Economic analysis of soybean-maize crop rotation in a no-tillage system

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Abstract

Brazil is one of the largest food suppliers in the world. The country faces new challenges to remain competitive considering the dynamism of Brazil´s agribusiness sector, with the need to balance agricultural production with environmental preservation. New technologies that result in sustainable production systems that provide yield gains are necessary. This study aims to economically analyse a conservationist system conducted during 10 consecutive years. The treatments were the combination of summer and winter crops under no-tillage system. The summer crop sequences (sown in October/November) were (i) continuous maize cultivation, (ii) continuous soybean, and (iii) soybean/maize rotation. The winter crops (sown in February/March) were (i) maize, (ii) sunflower, (iii) oilseed radish, (iv) pearl millet, (v) pigeon pea, (vi) grain sorghum, and (vii) sunn hemp, consisting of 21 treatments. An investment analysis was performed based on a discounted cash flow. The capital asset pricing model (CAPM) was used to define the discount rate. The data were extrapolated to a typical property of 50 hectares. The results indicate that the yield gain is significant in the conservationist system adopted and superior to that reported in the national average. The minimum attractiveness rate was high for all the treatments. The adoption of soybean and maize rotation, with maize as off-season provided the best economic alternative. The second best alternative is the soybean monoculture with maize as off-season, widely adopted in Brazil for its great agronomic benefit. In conclusion, the investment costs are high, making the small-scale production of soybean and maize not sustainable in the long term. Furthermore, an idleness of the defined machinery and labour capacity was observed. However, the production of maize or sunflower in the off-season resulted in a positive operational cash flow in all treatments.

Keywords: Farm management. Alternative crops. Conservation agriculture. Soybean. Maize.

1. Introduction

Brazil is one of the largest players in global agribusiness (ALAN BOJANIC, 2017) and, by 2017, was the largest global exporter of food in volume and income (HUBBARD; ALVIM; GARROD, 2017). The agribusiness dynamics in Brazil have greatly changed over the past 60 years because of investments in research, technology development, rural extension, and public development policies (CHADDAD, 2014; PIVOTO et al., 2018). The competitive strategy of Brazilian agribusiness has been based on yield gains and cost reduction, which have ensured food security in the country and have provided a relevant contribution to the world food supply. Moreover, there is a legitimate concern about achieving the balance of agricultural practices with environmental preservation and local development (KOK et al., 2018).

Thus, research and new technologies applied to agribusiness that allow for the construction of sustainable, productive models have been promoted in Brazil (GRASSINI et al., 2017). This context is similar for soybean, the main agricultural commodity in Brazil, whose production in the 2017/2018 growing season was 119.3 million tons cultivated on 35.1 million ha (CONAB, 2018a).

According to Sentelhas et al. (2015), the increase in soybean production in Brazil can be determined by factors such as plant breeding, sowing date, soil condition improvement, crop rotation, and knowledge transmission. The conservationist system (CS) incorporates a few of these principles and is an alternative to increase production, improve the economic performance of grain-producing farms, and benefit the natural environment (SCOPEL et al., 2013; PALM et al., 2014; ALVAREZ; STEINBACH; DE PAEPE, 2017).

The implementation of a CS must be properly oriented, given its ineffectiveness when practices are improperly used, especially by small producers, which compromises the widespread adoption of the system due to lack of knowledge (DERPSCH et al., 2015).

Studies on the performance of CSs are essential to address local specificities since the environmental benefits provided depend on the location and can be positive or negative (PALM et al., 2004; PANNELL; LLEWELLYN; CORBEELS, 2014). Furthermore, the adherence to a no-tillage policy, also depends on the scale of the property, topographical and soil characteristics, and the region's climate pattern (WADE; CLAASSEN, 2017).

It is important to emphasize that CSs improve soil quality, thus directly influencing crop yield and contributing to reducing the stresses suffered by plants caused by climate changes (CONGREVES et al., 2015). This fact is of interest to Brazil because the cultivation of two harvests in a single agricultural year is affected by annual climatic variability, with direct repercussions on revenue generation. Because the agronomic implications of CSs are already consolidated in the literature, studies that address the economic viability of rural enterprises are lacking.

The continuity of an agricultural enterprise is further defined by its ability to generate wealth over the years. To obtain an appropriate sustainable management of the rural enterprise, considering the entirety of the property is crucial because the decisions of both investments and operations have a general repercussion on the profitability (HILKENS et al., 2018).

The cash flow is a valuable technique to access the economic viability of investment decisions and alternatives (REGAN et al., 2015), in complement with economic indicators as the net present value (PANNELL; LLEWELLYN; CORBEELS, 2004; KOMAREK; LI; BELLOTTI, 2015; MARASENI; COCKFIELD, 2015).

Furthermore, as a major global soybean supplier, Brazil must evaluate alternative crop rotation systems that encompass the adoption of legumes because they are feasible for achieving sustainability, considering their productive potential and economic return (STAGNARI et al., 2017). The principle of the diversification also must be considered in choosing among alternative investment options, as it assess the relationship between risk and return (MARKOWITZ, 1952; CHADDAD, 2014).

This study aims to economically analyse a direct seeding system of soybean and maize, rotated and in monoculture, examining the financial changes by the diversification of off-season crops.

The analysis is structured as a discounted cash flow (DCF), illustrating the relationship between crop diversification and the discount rate, which is a critical point of the economic analysis. Furthermore, this article support the producer to choose the most profitable option among the defined treatments for a rural property of 50 hectares.

2. Conservationist System

The CS consists of three agricultural practices complementary to each other and required for its proper implementation: (i) minimum soil disturbance, (ii) full-time soil cover, and (iii) diversified crop rotation (PALM et al., 2014; ALARY; CORBEELS; AFFHOLDER, 2016; ALVAREZ; STEINBACH; DE PAEPE, 2017).

The no-tillage system, intensified in the 1950s, is widely used in modern agriculture due to the deleterious effects of conventional soil management and the development of new methods to control invasive plants (PERRY; MOSCHINI; HENNESSY, 2016). Van Eerd et al. (2014) concluded that the non-tillage of soil allows for better soil quality and demonstrated the influence of soil rotation and crop rotation in a field experiment consisting of grain crops.

Allied to the minimum soil disturbance, direct sowing is introduced as an essential practice. According to Alary, Corbeels and Affholder (2016), direct sowing on the straw from the previous crop has been adopted in Brazil since the 1980s, especially on properties larger than 500 hectares in the Central Plateau region (Cerrado, Savana). The authors add that, for the small producer, there are obstacles that prevent the full adoption of this system, highlighting the greater financial need and changes in the production dynamics.

Relevant to the second and third pillars of the CS, the presence of straw on the soil surface and crop rotation increases the efficiency of the productive system, focusing on the succession crop. The subsequent crop uses the nutrients left by the plant remains of the previous crop, causing a positive economic effect, given that the destination of the resources inserted into the system improves (ALARY; CORBEELS; AFFHOLDER, 2016). The adoption of a legume species in a crop rotation system represents an agronomic advantage due to the biological fixation of nitrogen (MATSUURA et al., 2017).

Liu et al. (2016) verified that the economic scenario of the enterprise is positive when the diversity in crop rotation is increased due to the lower occurrence of pests and diseases through the breakdown of their biological cycles. The most effective method for avoiding weeds is crop rotation, which suppresses weeds' potential for establishment in the agricultural environment (COLBACH et al., 2014).

A diversified crop rotation accompanied with a minimum soil disturbance potentiates carbon sequestration by increasing the content of organic carbon present in the soil (FERREIRA et al., 2013; LU; LU, 2017). Likewise, carbon sequestration is also maximized by the adoption of cover crops, conveniently managed in the off-season (MCDANIEL; TIEMANN; GRANDY, 2014), avoiding the incidence of opportunity cost in crops with no economic return when planting during the main harvest.

3. Investment Analysis

As concluded by Rochecouste et al. (2015), the demonstration of the economic viability of a CS is crucial to strengthening its adoption. The adoption of DCF in projects allows for the economic evaluation of the value-generating capacity of the enterprise, as well as comparisons in the same unit of time (REGAN et al., 2015). The cash flow of a rural property varies because of the period of analysis and the type of activity performed, and is influenced by other factors, such as the costs and revenues estimate and the size of the area (WASILEWSKI; FORFA, 2016).

Lalani, Dorward and Holloway (2017) adopt cash flow to compare different investment options. The value of land is closely related to its wealth-generating capacity, measured by the economic performance made possible by the cash flow (CHADDAD, 2014).

Cocks (1965) states that the DCF principle involves the determination of a discount rate for each investment option that is to be analysed; that is, the approach aims to find a sufficient interest rate to make the investment feasible given the availability of financial resources. The use of alternative practices in management, such as those from a CS, allows for the reduction of economic risk (LALANI; DORWARD; HOLLOWAY, 2017). The authors further indicate that the risk analysis assists in the decision-making regarding which crop composition to choose, observing its peculiarities.

The risk of the rural enterprise can be reduced by diversification fundamentals, emphasizing the efficient choice of investments, the improvement and evolution in agricultural management, the decision-making based on the climatic pattern and the market price of the agricultural product (CHADDAD, 2014).

In the case of smaller-scale projects in which investment resources are scarce, the values of the discount rates must be carefully monitored because they are related to the project's useful life, which, in turn, influences the cash-generating capacity (KOMAREK; LI; BELLOTTI, 2015).

In their study, Khanna, Louviere and Yang (2017) found that the investment decision on perennial crops involves the adoption of discount rates superior to the rates made available by the market, which suggests the need for a premium added to the basic interest rate for producers to opt for the investment.

The Capital Assets Pricing Model (CAPM) developed by Sharpe (1970) also delineates the need for a risk premium, besides the investment return. The systematic risk expressed by the Beta value, accounts for the relationship between assets and market returns, and has an impact on the cost of capital (HUSSAIN et al., 2019).

The net present value (NPV) is widely used in the literature, especially in the CS approach, when considering investment analysis techniques based on cash flow (PANNELL; LLEWELLYN; CORBEELS, 2004; KOMAREK; LI; BELLOTTI, 2015; MARASENI; COCKFIELD, 2015). According to Regan et al. (2015), the NPV identifies the profitability of the business and compares different time horizons in different types of investments. The modified internal rate of return (MIRR) is used in addition to the NPV, which returns the minimum attractiveness rate of the investment (HURLEY; RAO; PARDEY, 2017).

However, a few weaknesses are identified in this analysis method. As the project time elapses, future variations in the scenario are generally subject to change and are not considered in the analysis (REGAN et al., 2015). Additionally, the reduced liquidity of components such as land, equipment, machines, might lead to a high depreciation and to a low residual values, which reduce the feasibility of the investment (REGAN et al., 2015).

In addition to the NPV and MIRR, there are other indicators to assess the economic viability in agriculture. Zorn et al. (2018) discusses some of the most used indicators expressed as financial ratios, also related to sustainability. It is worth to cite the operating expense ratio, which represents the proportion of the revenue dispended to cover operation expenses.

The relationship between profit and farmland size is also employed in the literature, as the work of Yan, Chen and Hu (2018) about the influence of farmland size on profit and production efficiency, in an attempt to find the optimal point.

4. Materials and Methods

4.1. Experiment outline

This article was drafted by observing a field experiment conducted at Jaboticabal/SP, Brazil (21°15'8.74"S and 48°16'21.50", 590 m asl). The climate is characterized by a dry winter and humid summer. The average annual temperature between January 2001 and June 2017 was 23.4°C, and the average annual rainfall was 1,077.9 mm, concentrated between October and March (Figure 1). The soil of the experiment was characterized as an Oxisol (USDA, 2017).

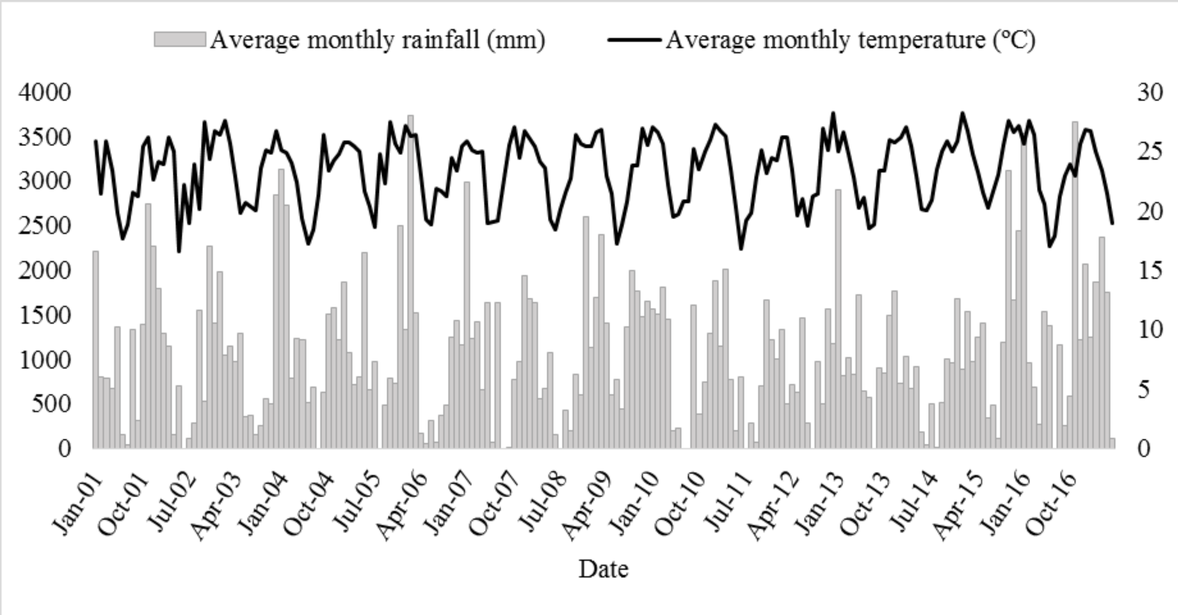

Figure 1: Average monthly rainfall and temperature in Jaboticabal, São Paulo, Brazil, between January 2001 and June 2017 (UNESP, 2017).

The experiment was conducted using a split-block design as described in detail in Martins et al. (2009, 2012). Two sets of treatments were composed of 3 summer crop sequences and 7 winter crops, totaling 21 plots per experimental block. The treatments were randomized across each other in strips in an otherwise randomized complete block design with three replications (blocks). Each plot was 40 m long by 15 m wide.

The experiment was established in September 2002 under no-tillage. The summer crop sequences (sown in October/November) were (i) continuous maize cultivation (MM), (ii) continuous soybean (SS) [Glycine max (L.) Merr.], and (iii) soybean/maize rotation (SM). The winter crops, (sown in February/March of each year in the same plots), were (i) maize, (ii) sunflower, (iii) oilseed radish, (iv) pearl millet [Pennisetum americanum (L.) Leeke], (v) pigeon pea, (vi) grain sorghum [Sorghum bicolor (L.) Moench]; and (vii) sunn hemp (Crotalaria juncea L.).

Conventional tillage (subsoiling, ploughing, and grading) was conducted at the experiment establishment. Lime was applied in two dates: in 2002 at 0.0-0.20 m depth and in 2005, applied at the soil surface without incorporation. The soil chemical analyses were performed with the aim of fertilization recommendation, expecting high yield. For soybean, 300 kg ha^{-1} of the NPK 02-20-20 was applied at sowing, while for maize, 400 kg ha^{-1} of the 04-20-20 + 0.3% Zn was used. For the maize crop, 400 kg ha^{-1} of the 30-00-10 was applied at V4 crop vegetative stage.

During maize cultivation, only one application of phytosanitary product was performed to control weeds. For the soybean crop, four applications were made among herbicides, fungicides, and insecticides. Mineral oil was added to all applications for both cultures. Azoxystrobin + Cyproconazole was used as the insecticide, Tiametoxam + Lambda-Cialotrina was used as the fungicide, and glyphosate, atrazine, and 2,4-D were used as herbicides. Their application was based on the quantities and technical recommendations provided by the manufacturers. It is worth noting that the fertilization or application of phytosanitary products was not performed for the off-season crops to explore the potential of the CS and its residual effects.

Table 1 details the amounts of seed used, distance between rows, and final populations of the crops sown in the experiment. The soybean seeds are certified, of early cycle, and were inoculated with *Bradyrhizobium japonicum*.

Table 1: Amount of seed used, distance between rows and final plant population for each crop.

Crop	Amount of seeds (kg ha^{-1})	Distance between rows (m)	Final plant population (plants ha^{-1})
Soybean	70	0.45	480,000
Maize (summer)	23	0.90	66,000
Maize (winter)	20	0.90	55,000
Sunflower	10	0.90	88,000
Oilseed radish	20	0.45	555,000
Pearl millet	20	0.45	665,000
Pigeon pea	25	0.45	665,000
Grain sorghum	20	0.45	175,000
Sunn hemp	30	0.45	555,000

Source: prepared by the authors.

For each agricultural year, non-selective herbicides were applied at the end of the productive cycle of each crop, followed by mechanized grinding of the crop residues to prepare the area for sowing the next year's crops. The harvests of the summer (soybean and maize) and winter crops with commercial value (maize, sunflower, and grain sorghum) were performed by an automated harvester. For the winter crops with no commercial value, the harvest was performed using a shearer during the full blossom stage.

The sources of data for the construction of the cash flow were as follows:

i. Primary: identification of the yields and production factors (inputs, labour, machinery, and equipment).

ii. Secondary: Institute of Agricultural Economics, Central Bank of Brazil, Dow Jones Index, and resale of agricultural products.

The results were extrapolated for a 50-ha property, typical of the study region, to avoid distortion of the analysis by the apportionment of fixed costs and to allow for the discussion of the contribution margin.

A few yields data were obtained at random, sometimes with the lack of information, especially for the winter crops. In such cases, the maximum and minimum values of the treatment in question were used as indicators. However, the randomly generated numbers captured the yield variability over time, an essential aspect in this work.

4.2. Revenue estimate

To estimate the revenue, an econometric model was applied to the historical price series, aiming to raise the maximum amount of data and, therefore, forecast current and future commodity to obtain a value close to the reality.

We adopted the model proposed by Box and Jenkins (1976) referred to as the autoregressive integrated moving average (ARIMA), which consists of integrating the autoregression of a historical series with its moving average.

The expected return on investment was measured by determining the beta (β) index, that is, the systematic risk. The price of the commodity in the market and the Dow Jones index, both of which encompass the international scenario, were determined using logarithmic values for their correlation. We accounted for 1,340 values for soybean and 1,341 values for maize, obtained from the ESALQ/BM&F indicator, both nominal and daily, corresponding to the period between January 3rd, 2011, and August 8th, 2016, excluding holidays and weekends.

The SM rotation treatment was processed according to Markowitz's Modern Portfolio Theory (1952) such that soybean and maize each represented 50% of the return revenue, considered as the average of the 10 years characterized for the cash flow.

The GRETL® software was used for the analysis. The stationarity of the series was validated using the augmented Dickey-Fuller test (DICKEY. FULLER, 1979). Subsequently, the autocorrelation function and the partial autocorrelation function were determined to obtain the order of the ARIMA. Finally, the forecast was applied to the series, following the ARIMA modelling (p, d, q).

4.3. Estimation of the operational costs

The costs were divided as follows:

i. Fixed costs: hired and family labour, administrative expenses, machinery and equipment insurance and maintenance.

ii. Variable costs: inputs, machinery operations, processing and storage, land leasing, taxes.

The representativeness of each cost component as a percentage of the total production cost was analysed for each treatment, as well as the revenue allocated to the total cost.

The investments were based on the dimensions of machines and implements for a property of 50 ha: 55-kW wheeled tractor (US$ 27,298.85); seeder-fertilizer, width 3.6 m (US$ 21,551.72); straw disintegrator, width 2.3 m (US$ 6,609.20); bar sprayer, manual, width 12 m, 800-L tank (US$ 3,709.77). A masonry and metal warehouse was built with an area of 120 m^2 as a garage for the machines and equipment, valued at US$ 41,379.31.

Tractor and seeder insurance as well as machinery and implement maintenance were defined as a percentage of the purchase price (CONAB, 2010), and considered fixed costs. The fuel and lubricant were categorized as variable costs.

A linear depreciation was used with a useful taxable life for tax reduction, following the recommendations of the Brazilian Federal Revenue Service (1999). The useful life according to CONAB (2010) was used to repurchase the machines and equipment. The depreciation was not accounted for in the investment analysis, used only for tax purposes, with no effect on the cash flow. A residual value of 20% was considered for the tractor and seeder and of 5% for the other implements (CONAB, 2010).

The harvest was conducted by third parties due to the unfeasibility of purchasing a harvester because of its high price. The subsoiling, plowing, and harrowing were also performed by a specialized contractor, as performing these tasks did not justify the purchase of the respective equipment because they were used in only two years of the experiment.

The taxes were extracted from the Federal Revenue Service of Brazil (2017), recorded as percentages:

i. Tax on corporate income: 15% on operational results. The 10% rate is added to the profit surplus if it exceeds US$ 86,206.90.

ii. Social contribution on net income: 9% prior to the deduction of income tax.

The cost of land is related to the lease due to the untruth of the analysis for the asset purchase.

4.4. Cash flow analysis and economic indicators

A discounted cash flow was designed, including the following components: revenue, variable costs, fixed costs, depreciation, taxes, and investments. Other economic indicators were also included, as the contribution margin, NPV, MIRR and breakeven point.

To calculate the revenue for soybean and maize, we multiplied the yield of each year, by the respective price predicted by the ARIMA model. The future prices was referred to 2016 and 2017. The technical coefficients, and the prices of inputs and machinery were collected in 2016, as extrapolated for the other seasons. The costs were calculated multiplying the quantity of each input used, by its unit price.

The contribution margin represents the subtraction of the variable costs by the revenue. The NPV is calculated as demonstrated by Damodaran (2004) in Equation 1, where *r* is the discount rate, *N* is the project lifetime (years), *CF* is the cash flow, and *t* is the time horizon:

$$NPV = \sum_{t=1}^{t=N} \frac{CF_t}{(1+r)_t} - Investment \qquad (1)$$

The IRR is calculated by equalizing the NPV to zero (DAMODARAN, 2004). The breakeven point is referred as the minimum area needed to be cultivated as to pay all the fixed costs.

The discount rate of the cash flow was calculated using the capital asset pricing model (CAPM) methodology to determine the expected return from the systematic risk (beta) of each investment. The T-Bond was used as a risk-free asset and the Dow Jones index as an indicator of the market return given that the prices of the commodities used are highly associated with the uncertainties of the international market (FARINELLI et al., 2018). To contextualize the Brazilian scenario, the Brazilian risk defined by the Emerging Markets Bond Index Plus (EMBI +) was added to the return rate.

5. Results and Discussion

5.1. Crops yields under no-tillage

The summer and winter crops yields during the ten years of the experiment, according to the treatments adopted, are presented in Table 2 for the soybean and maize rotation, Table 3 for maize as monoculture, and Table 4 for soybean as monoculture; the numbers represent the mean of the 3 replicates per treatment. Despite a limited number of replicates, the coefficients of variation are lower than 10% for most of the observed values.

Table 2: Summer and winter crop yields for the treatment soybean/maize rotation, during the growing seasons 2003/04, 2004/05, 2005/06, 2006/07, 2007/08, 2008/09, 2009/10, 2010/11, 2014/15 and 2015/16

	Summer crop yield (Kg ha^{-1})									
	2003/04 (maize)	2004/05 (soyb.)	2005/06 (maize)	2006/07 (soyb.)	2007/08 (maize)	2008/09 (soyb.)	2009/10 (maize)	2010/11 (soyb.)	2014/15 (soyb.)	2015/16 (maize)
Winter crop	Average	Average	Average	Average	Average	Average	Average	Random	Average	Average
Maize	6608.70	3300.60	8571.47	2943.20	6807.00	2599.80	7000.20	3960.00	4053.71	6557.20
Sunflower	6751.90	3187.40	8333.70	3008.60	6703.80	2899.80	7000.20	3120.00	4005.22	6566.80
Oilseed Radish	7209.62	3446.00	8831.88	3280.60	6967.80	3199.80	7399.80	4080.00	4177.11	6752.80
Pearl Millet	7784.75	3371.80	8263.38	3181.20	7050.00	3000.00	7600.20	3480.00	4137.72	6987.00
Pigeon Pea	6464.18	3076.00	7996.75	2757.20	6931.20	2200.20	7099.80	2520.00	3872.41	6573.40
Grain Sorghum	5909.62	2388.00	8433.95	2914.40	6646.80	2200.20	6900.00	3960.00	4128.43	6978.80
Sunn Hemp	7462.46	3749.80	8948.10	3214.00	6454.20	3100.20	7200.00	3600.00	3940.46	6209.00
	Winter crop yield (Kg ha^{-1})									
	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2014/15	2015/16
Winter crop	Average	Random	Average	Average	Random	Average	Average	Random	Random	Random
Maize	3981.00	3120.00	639.80	3111.20	660.00	3100.20	3700.20	3120.00	3120.00	1920.00
Sunflower	1418.80	1740.00	324.20	1170.00	1320.00	1900.20	2200.20	1680.00	1320.00	780.00
Grain Sorghum	2108.80	2820.00	213.60	1617.20	900.00	3100.20	2200.20	3060.00	2520.00	1680.00

Source: prepared by the authors.

Table 3: Summer and winter crop yields for the treatment continuous maize, during the growing seasons 2003/04, 2004/05, 2005/06, 2006/07, 2007/08, 2008/09, 2009/10, 2010/11, 2014/15 and 2015/16

	Summer crop yield (Kg ha^{-1})									
	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2014/15	2015/16
Winter crop	Average	Average	Average	Average	Average	Average	Average	Random	Average	Average
Maize	6602.91	6272.80	8027.59	6649.20	5893.20	7159.80	7000.20	7380.00	8130.28	6245.60
Sunflower	6663.73	6437.00	7783.96	6594.20	5560.80	6499.80	7000.20	6840.00	7735.96	6255.00
Oilseed Radish	6801.87	7322.00	8082.72	7059.80	6217.80	7200.00	7399.80	6480.00	8066.97	6485.00
Pearl Millet	6435.12	7458.80	7697.50	7425.60	6430.80	7800.00	7600.20	8040.00	8246.38	6388.60
Pigeon Pea	6674.26	7392.00	8062.62	7018.20	6219.00	7099.80	7099.80	7800.00	8572.89	5999.60
Grain Sorghum	6371.51	6138.80	7615.28	6797.60	5146.80	6900.00	6900.00	5820.00	8143.08	6657.60
Sunn Hemp	7051.24	7660.40	8330.12	6790.20	5451.00	8400.00	7200.00	8520.00	8786.95	6242.20

	Winter crop yield (Kg ha^{-1})									
	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2014/15	2015/16
Winter crop	Average	Random	Average	Average	Random	Average	Average	Random	Random	Random
Maize	4437.60	1560.00	508.20	2798.20	3840.00	3199.80	3199.80	3660.00	1920.00	600.00
Sunflower	1450.20	360.00	281.80	1417.80	1320.00	1699.80	1999.80	1740.00	1560.00	1680.00
Grain Sorghum	2622.60	660.00	168.20	1892.40	2280.00	3199.80	1699.80	1260.00	420.00	2400.00

Source: prepared by the authors.

Table 4: Summer and winter crop yields for the treatment continuous soybean, during the growing seasons 2003/04, 2004/05, 2005/06, 2006/07, 2007/08, 2008/09, 2009/10, 2010/11, 2014/15 and 2015/16

	Summer crop yield (Kg ha^{-1})									
	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2014/15	2015/16
Winter crop	Average	Average	Average	Average	Average	Average	Average	Random	Average	Average
Maize	2900.69	3284.20	3118.29	2754.00	3187.80	2599.80	3400.20	2940.00	3648.42	2753.80
Sunflower	3054.71	2915.80	2359.91	2612.80	3336.00	2899.80	3600.00	2580.00	3967.62	3387.80
Oilseed Radish	3162.48	3709.80	2913.33	2948.80	3481.80	3199.80	3700.20	3660.00	3832.95	3453.20
Pearl Millet	3016.63	3402.60	2749.52	2677.60	3424.80	3000.00	3499.80	3420.00	3741.02	3155.20
Pigeon Pea	2713.67	3331.60	2622.78	2642.80	3219.00	2200.20	3400.20	2940.00	3739.62	3157.80
Grain Sorghum	2595.51	2302.40	2964.07	2790.20	2721.00	2200.20	3700.20	3240.00	3982.05	2488.80
Sunn Hemp	3201.94	4011.80	3067.62	3206.00	3369.00	3100.20	4099.80	4080.00	4036.14	3507.80
	Winter crop yield (Kg ha^{-1})									
	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2014/15	2015/16
Winter crop	Average	Random	Average	Average	Random	Average	Average	Random	Random	Random
Maize	5003.80	1440.00	196.40	2487.60	3900.00	5200.20	3199.80	780.00	4560.00	4920.00
Sunflower	1279.20	960.00	81.00	673.40	720.00	1600.20	1500.00	540.00	480.00	960.00
Grain Sorghum	2748.20	2400.00	134.00	1905.00	3120.00	4600.20	3199.80	2400.00	1020.00	3000.00

Source: prepared by the authors.

The yields reported for the experiment are significant compared to those reported in other scientific studies. Evaluating the results of two consecutive years of a no-tillage system experiment in Brazil, Torres et al. (2015) found soybean first year yields of 3,300 kg ha^{-1} and for the second year 4,300 kg ha^{-1}. For maize in the first year 9,500 kg ha^{-1} and in the second year 8,400 kg ha^{-1}, both rotated with millet as winter crop. When the winter crop was *Crotalaria juncea*, the authors observed soybean yields of 4,000 kg ha^{-1} in the first year and 5,300 kg ha^{-1} in the second year. For maize, in the first year the yield was 11,000 kg ha^{-1} and in the second year 8,400 kg ha^{-1}.

The gain in efficiency in the rotated no-tillage system was evidenced by Anderson (2016), who verified an increase of 116% in maize yield over 25 years (average of 9,500 kg ha^{-1}), in contrast to the 32% increase in conventional soil tillage, in addition to a reduction in the use of nitrogen fertilizers and fuel consumption.

According to official data from the US Department of Agriculture (2017), Brazil's average yield in the 2016/2017 crop season was 5,000 kg ha^{-1} of maize, 3,000 kg ha^{-1} of sorghum, 3,000 kg ha^{-1} of soybean, and 1,000 kg ha^{-1} of sunflower.

The soybean yield was superior in 71% of the treatments of the SM rotation and 61% in the SS monoculture, both relative to the national average. Yield contributed to increase income despite the early cycle of the selected soybean cultivar, which refers to lower yields (Rio et al., 2016).

Maize exceeded the national average in 80% of SM and 100% of MM treatments, which was possible due to the decrease in production risk through the uniform distribution of rainfall and accumulated rainfall throughout the experiment, considering that rainfall is directly related to yield (Mupangwa et al., 2017). The presence of a satisfactory amount of straw on the soil surface also increased the nitrogen fertilization efficiency (MAGALHÃES et al., 2016).

An atypical year occurred during the 2005/2006 growing season due to unfavourable climatic conditions, characterized by a yield drop for all crops.

Although the soil tillage promoted higher crop yields in the first year after establishment, no-tillage system allows for an increase in yield in the medium and long terms, surpassing conventional tillage (CALONEGO et al., 2017).

A first highlight of this paper that attests the perform of the diversification is the higher maize and soybean yields observed under crop rotation in most of the studied years when compared to the MM and SS treatments, regardless of the winter crops. The distinct crop rotation in a no-tillage system can promote a better soil structure, directly influencing yield (MUNKHOLM; HECK; DEEN, 2013).

When evaluating the summer crops in the SM rotation as a function of the winter crops, millet conferred greater yields to the summer crops when maize was the summer crop, while oilseed radish was the most appropriate crop when soybean was the summer crop. Crotalaria also increased maize and soybean yields.

For the years of SM rotation, maize yield ranged between 6,987 kg ha^{-1} in the 2015/2016 growing season and 8,948 kg ha^{-1} in the 2005/2006 growing season. Soybean yields ranged between 3,200 kg ha^{-1} (2008/2009) and 4,177 kg ha^{-1} (2014/2015).

Maize yield as continuum crop (MM) was higher when crotalaria was the winter crop in some years and millet in others. The highest maize yield was obtained in the 2014/2015 growing season (8,727 kg ha^{-1}) while the lowest yield occurred in the 2006/2007 growing season (7,425 kg ha^{-1}).

Higher soybean yield as continuum crop (SS) was observed when crotalaria was the winter crop in some years and the oilseed radish in others. The highest soybean yield (4,099 kg ha^{-1}) was observed in the 2009/2010 growing season, contrasting with the 2005/2006 growing season, which was the lowest (3,118 kg ha^{-1}).

In terms of yield, as discussed above, the crops crotalaria, millet and oilseed radish, cultivated as off-season have the potential to benefit summer crops.

In an experiment conducted in Brazil with soybean as summer crop rotated with cover crops under no-tillage, Calonego et al. (2017) showed that cover crops reduced soil compaction on the 0.10 - 0.20 m soil depth, mainly under crotalaria as cover crop, and on the 0.20 - 0.40 m soil depth under sorghum and crotalaria as cover crop, which favoured root growth and increased soil macroporosity, water infiltration, and soil aeration. Furthermore, the summer soybean yield was higher under crotalaria as a cover crop.

As discussed by Pissinati, Moreira and Santoro (2016), the oilseed radish reverts amounts of residue exceeding 6 ton ha^{-1} with a high accumulation of nutrients (N, P, K, Ca, and Mg), also presenting a C:N ratio of 25:1, which contributes for accelerating the release of nutrients, which impact next crop yield.

Because of phosphorus and potassium losses in agricultural systems, especially in the 0.10 - 0.20 m layer, regardless the soil management, Rosolem and Calonego (2013) observed that phosphorus fertilization in no-tillage system along with millet as cover crop increases the content of carbon, which contributed to increase the yield of the subsequent crops and the production of biomass in the winter period.

The significant contributions to increase crop yield when millet is used as cover crop have been confirmed in other studies, such as that of Souza, Figueiredo and Sousa (2016), who concluded that in the no-tillage system, phosphate fertilization and millet as winter crop increase soil organic content.

It is important to highlight that the low yield conferred to summer crops when sunflower, sorghum, and maize were winter crops may be due to the late management of the plant residues when the grains are harvested. Moreover, Rawat et al. (2017) discussed the yield decrease in crop sequence due to the allelopathy caused by sunflower, which inhibits the growth and development of certain crops.

Winter crops did not influence summer crop yields in some growing seasons. As reported by Rio et al. (2016), yield variation can be explained by several factors, including the sowing period, accumulated precipitation, and temperature.

Winter crops should be planted prior to the beginning of the dry season, which begins in April, as shown in Figure 1, considering agroclimatic zoning, which is important to define the best season for sowing (SENTELHAS et al., 2015).

However, the no-tillage system allows for yield gain even during periods of lower water availability, as reported by Anderson (2016), who attested to a 9% increase in maize yield when compared to a volume of rainfall 22% lower in a specific period.

5.2. Cash flow revenue prediction model

The ARIMA soybean (4,0,5) and ARIMA maize (2,0,2) were defined. Felipe et al. (2012) obtained ARIMA (5,0,0) when using daily soybean prices quoted in northern Paraná over a 12-year horizon, using a similar approach.

There is a downward tendency in soybean future prices for the next 10 months, at 2.27%, representing a value of US$ 24.29 per 60 kg bag from June 30th, 2017. Concerning maize, for the same date, there was an increase of 1.99%, with a final value of US$ 13.62 per bag of 60 kg.

The price for soybean stabilized at 6.52% and that for maize at 4% concerning the range between the minimum and maximum prices and considering a 95% interval of confidence. The minimum and maximum prices gradually increase as the prediction date extends due to the high interval of confidence, presenting values that are far from reality.

The average price for the months of February and March 2017 will be considered to determine the revenue, which is consistent with the grain harvest in Brazil. The prices of US$ 13.30 and US$ 24.54 (per bag of 60 kg) will be considered for the future cash flows of maize and soybean, respectively.

The ARIMA analysis was not effective for sorghum and sunflower because of the limited amount of data available for analysis and the small monthly price variation. The value considered for the cash flow will, therefore, be the average for the last twelve months, that is, from December 2015 to November 2016. An average value of US$ 8.58 (per bag of 60 kg) was obtained for sorghum, and US$ 18.35 (per bag of 60 kg) was obtained for sunflower.

5.3. Representativeness of the costs

Table 5 shows the average relative percentages of the 10 years of the project for each treatment, demonstrating the composition of the production cost for the treatments comprising the soybean and maize crop rotation, Table 6 for continuous maize and Table 7 for continuous soybean.

Table 5: Production costs, total costs and revenue allocated, in percentage, according to the winter crop adopted, considering 10 years of the experiment, for the treatment soybean/maize rotation.

Offseason crop	Maize		Pearl millet		Wild radish		Sunflower		Pigeon pea		Sorghum		Crotalaria	
Main crop [1]	S	M	S	M	S	M	S	M	S	M	S	M	S	M
Seeds (main season)	5.3	7.5	5.8	8.1	5.9	8.3	5.9	8.1	6.1	8.4	5.7	8.1	5.7	8.1
Seeds (offseason)	7.4	6.5	6.4	5.5	4.1	3.6	0.7	0.6	3.9	3.3	3.7	3.2	7.2	6.3
Fertilizer (planting)	10.2	9.3	11.1	10.0	11.3	10.3	11.3	10.1	11.6	10.4	11.0	10.1	11.0	10.0
Fertilizer (topdressing)	0.0	12.0	0.0	13.0	0.0	13.3	0.0	13.0	0.0	13.4	0.0	13.0	0.0	12.9
Limestone	0.0	1.1	0.0	1.2	0.0	1.2	0.0	1.2	0.0	1.2	0.0	1.2	0.0	1.2
Agrochemicals	13.3	4.8	14.5	5.2	14.8	5.3	14.8	5.2	15.3	5.4	14.4	5.2	14.4	5.1
Field operations (owned machinery)	2.2	1.8	2.4	1.9	2.5	1.9	2.5	1.9	2.6	2.0	2.4	1.9	2.4	1.9
Field operations (rented machinery)	9.0	8.8	6.7	7.9	7.2	8.0	8.8	9.0	5.9	7.7	7.7	8.3	6.8	7.7
Post-harvest	5.2	6.5	3.0	5.7	3.2	5.7	4.2	6.3	2.6	5.5	4.9	6.3	3.0	5.5
Taxes	3.5	3.6	2.3	0.0	2.1	0.0	3.2	3.0	1.8	0.0	2.8	1.1	2.1	0.0
Leasing (land)	21.2	18.5	23.1	20.1	23.6	20.5	23.5	20.1	24.3	20.7	22.9	20.1	22.9	20.0
Variable costs	77.4	80.2	75.3	78.6	74.8	78.1	74.9	78.5	74.1	77.9	75.5	78.5	75.5	78.6
Machinery general expenses	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Hired labour and family labour	22.4	19.5	24.4	21.2	24.9	21.6	24.8	21.2	25.6	21.8	24.1	21.2	24.2	21.1
Administrative expenses	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Payable fixed costs	22.7	19.8	24.7	21.4	25.2	21.9	25.1	21.5	25.9	22.1	24.4	21.5	24.5	21.4
Total costs	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Revenue allocated	89.2	102.8	120.1	115.6	111.3	115.2	91.6	99.6	138.9	120.7	105.5	110.4	118.0	121.9

Note: [1] S represents soybean, and M represents maize.
Source: prepared by the authors.

Table 6: Production costs, total costs and revenue allocated, in percentage, according to the winter crop adopted, considering 10 years of the experiment, for the treatment continuous maize.

Offseason Crop	Maize	Pearl Millet	Oilseed Radish	Sunflower	Pigeon Pea	Grain Sorghum	Sunn Hemp
Seeds (main season)	7.6	8.1	8.3	8.3	8.3	8.2	8.1
Seeds (offseason)	6.6	5.6	3.6	0.6	3.3	3.3	6.3
Fertilizer (planting)	9.4	10.1	10.3	10.3	10.3	10.1	10.0
Fertilizer (topdressing)	12.2	13.0	13.3	13.3	13.4	13.1	12.9
Limestone	0.5	0.6	0.6	0.6	0.6	0.6	0.6
Agrochemicals	4.9	5.2	5.3	5.3	5.3	5.2	5.1
Field operations (owned machinery)	2.1	2.2	2.3	2.3	2.3	2.2	2.2
Field operations (rented machinery)	8.7	7.3	7.5	8.6	7.3	7.7	7.3
Post-hasvest	6.7	5.6	5.5	6.3	5.6	6.3	5.6
Taxes	2.3	0.7	0.8	2.0	0.7	1.3	0.7
Leasing (land)	18.9	20.1	20.6	20.6	20.7	20.3	20.0
Variable costs	79.8	78.5	78.0	78.0	77.9	78.3	78.6
Machinery general expenses	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Hired labour and family labour	19.9	21.2	21.7	21.7	21.8	21.4	21.1
Administrative expenses	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Payable fixed costs	20.2	21.5	22.0	22.0	22.1	21.7	21.4
Total costs	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Revenue allocated	99.7	118.8	120.0	99.6	118.5	112.5	119.8

Source: prepared by the authors.

Table 7: Production costs, total costs and revenue allocated, in percentage, according to the winter crop adopted, considering 10 years of the experiment, for the treatment continuous soybean.

Offseason Crop	Maize	Pearl Millet	Oilseed Radish	Sunflower	Pigeon Pea	Grain Sorghum	Sunn Hemp
Seeds (main season)	5.3	5.9	6.0	6.0	6.1	5.8	5.8
Seeds (offseason)	7.4	6.4	4.1	0.7	3.9	3.7	7.3
Fertilizer (planting)	10.1	11.2	11.4	11.5	11.6	11.1	11.1
Limestone	0.6	0.7	0.7	0.7	0.7	0.7	0.7
Agrochemicals	13.3	14.7	15.0	15.2	15.2	14.6	14.6
Field operations (owned machinery)	2.2	2.5	2.5	2.5	2.6	2.4	2.4
Field operations (rented machinery)	9.0	6.9	7.4	8.1	6.7	7.9	6.4
Post-hasvest	4.9	2.8	3.1	3.6	2.7	4.6	3.1

Taxes	3.5	0.7	0.9	1.9	0.8	1.4	0.9
Leasing (land)	21.1	23.3	23.7	24.1	24.1	23.1	23.1
Variable costs	77.4	75.1	74.7	74.3	74.2	75.3	75.3
Machinery general expenses	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Hired labour and family labour	22.3	24.6	25.0	25.4	25.5	24.4	24.4
Administrative expenses	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Payable fixed costs	22.6	24.9	25.3	25.7	25.8	24.7	24.7
Total costs	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Revenue allocated	97.2	127.4	117.9	108.6	122.9	110.6	116.1

Source: prepared by the authors.

Observing the variable costs of the treatments when maize was summer crop, regardless of the summer and winter crops adopted, the expenses with fertilizers are higher, surpassing 20% of the total cost, due to the topdressing N application.

When soybean was the summer crop, although the cost variable was lower than that of maize, the expressive cost refers to phytosanitary products due to the greater need for pulverization. The decrease in the use of herbicides was not considered in this study and is a topic for future research.

Seed costs were superior to 10% of the total cost for most of the treatments, except for sunflower, which presents lower costs when compared to the other winter crops, constituting an advantage for cost reduction.

In general terms, the expression of costs of land lease is remarkable given the competitiveness with sugarcane cultivation in the region and adequate soil fertility. The same is true for hired labour and family labour costs, which are highly representative mainly because of their idle capacity of hiring an employee for an indefinite period.

In terms of the percentage of allocated revenue in the total cost, the results are unfavourable for most treatments, exceeding 100%. Based on the values obtained, adopting sunflower or maize as winter crop contributes to increase the revenue, as indicated by the positive balances returns.

5.4. Estimation of the discount rate and NPV

The discount rate were defined as 4.08% per year for maize, 4.09% per year for soybean/maize rotation, and 4.10% per year for soybean, using the capital asset pricing model (CAPM) as described in the methodology.

The NPV for the treatments included in the soybean and maize rotation is presented in Table 8, for the continuous maize in Table 9, and for the continuous soybean in Table 10, with the discounted sum of the 10 years considered in the investment, over an area equivalent to 50 hectares. The values were updated to present values according to the minimum attractiveness rate (MAR) found for each treatment. The MIRR and breakeven point are also indicated.

Table 8: Discounted cash flow for the treatment soybean/maize rotation, according to the winter crop adopted, representing the sum of the 10 years of the experiment, in present values, considering an area of 50 hectares.

	Offseason crop						
Components	Maize	Pearl millet	Oilseed radish	Sunflower	Pigeon pea	Grain sorghum	Sunn hemp
Revenue	827,469.70	618,184.08	631,754.62	754,438.84	551,353.46	679,197.89	616,162.42
Variable costs	556,663.49	514,060.98	499,343.00	492,189.55	487,691.44	509,584.27	519,532.18
Contribution margin	270,806.21	104,123.10	132,411.63	262,249.30	63,662.02	169,613.62	96,630.24
Payable fixed costs	160,740.33	160,740.33	160,740.33	160,740.33	160,740.33	160,740.33	160,740.33
EBITDA[1]	110,065.88	(56,617.23)	(28,328.71)	101,508.97	(97,078.31)	8,873.29	(64,110.09)
Depreciation	68,415.69	68,415.69	68,415.69	68,415.69	68,415.69	68,415.69	68,415.69
Operational results	41,650.19	(125,032.92)	(96,744.40)	33,093.27	(165,494.00)	(59,542.40)	(132,525.78)
Income tax	17,592.98	4,534.52	4,081.85	13,999.07	3,349.07	8,383.34	4,147.32
CSLL[2]	10,555.79	2,720.71	2,449.11	8,399.44	2,009.44	5,030.01	2,488.39
Tax for surplus profit	-	-	-	-	-	-	-
Net results	13,501.43	(132,288.15)	(103,275.36)	10,694.76	(170,852.51)	(72,955.75)	(139,161.49)
Depreciation	68,415.69	68,415.69	68,415.69	68,415.69	68,415.69	68,415.69	68,415.69
Operational cash flow	81,917.12	(63,872.46)	(34,859.67)	79,110.45	(102,436.81)	(4,540.06)	(70,745.79)
Investment	218,194.30	218,194.30	218,194.30	218,194.30	218,194.30	218,194.30	218,194.30
Reinvestment	11,862.97	6,145.13	4,363.89	3,664.15	3,282.51	6,637.63	6,541.30
Accumulated discounted cash flow	(148,140.15)	(288,211.89)	(257,417.87)	(142,748.00)	(323,913.62)	(229,371.99)	(295,481.40)
MIRR[3]	-18.79%	-32.99%	-32.17%	-20.54%	-	-25.73%	-
Break-even point	72 ha	185 ha	145 ha	73 ha	300 ha	114 ha	199 ha

Note: [1] Earnings before interest, taxes, depreciation and amortization. [2] Social contribution on net income (CSLL, in Portuguese). [3] Modified internal rate of return. Values are expressed in dollars (US$). Numbers shown in parentheses indicate negative values.
Source: prepared by the authors.

Table 9: Discounted cash flow for the treatment continuous maize, according to the winter crop adopted, representing the sum of the 10 years of the experiment, in present values, considering an area of 50 hectares.

	Offseason Crop						
Components	Maize	Pearl Millet	Oilseed Radish	Sunflower	Pigeon Pea	Grain Sorghum	Sunn Hemp
Revenue	845,825.47	656,739.17	637,503.32	764,159.60	643,825.41	687,097.93	665,525.23
Variable costs	605,133.41	564,928.15	547,811.41	539,111.57	545,179.49	563,893.41	572,247.31
Contribution margin	240,692.06	91,811.02	89,691.92	225,048.04	98,645.92	123,204.52	93,277.92
Payable fixed costs	160,817.51	160,817.51	160,817.51	160,817.51	160,817.51	160,817.51	160,817.51
EBITDA[1]	79,874.55	(69,006.48)	(71,125.59)	64,230.53	(62,171.59)	(37,612.99)	(67,539.59)
Depreciation	68,445.53	68,445.53	68,445.53	68,445.53	68,445.53	68,445.53	68,445.53
Operational results	11,429.02	(137,452.01)	(139,571.1)	(4,215.00)	(130,617.12)	(106,058.52)	(135,985.12)
Income tax	11,280.29	2,928.93	3,226.70	8,645.70	2,780.86	5,792.37	2,714.31
CSLL[2]	6,768.17	1,757.36	1,936.02	5,187.42	1,668.51	3,475.42	1,628.59
Tax for surplus profit	-	-	-	-	-	-	-
Net results	(6,619.44)	(142,138.31)	(144,733.8)	(18,048.12)	(135,066.49)	(115,326.32)	(140,328.02)
Depreciation	68,445.53	68,445.53	68,445.53	68,445.53	68,445.53	68,445.53	68,445.53
Operational cash flow	61,826.09	(73,692.78)	(76,288.32)	50,397.41	(66,620.96)	(46,880.79)	(71,882.49)
Investment	218,237.96	218,237.96	218,237.96	218,237.96	218,237.96	218,237.96	218,237.96
Reinvestment	11,433.48	8,449.34	6,559.35	6,329.08	5,846.19	9,271.25	9,065.67
Accumulated discounted cash flow	(167,845.35)	(30,0380.08)	(301,085.6)	(174,169.6)	(290,705.11)	(274,390.00)	(299,186.12)
MIRR[3]	-21.17%	-34.56%	-33.89%	-23.19%	-34.33%	-29.53%	-
Break-even point	81 ha	211 ha	215 ha	86 ha	195 ha	158 ha	208 ha

Note: [1] Earnings before interest, taxes, depreciation and amortization. [2] Social contribution on net income (CSLL, in Portuguese). [3] Modified internal rate of return. Values are expressed in dollars (US$). Numbers shown in parentheses indicate negative values.
Source: prepared by the authors.

Table 10: Discounted cash flow for the treatment continuous soybean, according to the winter crop adopted, representing the sum of the 10 years of the experiment, in present values, considering an area of 50 hectares.

	Offseason Crop						
Components	Maize	Pearl Millet	Oilseed Radish	Sunflower	Pigeon Pea	Grain Sorghum	Sunn Hemp
Revenue	776,093.50	526,543.06	559,094.92	609,009.73	491,419.98	613,070.98	585,390.50
Variable costs	494,500.45	464,672.80	452,594.57	437,142.96	442,763.28	466,190.34	469,989.19
Contribution margin	261,722.70	61,870.26	106,500.35	171,866.77	48,656.70	146,880.63	115,401.32
Payable fixed costs	160,640.30	160,640.30	160,640.30	160,640.30	160,640.30	160,640.30	160,640.30
EBITDA[1]	101,082.39	(98,770.04)	(54,139.96)	11,226.47	(111,983.60)	(13,759.67)	(45,238.99)
Depreciation	65,623.90	65,623.90	65,623.90	65,623.90	65,623.90	65,623.90	65,623.90

Operational results	35,458.49	(164,393.94)	(119,763.86)	(54,397.43)	(177,607.50)	(79,383.57)	(110,862.89)
Income tax	15,376.28	2,614.02	3,351.87	7,123.50	2,840.73	5,213.71	3,236.41
CSLL[2]	9,225.77	1,568.41	2,011.12	4,274.10	1,704.44	3,128.23	1,941.85
Tax for surplus profit	-	-	-	-	-	-	-
Net results	10,856.44	(168,576.38)	(125,126.85)	(65,795.04)	(182,152.68)	(87,725.51)	(116,041.15)
Depreciation	65,623.90	65,623.90	65,623.90	65,623.90	65,623.90	65,623.90	65,623.90
Operational cash flow	76,480.34	(102,952.48)	(59,502.95)	(171.14)	(116,528.78)	(22,101.61)	(50,417.25)
Investment	203,532.73	203,532.73	203,532.73	203,532.73	203,532.73	203,532.73	203,532.73
Reinvestment	18,269.58	10,887.60	9,602.96	8,286.55	8,606.98	11,017.86	11,745.02
Accumulated discounted cash flow	(145,321.97)	(317,372.82)	(272,638.65)	(211,990.4)	(328,668.50)	(236,652.20)	(265,695.01)
MIRR[3]	-18.94%	-	-	-27.30%	-	-30.66%	-
Break-even point	73 ha	303 ha	175 ha	108 ha	383 ha	128 ha	163 ha

Note: [1] Earnings before interest, taxes, depreciation and amortization. [2] Social contribution on net income (CSLL, in Portuguese). [3] Modified internal rate of return. Values are expressed in dollars (US$). Numbers shown in parentheses indicate negative values.
Source: prepared by the authors.

From an economic perspective, the SM rotation when maize was the winter crop presented the smallest loss (US$ - 145,321.97) and a low MIRR (- 18.94%). However, from an agronomic perspective, this option is not advantageous in sequential planting, reducing the diversity of crop rotation.

The lower costs were obtained in the SS, especially under maize as winter crop due to the higher contribution margin in relation to that of other crops, as well as the operational cash flow (OCF), which represents the second most economically attractive crop sequence. In addition, this system represents great agronomic viability due to species diversification.

This finding is of particular interest in the grain production in Brazil and a central contribution of this paper, once it attests the superiority of the succession soybean-maize, widely adopted by Brazilian producers, proven by the expressive percentage of maize production as the winter crop and soybean production as summer crop (CONAB, 2017b). It also indicates why producers prefer to adopt maize instead of other alternative crops in the off-season, when soybean is cultivated as the first crop.

The MM provided higher incomes of all the crop sequence options regardless of the winter crop, mainly due to the maize yield and maize price, which contributed to generating revenue. In general, the adoption of maize or sunflower as winter crop allows for cultivation in smaller areas, expressed by the break-even point, favouring small and medium producers. Although the NPV and the MIRR of maize as monoculture were negative, the MM can generate income due to the commercialization of the grains produced during the winter season, returning positive OCFs.

As reported by Matsuura et al. (2017), growing sunflower crops in succession to soybean increases revenue and reduces costs due to the use of agricultural equipment unused during the off-season. According to these authors, it is possible to reduce nitrogen fertilization in the sunflower crop because of the greater availability of this nutrient from the biological fixation of N by the soybean.

The economic unfeasibility is partially explained by the high investment and reinvestment costs, resulting in a large capital contribution in machinery, equipment and improvements. This is also a central finding of this paper, because it express the need of a contribution margin that meets the investment cost, in order to sustain the activity in the long run.

Table 11 shows the NPVs in perpetuity, that is, the capacity to generate infinite time value for each treatment.

Table 11: Net present value representing the perpetuity of the different treatments.

Winter crop	Soybean/maize rotation	Continuous maize	Continuous soybean
Maize	(436,759.32)	(495,841.01)	(427,601.81)
Sunflower	(849,730.66)	(887,369.00)	(933,851.88)
Oilseed Radish	(758,941.12)	(889,453.29)	(802,224.07)
Pearl Millet	(420,861.71)	(514,523.93)	(623,770.04)
Pigeon Pea	(954,989.53)	(858,787.63)	(967,088.78)
Grain Sorghum	(676,253.90)	(784,100.89)	(696,335.95)
Sunn Hemp	(871,163.23)	(883,841.85)	(781,792.78)

Note: Values are expressed in dollars (US$). Numbers shown in parentheses indicate negative values.
Source: prepared by the authors.

The capacity to afford the fixed and variable costs occurred in none of the options of crop sequences tested in the present study considering an area of 50 hectares. Therefore, the enterprise is not sustainable in the long term based on the adopted model.

6. Conclusion

First, the MAR was high, indicating high cost of equity, thus constituting an impediment for adoption of small-scale commodities. This fact was corroborated by the balance of the treatments over 70 ha when both the summer and winter crops generated revenue. The breakeven point for the winter crops used as cover crop was greater than 140 ha.

An increased availability of rural agricultural credit, provided by the country's government, with more attractive interest rates and lengthening payment terms, may favour the viability of agricultural enterprises.

Second, because the investment costs are high, the small-scale production of soybean and maize is unfeasible regardless of the winter crop adopted and requires higher returns or reduction of fixed costs.

Third, it is possible to use idle machinery capacity. With the same defined investment, it is possible to manage a larger area, positively changing the results. A similar pattern is observed regarding labour availability, which can be intensified because it is contracted for an indefinite time.

However, despite the economic viability of the options for the negative results of the NPV and MIRR, inferior to the MAR for all crop sequence, the adoption of maize or sunflower as winter crop allowed for positive operational cash flow (OCF) for most of the crop sequence tested, indicating the income generation capacity of the CS, even on a smaller scale.

The results of the present study can help Brazilian producers in the decision-making process, as it assess the costs of capital, the representativeness of costs, the competitiveness of alternative grain crops in a CS system, and the economic viability of selected production systems.

However, the results may not be compared with those of other studies, since the assumptions adopted here, specifically the time horizon addressed, the defined MAR, and the size of area, may be different. Nevertheless, the scale gains are not addressed in this work, and the valuation of land over time was not considered.

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