al. 2018; Osaki & Batalha, 2014; Power et al. 2011; Power & Cacho 2014). Further, there are no studies on cotton second crops in succession to soybean related to risks, which is the focus of this study.

4 Material and methods

In this section, we describe the data collection procedures and how the data were prepared for the risk analysis. Subsequently, we show the processes used to build the mathematical optimization model using the Monte Carlo simulation and portfolio theory (Markowitz, 1952).

4.1 Data collection and object of study

The data used in this study were collected by the Center for Advanced Studies and Applied Economics (CEPEA) using the case study methodology. Cases included individual data from 20 farms for the 2012-2013, 2013-2014, 2014-2015, and 2015-2016 crop seasons (Centro de Estudos Avançados em Economia Aplicada, 2019a). Data on different technologies used in each crop, both conventional and genetically modified (GM), were aggregated. The data refer to farms in the central-eastern, northwestern, medium-northern, and northern regions of Mato Grosso, according to the technical division of the Mato Grosso Cotton Association (Associação Mato-grossense do Algodão, 2018) (Figure 1).

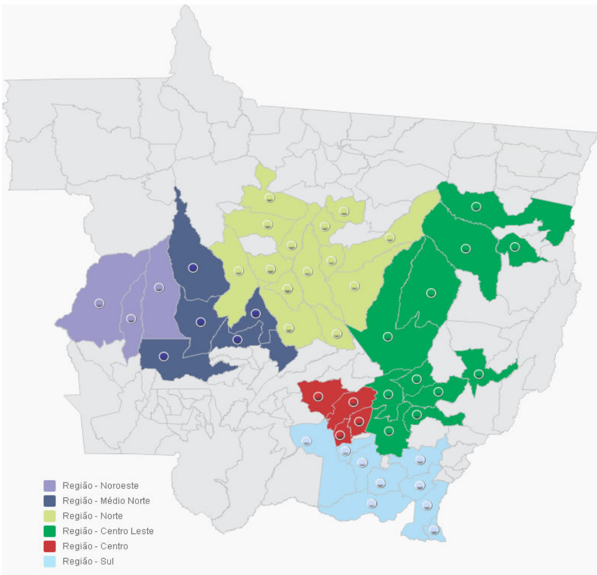

Figure 1. Regional divisions from the Mato Grosso Cotton Producers Association (AMPA). Source: AMPA (Associação Mato-grossense do Algodão, 2018).

The data for this study were divided into two regions to analyze the risks of cotton-producing farms with production systems involving two harvests. The first corresponds to the central-eastern region of Mato Grosso (Associação Mato-grossense do Algodão, 2018), called Central East, while the second region aggregates the northwestern, medium-northern, and northern regions of the state, named the Northern Aggregate. Therefore, this study can be analyzed using two sets of systems: 1) cotton and soybean as the first crop and corn as the second crop, or 2) soybean as the first crop and cotton and corn as the second crop.

The study was delimited based on climatic restrictions that prevent the Central East region from growing second-crop cotton, as the region suffers from low temperatures and water deficits (Rosolem, 2014). However, the Northern Aggregate region has no restrictions on sowing and growing second-crop cotton, so this region accounts for much of the increase in second-crop cotton cultivation in the state (Instituto Mato-grossense de Economia Agropecuária, 2018).

For these regions, data were collected from 20 farms. Some of them participated in more than one season. The data on costs were collected for different GM technologies of each crop; thus, there were 35 production cost structures for cotton during the analysis period and 41 cost structures for second-crop cotton. There were 31 production cost structures for soybeans and 31 for second-crop corn, all based in BRL per hectare, but considering an exchange rate of 3.20 BRL/US$.

Cost structure data were collected at the end of each crop year and correspond to the effective technical coefficients of cultivation for the season. Total cost (TC) is the production cost criterion used in this study, which computes the operating costs (OC) plus the annual replacement cost of property (CARP) for machinery, implements, and improvements (Barros et al., 2019). The prices of agricultural inputs refer to the cash value paid by the producer in the current crop year; that is, the data refer to farm activities occurring during the crop year.

The yield for each crop corresponds with the average values recorded at each farm during the crop year. The values of monthly prices for marketing soybean, corn, and cotton for each region were obtained for the period between 2012 and 2016 from the CEPEA database (Centro de Estudos Avançados em Economia Aplicada, 2019b). In this study, the values of production costs were corrected with the General Price Index-Internal Availability (IGP-DI) based on December 2017.

4.2 Monte Carlo simulation

The Monte Carlo simulation is one of the main tools used to perform economic risk analysis. Developed by Hertz (1979), it is an effective risk model that can be applied to cash flows, and thus measures risk for variables without controlling for behaviors (Oliveira & Medeiros Neto, 2012).

The selection of variables that influence risk in a given system is crucial before using the Monte Carlo simulation method. The literature reviewed in this study showed that price and output, which incorporate production cost items, are the two risk variables in agriculture that can be quantified as objects of prediction for stochastic analysis. Therefore, studies should assume the items of operational cost (inputs, labor, mechanical operations, taxes, interest, etc.) as variables to simulate the yield and sales price of each crop.

The work developed by Hertz (1979), one of the first to use the Monte Carlo stochastic methodology, proposes that the analysis should follow four fundamental steps, which are used in this study:

- Identify the probability distribution of each variable that affects risk;
- Select a random value for each study variable based on its probability distribution function;

- Calculate the economic performance indicator from the random values generated by the statistical distribution of each variable;
- Repeat steps 2 and 3 until the probability distribution of the performance indicator meets the requirements of the decision-making process.

Some authors report difficulties and took special care in correctly identifying the probability distributions of the risk variables (Burnham & Anderson, 2004; Evans & Olson, 1998; Minardi, 2000). In this study, the probability distribution fit for each variable affecting risk was based on the Akaike's information criterion (AIC), which assesses the quality of the parametric model estimated using the maximum likelihood method (Akaike, 1974). In other words, the AIC criterion ranks the theoretical models that fit the distribution of the sample data, and the lower the AIC value, the closer the sample-based distribution is to the "true" model.

Considering that the probability distributions chosen for each variable are theoretical models with an approximation of the real values, negative numbers can occur in the simulations, which would not be applicable for an input price series, production, or yield sales. Therefore, before the simulation, Monte Carlo step 2 truncations were added to each distribution function over the zero value to restrict the models to positive values.

Another crucial problem in the Monte Carlo simulation is determining the interdependence between variables (Evans & Olson, 1998; Minardi, 2000). For this purpose, a correlation matrix of the risk variables was built.

From the parameters established for distributions chosen through AIC, 10,000 random interactions for each risk factor (inputs) were simulated to compose the production costs and revenues (outputs) of each crop under analysis. Finally, the contribution margin is determined using the net operating revenue (NOR) and total net revenue (TNR), calculated by subtracting gross revenue (GR) from the operating cost (OC) and total cost (TC), respectively. Finally, the NOR and TNR statistical distributions for each crop and productive system are obtained, allowing for the evaluation of negative margin probability, that is, the cultivation risk for the region. The commercial software @Risk was used for the entire process described in this section.

4.3 Portfolio theory and the efficient frontier

Markowitz (1952) argued for the possibility of decreasing risks through asset diversification, where the central proposal is to structure a portfolio in which losses resulting from one asset can be offset by negatively correlated profits from another asset.

Portfolio theory is based on the assumption that investors are risk averse and that profitability and risks are variables of interest to the investor. Therefore, decisions correspond to a combination of portfolios that offer the least risk within an expected return or the highest possible return within an acceptable risk level (Markowitz, 1959). For farms, crop yield is the main revenue diversification asset and in each crop year, rural producers must determine the proportion of each activity within different combinations, as the effect of crop diversification is reflected in the risks, similar to what occurs in the stock market portfolios.

To find the optimal portfolio, an optimization model is traditionally used to maximize responses from a vector of selected indicators. However, when dealing with models linked to uncertainty variables, traditional optimizers fail to force users to assume how variables interact in the real world. Therefore, to solve problems related to uncertainty, the optimization process via simulation is the most appropriate, given that the search and optimization tasks are processed in a data space that considers "all" possible solutions.

The RiskOptimizer tool from @Risk software was used to determine the crop combination with the best financial and economic outcome in each region. This required an outline of the farm structure to delimit the amount of resources to be optimized. The data collected do not allow for the formulation of an average or modal farm; therefore, a hypothetical farm was designed in each region and the sum of the financial investments and the area of all the farms surveyed in the four harvests compose the total available resources. This information is also the basis for the following model constraint inputs:

- The OC cannot be higher than the amount disbursed by the four crops studied;
- The first-crop area cannot exceed the total physical area for all the farms studied in the four harvests;
- The second-crop area is limited to the total area effectively sown in the four crops studied.

In this study, the objective function is to maximize the NOR and TNR.

The function to maximize NOR is:

$$Max_{NOR} = \sum_{j=1}^{n} \left[\left(GR_{jc} - OC_{jc} \right) * A_{jc} \right] \tag{1}$$

where:
j = each simulated value;
c = crop under analysis (soybean, first-crop cotton, second-crop cotton, second-crop corn);
A = crop total area in the region, in hectares.

To maximize TNR, only ACRP is discounted from the optimization results performed for the NOR, as follows:

$$Max_{TNR} = Max_{NOR} - ACRP_{region} \tag{2}$$

To construct an efficient frontier, following portfolio theory, the return versus risk is analyzed, in which the return is calculated by dividing the TNR by the total invested (CO+CARP) and the risks, based on the variation coefficient (VC) of the results of TNR optimization. For this efficient frontier context, the model solved the net revenue maximization task in 20 trials to evaluate the constraints and 100 area-use sets, generating 2,000 crop combinations.

5 Results and Discussion

In this section, we describe the results of the risk-return ratio for crop combinations in each region. The aim is to present an efficient frontier that shows the area allocated for each crop, based on each region's average, to have the best risk-return ratio.

5.1 Analysis for the North Aggregate region

The model restrictions in the North Aggregate region based on its characteristics are:

1. The OC has a limit of 312.5 million USD (exchange rate of 3.20 BRL/USD).
2. The first crop cannot exceed an area of 175,000 ha, which is the total area cultivated in the first harvest for all farms, in the years studied.
3. The area for the second crop is limited to 140,000 ha, with cotton for the second crop not exceeding 75,000 ha.

The optimization model simulation generated 2,000 combinations, but only 75 of these areas represent the construction of the efficient frontier. The red/yellow dots in Figure 2 depict the calculation of the case study's original area. The nomenclature "base farm" and "original farm" represents the original study site and "simulated farm" depicts alternative uses simulated by the optimization model.

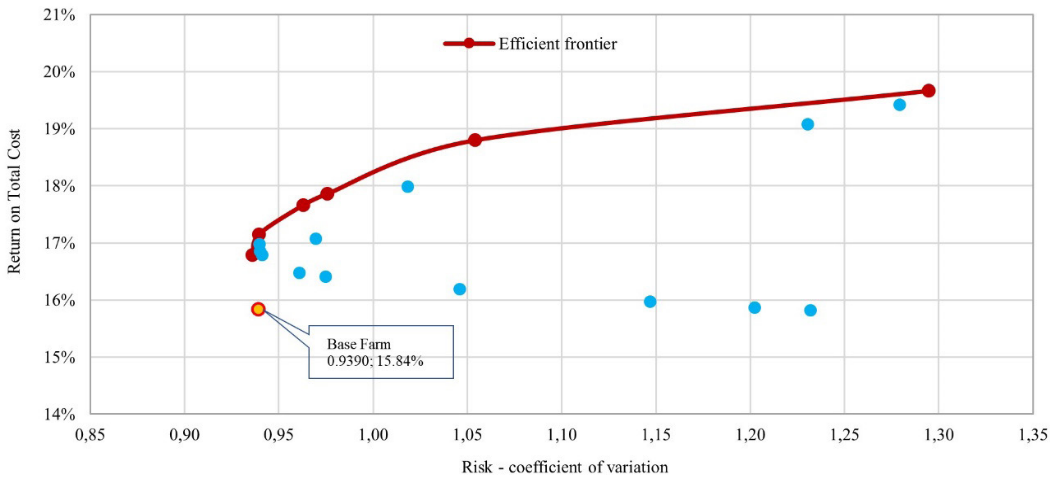

Figure 2. Efficient frontier that maximizes the return-risk ratio for the combination of soybean, second-crop cotton, and second-crop corn in the North Aggregate region. Source: Research data. Note: The item "Base Farm" represents the results of using the farm area studied. Source: Research Data.

The efficiency curve tipping point occurs in the area set specified by a risk value (VC) of 0.936 and a return on the total cost of 16.8%, meaning that the area sets present greater returns and risks from this curve inflection in an increasing direction. However, in the direction of the decreasing inflection point, combinations that increase risks occur while presenting lower returns. According to portfolio theory, the growing curve above the inflection point defines the best choices for the relationship between returns and risks by providing information on the risks assumed by the rural producers (Markowitz, 1959).

The return-risk ratio point calculated for the original farm is positioned at a risk of 0.939 and a return of 15.8%. This is below the theoretical curve boundary that maximizes the returns on invested capital, especially with a return below the values indicated by the frontier portfolio. Thus, an area set with the same risks as the original farm can be found on the efficient frontier, but with a higher return or even a combination with less risk and greater profitability.

To better explore the optimization model results, 12 farms with different area use combinations were selected on the efficient frontier curve. These combinations and their respective risk and return conditions are shown in Figures 3 and 4, respectively.

The area for crop combinations on the original farm comprises 174,567.5 ha of soybean, 72,650 ha of second-crop cotton, and 61,075.3 ha of second-crop corn. The portfolio design of the inflection point comprises 175,000 ha of soybean, 68,289.3 ha of second-crop cotton, and 71,710.7 ha of second-crop corn, simulated on farm 10. Comparatively, the theoretical curve inflection point presents a lower risk and higher profitability than the original farm, with a difference concentrated in the second-crop areas. From this viewpoint, the original farm needed to increase the crop area with corn and reduce the crop area with second-crop cotton to reduce risks and improve return, based on the rate obtained for each Real invested. This area's cultivation required 283,446,885.06 USD to cover operating costs, which is lower than the original farm.

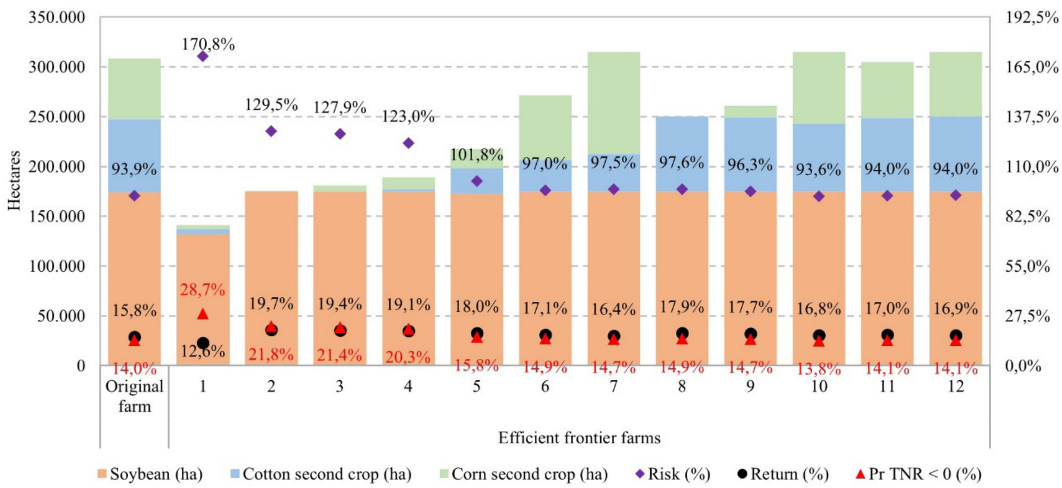

Figure 3. Combination of area use, risks, return on total cost and probability of negative income (Pr TNR < 0) for soybean, second-crop cotton, and second-crop corn for the efficient frontier farms and the original farm. Source: Research data.

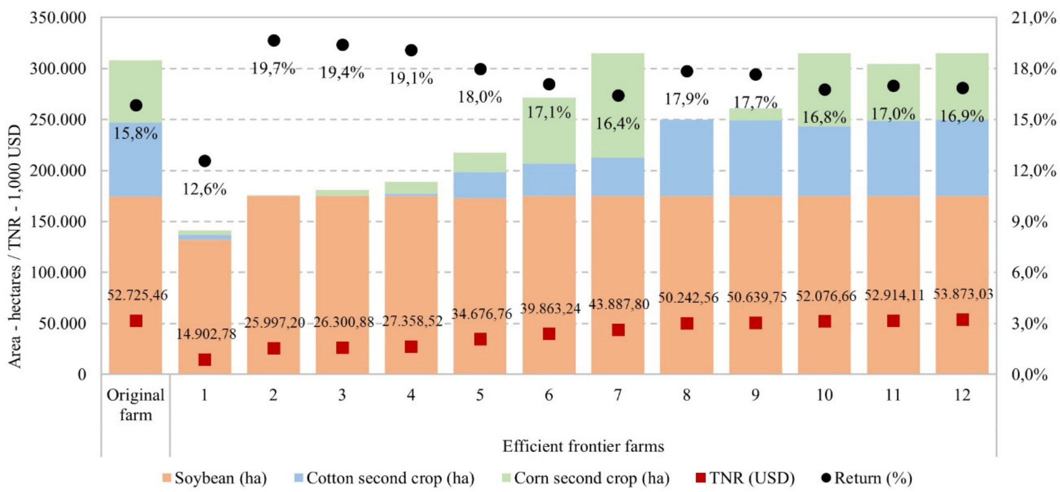

Figure 4. Combination of area use, TNR and return on total cost of soybean, second-crop cotton, and second-crop corn for the efficient frontier and original farms. Source: Research data. Note: Exchange rate 3.20 BRL / USD.

The efficient frontier data show that cropping with soybean in all the available areas in the summer (175,000 ha) reduces risks and increases return on investment (i.e., optimizing the CARP). In addition, the second crop cultivation increment considerably reduces the production risks in exchange for a slight decrease in the return (see farm 4 onward in Figure 3).

Although the cultivation of the second crop implies lower returns (%) than that of the summer crop alone, there are increases in the net revenue gains. Second-crop cotton generates this benefit to a greater extent than second-crop corn.

Therefore, planting cotton to the maximum area possible, providing the structure is ready and there are no financial limitations, will generate the highest revenues. The remaining 140,000 ha for the second harvest could be cropped with corn to further increase revenues and mitigate the farm risks – compare farm 9 with farm 12 (Figure 4). To achieve the maximum revenue condition presented in the efficient border, 292,847,898.14 USD are required to fully cultivate 175,000 ha of the summer crop with soybean, 75,000 ha with cotton, and 65,000 ha with corn in the second harvest.

5.2 Analysis for the Central East region

According to the characteristics of the Central East, the restrictions of the optimization model in this region are as follows:

1. he OC cannot exceed 215.5 million USD (exchange rate 3.20 BRL/USD).
2. The first crop is limited to a maximum of 155,000 ha, of which cotton must not exceed 60,000 ha.
3. The second-crop area can reach a maximum of 31,000 ha of the planted area.

The crop combinations generated by the optimization model show that only 89 of the 2,000 area sets belong to the efficient frontier. The theoretical optimization curve is shown in Figure 5.

For the original farm, the area for crop combination comprises 58,707.9 ha of cotton, 93,201.8 ha of soybean, and 28,977.3 ha of second-crop corn. However, the inflection point of the efficient frontier presents a combination for area use with 16,948.6 ha of cotton, 138,051.4 ha of soybean, and 30,060.6 ha of second-crop corn (See simulated farm 7 in Figure 6). In contrast, the farm at the inflection point presents lower risks and higher profitability than the original farm, mainly linked to the area division of the first crop, since the inflection point has 71% fewer areas cropped with cotton and 48% more areas cropped with soybean. Thus, the efficient frontier curve shows a point with the same risks as those of the original farm, but with a higher return on investment. In this case, the original use of the area needs to reduce the area cropped with cotton by 3%, increase soybean by 5%, and increase second-crop corn by 7% to increase the RLT by 3%.

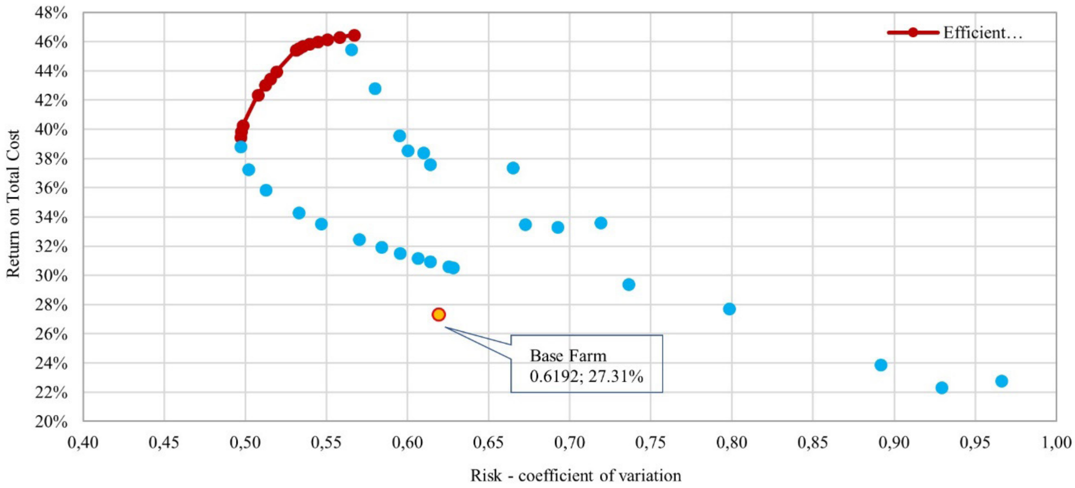

Figure 5. Efficient frontier that maximizes the risk-return ratio for the combined land use to crop cotton, soybean, and second-crop corn in the Central East region. Source: Research data. Note: The item “Base farm” represents the results of using the farm area studied.

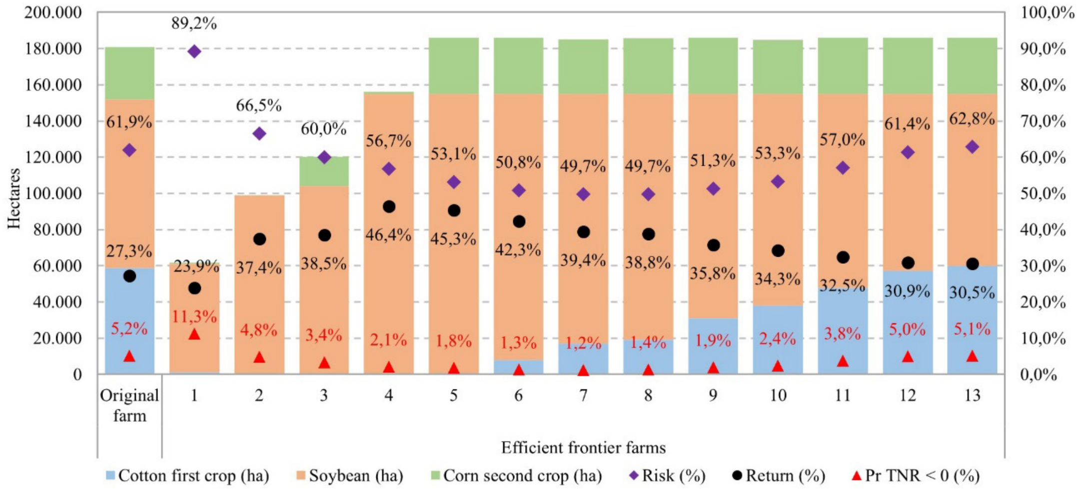

Figure 6. Land use combination, risks, return on total cost and negative income probability (Pr TNR < 0) for the crops of cotton, soybean, and second-crop corn for efficient frontier and original farms. Source: Research data.

On the efficient frontier, the areas with the best risk-return ratio are formed by the total use of the area with a first crop of 155,000 ha (farms 4 to 7, Figure 6). The theoretical curve shows that soybean monoculture in summer generates the highest returns; however, it exposes the farm to greater risks. Therefore, cropping up to 11% of first-crop cotton reduces production risks and provides profitability above the tipping point. Salassi et al. (2013) also found better risk-return conditions for farms in the southeastern United States that planted cotton and grains in a crop rotation system. Thus, the proportion of the area cropped with cotton was much higher.

Whereas, second-crop corn acts as a mitigating factor for farming risks in the Central East region. For the best risk-return conditions in the efficient border, the addition of a second-crop corn area considerably reduces the risks, but with losses in profitability, as observed in the results for farms 4 and 5. In addition, the highest return on TC in the theoretical curve corresponds to a small parcel use of 1,073.7 ha of second-crop corn, along with 155,000 ha of soybean (See farm 4, Figure 6).

The increase in the cropped area for cotton and corn represents a percentage loss of return for the farm, but greater net revenues. Thus, the model highlights that the maximum available area should be used to maximize net revenue, which is represented in farm 13. Financial resources of 194,285,671.83 USD, an area set of 60,000 ha of cotton crops, 95,000 ha of soybean, and 31,000 ha of second-crop corn were used to achieve this (Figure 7). Second-crop corn adds revenue to farms with minimal risk. However, first-crop cotton increases the net revenue, but it also increases the risk that the cropped area exceeds 11% of the total area available for the first crop (See farms 5 to 13 in Figure 7).

5.3 Diversification regarding risk

Portfolio theory allows for quantification of the relationship between risks and returns of diversified cropping systems and identifies optimal land use and available financial resources for farms. Our results align with the literature, in which the risk, defined as the variation coefficient of the crop portfolio, can be reduced by choosing appropriate crop combinations. Similar solutions have been reported for grains (Dill et al., 2010; Osaki et al., 2019), cotton

(Boyer et al., 2018; Power & Cacho, 2014), horticulture (Paut et al., 2019), and water resource management (Gaydon et al., 2012; Luo et al., 2017).

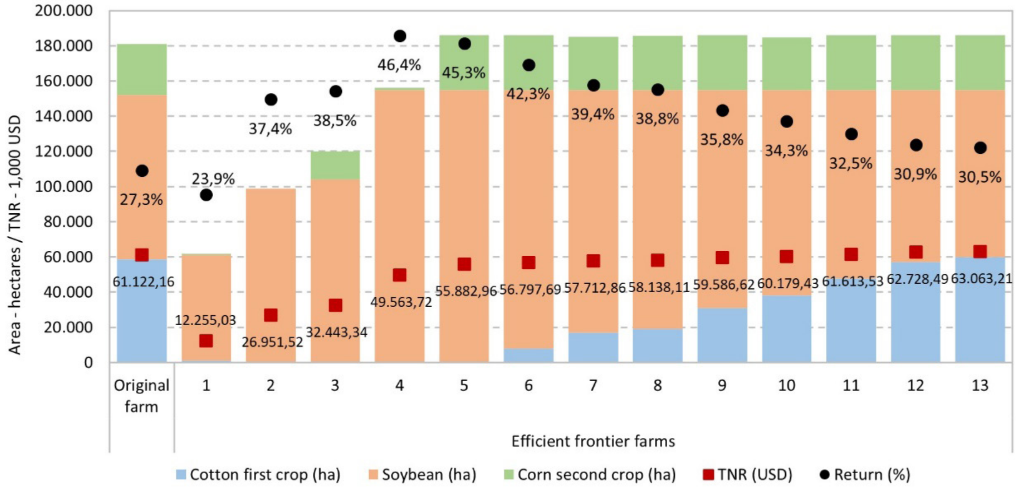

Figure 7. Combination of area use, TNR, and return on total cost for cotton crop, soybean, and second-crop corn for efficient frontier farms and the original farm. Source: Research data. Note: Exchange rate 3.20 BRL / USD.

For both regions in the present study, increasing the second-crop corn area contributed to mitigating farming risks, which contradicts previous findings by Esperancini (2006), Osaki & Batalha (2014), and Osaki et al. (2019). However, these results could not be compared because the studies were conducted in distinct regions where second-crop corn may present different expected production risks. The differences in the results are also supported by the issue of infrastructure costs (ACRP), which Esperancini (2006) did not consider. The ACRP has very different dimensions compared to the other two studies, as cotton farms have higher infrastructure costs than farms that grow only grains.

Our study revealed that cotton cultivation in the first and second crops contributes to increasing farm revenue; however, it also increases the probability of losses, as reported in some studies (Osaki & Batalha, 2014; Power & Cacho, 2014; Salassi et al., 2013). Thus, producers who want to maximize profits tend to cultivate a larger area with cotton, while those with a less risky approach opt for grain production.

Our study built an optimization model based on actual restrictions of infrastructure and financial capacities of farms in Mato Grosso; however, producers face additional restrictions, such as technical, commercial, and environmental. Thus, although we demonstrated better options for the economic sustainability of cotton farming properties, we were not able to measure the possible impacts on the balance of agronomic conditions, such as soil and pests. Therefore, bioeconomic mathematical models have gained increasing attention in the literature because they can better analyze the use of natural resources for economic gains (Paut et al., 2019; Rădulescu et al., 2014). An in-depth analysis was beyond the scope of this study, so this should be considered in future investigations of rural risk management.

6 Conclusions

The rural environment presents several risk sources. In the current study, we present a programming model that proposes optimal allocation of cotton, soybean, and corn cultivation in two regions of Mato Grosso, Brazil. We considered areas with first and second-crop cotton to compare the efficiency of the production systems and to fill the gap in the literature on second-crop cotton. We used mathematical optimization programming by simulation guided by the Monte Carlo simulation and based on portfolio theory.

In general, the results from both regions using the optimization model via simulation showed that planting soybean in the total area available for the first crop resulted in a greater return on the total cost. In addition, the increase in second-crop area reduced the return (%) for farms on the efficient frontier in both regions.

Conversely, an increase in the second-crop area mitigated risks for farms, while an increase in the second-crop cotton area promoted greater gains in net revenue than an increase in the area for second-crop corn. The model data indicate that cotton should be used in the second crop in the total area to maximize revenue gains, with corn added in the remaining area of the second crop to mitigate production risks and guarantee an even higher net revenue.

Regarding the first crop, cotton can be cropped in a greater proportion on farms, whose focus is to obtain maximum revenue despite higher exposure to risks. However, not planting cotton in the first crop does not mean there is less risk for farming activity. In the theoretical curve generated by the model, the lowest production risk was linked to the total use of the area during the summer crop, with 11% occupied by cotton and the remaining area cropped with soybean. According to the model, crop diversification contributes to the risk management of farming activities, as reported by several authors referenced in this study.

Future studies should examine additional variables, including investments in fixed assets because the relationship between crops ultimately will depend on the risk aptitude of each producer and the necessary resources. Therefore, risk analyses should be individually evaluated and should not be generalized. The results presented here indicate that a regional average context and aspects related to agronomic and financial issues, among others, should be evaluated together. Models using an alternative system and analytical methodologies should also be evaluated.

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