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Review

Optimization model of agricultural production system in grain farms under risk, in Sorriso, Brazil

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ABSTRACT

Brazil is among the world's largest grain producers and exporters. Its high productivity is the result of its technology in tropical agriculture, the way Brazilian farmers apply these technologies in their farms and Brazil's particular production conditions. The literature offers few scientific papers that describe and enhance decision support systems for agricultural planning in tropical agriculture, especially those that include two annual harvests in the same area. This paper brings important contributions to understand the double-crop production systems that make Brazil one of the world's leading and most competitive grain-producing countries. It proposes a decision support model focused on production planning in multiproduct farms under risk conditions and applies this theoretical model of farm planning that uses operations research to understand the different productive resource allocations in farms engaged in grain production. This model was implemented in a representative farm in the Sorriso region, one of the main grain producing areas in Brazil. The efficient frontier curves calculated in the study revealed that the representative farms in this region maximized their production factors. The results showed that the production system adopted by the producers in Sorriso has achieved good financial returns with lower risks.

Contents

1. Introduction

Brazil's expanding grain and fiber production has caught the attention of international markets. The growth rate of soybean production is 5.5% per year in Brazil against 3.6% in the World and corn to 5.3% per year and 3.9% in the World in the 2000s (USDA, 2013). Its agricultural production increase is mainly attributed to improvements in management and product technologies, as the use of direct seeding techniques, adapting agricultural machinery to soil conditions in Brazil, investments in genetic improvements and other production factors have enabled Brazilian

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farmers to harvest two crops annually in the same area. Crops sown between September 15 and December 15 are called first harvest and the crops following the previous production are called second harvest (seeding between December 16 and March 15). For example, the second corn harvest follows the first harvest, which for Brazil it is normally soybeans.

This paper presents new data of production costs and operating procedures commonly used in the production of soybeans and corn in the Central-West region of Brazil. This work differs from those commonly found in the literature by proposing an agricultural planning model that estimates intensive land use with two harvest seasons in the same harvest year. As the capital available for the production of grains and cereals is insufficient to fund the entire cost of their farm, producers in Mato Grosso sell part of the production before the crop is harvested, via contracts, to finance the crop. This aspect, which is not commonly considered in the planning models available in the literature, is taken into account in the model presented herein.

Agricultural production planning models at farm levels should take into account, among other factors, what products will be produced, which areas will be allocated to each of them, which production operational practices will be adopted and what level of production costs will be pursued. Linear programming models have been widely used to prepare this plan in order to optimize production systems. These models usually combine the production of different products with different soil management and agricultural practices, efficiently allocating resources and minimizing costs (Heady, 1954; McCorkle, 1955).

Table 1 presents some studies that use linear programming as a tool for developing farm planning. However, all these models do not incorporate the risk in their analyses. It is important to consider risk in farm planning, because when it is ignored the model always leads to the result of optimum combination with the highest return. Choosing a combination of activities without the risk can result in wrong farm planning decisions, in addition to also affecting the profitability and investment capacity of the farm in the long term. According to Hazell (1971) and Hazell and Norton (1986), farm planning that do not including the risk factor has had limited and sometimes unacceptable results.

The conditions of uncertainties and risks inevitably associated with crop production cannot be neglected. This is why farm planning studies by Hazell (1971), Peres (1976), Brink and McCarl (1978), Schurle and Erven (1979), Mapp et al. (1979), Peres (1981), Held and Zink (1982), Hall et al. (1983), Rodriguez (1987), Silva (1988), Teague and Lee (1988), Cortina (1992), Mohamed and Thani (1993), Kyle (1993), Dias (1996), Araújo (1997), De Zen (2002), Fasiaben (2002), Pizzol (2002) and Souza et al. (2008) among others, have incorporated the risk factor in the linear programming model for farm planning to determine the combination of activities of lower risks and higher returns.

Brink and McCarl (1978), for example, do not take into account the different marketing alternatives in determining the revenue of the property. Authors such as Rodriguez (1987), De Zen (2002), Pizzol (2002) and Fasiaben (2002) only consider the price of the product in the market and do not discriminate the different selling modes of the product – which compose the farm gross revenue. Thus, the proposed model seeks to anticipate the average gross income of the farms through two ways of negotiating the production sale, which is a characteristic of grain production in Brazil, hence contributing to its success.

Another relevant point of this work refers to how to estimate agricultural planning risks. The models proposed by Peres (1981), Rodriguez (1987), Araújo (1997), De Zen (2002), Pizzol (2002) and Fasiaben (2002) minimized the risk of the activity with the absolute deviation of total gross revenue, using this criterion due to the absence of past production costs. This study addresses uncertainty through the actual product gross margin of ten seasons (2000/01–2009/10). These unpublished cost data represent the article's major contribution and were collected through panels with producers and technical advisors over the course of 10 years.

Finally, it should be mentioned that the grain production system in Mato Grosso and Brazil has undergone many changes in recent years. It is therefore essential and extremely important to conduct studies that contribute to the understanding of production practices and economic and financial flows of the production of multiproduct farms working with two crops in the same harvest year. Mato Grosso is the main producer of second crop soybeans and of corn in Brazil, in which the average of the last five seasons (from 2005/06 to 2009/10) accounted for 28.95% of the national soybean production and 37.03% for second crop corn (CONAB, National Company for Food Supply). In 2000 the growth rate of the Brazilian soybean production area was of 4.5% and for the second crop corn it was of 8.5% per year. In the same decade Mato Grosso recorded an increase of 6.4% in soybean area and 19.1% for the second crop corn, per year. The role Mato Grosso plays in Brazil's grain production and the role Brazil plays in the global agricultural production underscore the importance of this article for all who want to know about the production and financial structure of large Brazilian farms that produce soybeans and corn.

To meet the proposed objectives, this paper is divided into four sections. The second section explains the materials and methods used for the analysis. The results and discussion are in section three, while the fourth section presents the final remarks.

Table 1
Some farm planning model using Linear Programming (LP) without risk. *Source:* Research data.

Author(s) and years	Main research focus
Peterson (1955), Swanson (1956), El-Nazer and McCarl (1986), Jolayemi and Olaomi (1995), Kebede and Gan (1999), Santos et al. (2007), Milan (2008) and Mohamad and Said (2011)	Developed farm planning model aimed at optimizing the combination of products produced with crop rotation practices
Lima (1988)	Used LP model for obtaining an optimal cost cutting plan for eucalyptus forests
Santaella (1995)	Developed an agricultural planning mathematical model aimed at eliminating or reducing the burning of sugarcane fields
Caixeta Filho et al. (2002)	Proposed an agricultural management model for the production of lilies in the region of Holambra
Junqueira and Morabito (2006, 2008)	Formulated a corn seed production and logistics planning model
Ashraf and Christensen (1974), Dodd et al. (1975) and Coote et al. (1976)	Proposed a linear programming model to schedule the distribution of animal manure in the fields
Stonehouse and Narayanan (1984)	Determined the animal manure nutrient value compared to the chemical fertilizers
Keplinger and Hauck (2006)	Presented an excrement application model to increase the distribution area, keeping under control the problem of excessive phosphate in the soil

2. Material and methods

This section was divided into four parts, of which the first part describes the study area representing the farm. Next, it describes the data obtained and processed in the article. The third part shows the criteria used to obtain the absolute deviation values. Lastly, the theoretical model used in the paper is presented.

2.1. Study area of a typical or representative farm

The criterion to choose the location for collecting information from a representative farming property should mirror the main producing area of the product studied, in which the production system and the combination of activities, land and resources most common in the region should prevail (Deblitz et al., 1998). The representative or typical property of an agricultural production structure must include the characteristics of a group of producers in a given region that use the same technologies (Elliot, 1928; Plaxico and Tweeten, 1963; Feuz and Skold, 1991). These key features should include the size, productivity, technology, combination of activities, the production system and work organization of the farm in the study area (Hazell and Norton, 1986; Deblitz et al., 1998).

These study criteria enabled to analyze typical cereal production farms in the region of Sorriso, State of Mato Grosso. In 2009 the region of Sorriso accounted for 32.7% of the soybean and 38.2% of the corn produced in this state. The size of an agricultural cultivation area of a typical property of Sorriso is of 1300 ha, an area occupied with early soybean and normal soybean production in the first season and corn in the second season. This activity is performed in the property by a set of machines, five tractors and two harvesters, and only one is equipped for harvesting corn. The workforce consists of four tractor operators, two general workers and a cook. The data series of 2001/00–2009/10 assumed a farm with direct sowing production system for soybean and corn crops.

2.2. Processing data

The data used by the model were obtained in two different ways and at two different times. First, field research was performed between the 2004/05 and 2009/10 seasons to obtain information at the production sites. These are unpublished data and are the results of a long data collection process in the field. They represent the conditions of a representative farm and were collected from the rural union of Sorriso between the months of June and July for each crop year by the panel method. Deblitz et al. (1998) and De Zen (2002) suggest applying this technique to a group of one or more researchers, a local professional (consultant) and 5–10 producers who in consensus should complete an electronic spreadsheet. The group then details the size of the property (agricultural area, pasture area, the legal reserve and permanent preservation area), number of machines, equipment, building and labor (permanent and temporary), average prices of machinery and implements, yield and value of production sales. Next, the steps of the production process in the farm are collected input data, such as: technical coefficients related to the time of use of machinery and equipment, quantity of inputs, and hours worked. This information helps to determine the cost related to the farm's inputs, mechanical operations, fixed costs and gross revenues. The data collected via panel was analyzed for the entire farm model for the crop year 2004/05–2009/10. The input data such as yield, labor hours, machinery hours and inputs were adjusted to represent the crop production situation of each season.

The analysis period was extended to ten crop years in order to increase the accuracy in determining the risks involved in agricultural planning. The second step was an additional period of four crop years, in which no field data were collected, and necessary to perceive any important changes in the production process over the years studied, as follows:

- Production costs for the 2000/01–2003/04 seasons were calculated with same input data (yield, labor hours, machinery hours and inputs) for soybeans and corn in the 2004/05 season.
- The average prices of fertilizers, pesticides, seeds and diesel were adjusted based on the variation of the values for the same products collected by SEAB (Paraná State Department of Agriculture and Food Supply).
- In the absence of same product price series, the monetary correction was by the average variation of values for the chemical group of herbicides, insecticides and fungicides.
- The products with active ingredients, such as acetamiprid, diafenthiuron, zeta-cypermethrin, carfentrazone-ethyl, trifloxysulfuron-sodium, flumioxazin, etefon and diuron + tidiazurom, assumed the same values in four seasons in US$, but they were adjusted by the exchange rate of each year.
- For the soybean production, two applications of fungicides against Asian soybean rust (*Phakopsora pachyrhizi*) were reduced for the 2002/03 harvest. Fungicides against rust were not considered for the 2000/01 and 2001/02 crop years.
- The average prices of the products (soybean and corn) are the values received by producers according to the Center for Advanced Studies on Applied Economics – CEPEA.
- The corn and soybean yields in the city of Sorriso were obtained from the Brazilian Geography Statistic Institute – IBGE for the season 2000/01–2003/04.

The nominal prices of fertilizers, crop protection, seeds, diesel, labor cost, crops prices and other inputs for the 2000/01–2009/10 season were obtained by converting the data to real prices by GPI-IA (General Price Index – Internal Availability, consulted in http://www.ipeadata.gov.br) for December 2010.

The operational costs (OC) used by the model refers to the value of the direct input costs (seeds, fertilizers, crop protection and foliar fertilizer), diesel, machine repair, labor, contracted service, warehousing, freight, crop insurance, overhead and field inventory costs. Table 2 shows operational cost found in the representative farm of Sorriso between the crop years 2000/01 and 2009/10.

There are two typical crop trade methods that compose representative farm's gross revenue of Sorriso: anticipated contract and spot market. The anticipated (future) contract is trading the product before the expected harvest production, which may or may not be the anticipated resource. This is a contract in which the price, date and place of delivery are fixed. The spot market is the transaction of the production during or after harvest (Table 2).

The average revenue and operational costs of the ten seasons (2000/01–2009/10) were calculated, and the gross product contribution margin was obtained from the difference between these two variables. Table 2 shows the average gross margin of the products found in the representative farm of Sorriso between the crop years 2000/01 and 2009/10.

The land use period considered was of 24 months. In this period all the incoming and outgoing monthly products in the cultivation area can be perceived, mainly for the double harvest production system. In the first harvest season the farm (producing soybeans and corn) concentrates the cultivation of early oilseeds between September and December. The normal soybean cycle is introduced into the agricultural area in October, remaining until March. For the second crop, corn enters as a cultivation option after the early soybean is harvested, occupying the area between January and July.

Table 2
Average gross margin (AGM) of the representative farm for the last ten seasons (2000/01–2009/10) – R$/ha. *Source:* Cepea – elaborated by researchers.

Product	Season	Average price trade in different negotiation form (R$/t)		Quantity trade for different negotiation form – (*t*)		Gross revenue	Operational cost	Average gross margin
		Anticipate	Spot[a]	Anticipate	Spot	R$/ha	R$/ha	R$/ha
Early soybean	00/01	447.04	587.76	1.11	2.06	1703.08	1460,21	242.88
	01/02	472.75	652.50	1.09	2.03	1839.16	1628,26	210.91
	02/03	513.28	895.61	1.65	1.35	2051.47	1630,77	420.69
	03/04	605.02	909.23	1.91	1.03	2085.38	1773,59	311.79
	04/05	686.70	521.48	1.05	1.95	1737.92	1617,82	120.10
	05/06	418.55	428.94	1.35	1.65	1272.79	1440,33	−167.54
	06/07	391.17	479.28	1.18	1.76	1305.47	1214,84	90.62
	07/08	414.54	698.70	1.50	1.50	1669.86	1193,57	476.30
	08/09	619.98	644.90	0.60	2.40	1919.75	1476,97	442.78
	09/10	564.58	571.63	0.92	2.15	1752.96	1161,23	591.73
Average (00/01–09/10)						1733.78	1459,76	274.02
Soybean	00/01	447.04	492.99	1.22	2.26	1659.08	1438,29	220.79
	01/02	472.75	561.06	1.20	2.23	1819.15	1600,71	218.45
	02/03	513.28	713.42	1.81	1.48	1986.70	1622,98	363.72
	03/04	605.02	951.54	2.00	1.23	2374.95	1847,94	527.01
	04/05	686.70	503.80	1.16	2.15	1873.79	1680,79	193.00
	05/06	418.55	354.17	1.46	1.78	1241.37	1432,06	−190.70
	06/07	391.17	449.73	1.30	1.94	1381.23	1175,83	205.40
	07/08	414.54	663.50	1.65	1.65	1778.76	1193,02	585.74
	08/09	619.98	654.49	0.64	2.54	2059.32	1454,24	605.08
	09/10	564.58	479.51	0.97	2.27	1636.30	1242,52	393.79
Average (00/01–09/10)						1781.07	1468,84	312.23
Corn	00/01	0.00	202.22	0.00	3.84	776.52	768,84	7.68
	01/02	0.00	272.50	0.00	3.66	996.36	798,68	197.67
	02/03	0.00	216.01	0.00	3.90	842.32	726,74	115.58
	03/04	0.00	226.80	0.00	3.91	887.78	757,96	129.82
	04/05	0.00	210.69	0.00	3.72	783.78	732,53	51.25
	05/06	0.00	172.69	0.00	4.20	725.29	817,59	−92.29
	06/07	0.00	238.31	0.00	4.80	1143.87	1070,84	73.03
	07/08	0.00	247.71	0.00	4.08	1010.64	915,20	95.44
	08/09	0.00	157.37	0.00	5.10	802.58	942,35	−139.77
	09/10	190.93	236.24	3.49	1.49	1018.51	965,84	52.67
Average (00/01–09/10)						898.77	849,66	49.11

[a] Cepea data.

Table 3 shows the machine operation in the land, technical coefficient, for seeding and harvesting of soybean and corn. These parameters are important because the dynamics and systematization of double crop in the farm depends on the availability of the set of existing machines. Thus, the model assumes that the sowing time for one hectare of soybean is 0.29 h using two tractors and two seeders working at a speed of 7 km/h for 8 h a day, with 70% work efficiency and 68% probability the operation will performed in 1 month. For corn sowing the speed of 6 km/h is used, providing a theoretical seeding capacity of 0.34 h/ha for 1 month.

The technical coefficients of the harvest were calculated assuming that the representative property of Sorriso has two harvesters, one used for the corn crop. The soybean harvest period is humid and rainy, requiring two machines in the field to enable the second harvest. Therefore, the model assumes a set of two harvesters, at a theoretical speed of 6 km/h for 6 h a day, with working efficiency of 70% and 68% probability that the operation will be performed in 1 month, which potentially results in the time to harvest one hectare of soybeans at 0.25 h. As the corn harvest period is dry, with no rain, and does not require two machines in the field, one harvester can harvest 0.43 h/ha in 1 month, assuming a theoretical speed of 7 km/h for 8 h a day, with a working efficiency of 70% and 68% probability that the operation will be performed in 1 month.

The available time for sowing and harvesting is 15 h for the 31 available days in 1 month, totaling 465 h. The values for the mechanical operation of soybean and corn seeding are not constant because they were adjusted according to the working days of the mechanical operation, which is the average value of days without rainfall and precipitation less than 5 mm recorded between 1995 and 2009 (Table 3). And the total available time varies according to the number of days in the month.

The model considers cash flow constraints, which are important elements to be considered in the financial management of farms in Brazil. The volume of funds offered under the government agricultural credit policy has never fully met the needs of the producers of Mato Grosso. From 2000/01 to 2009/10, the federal government offered the maximum amount of R$ 200000.00 per crop year per producer to finance the soybean crop. This amount represents only 10.5% of the amount necessary to cover the average soybean production costs in the typical property of Sorriso, according to Table 1. This situation explains why the producers sell part of their production before harvest as a way to finance their crops. The remaining production is traded after the product is harvested. These two forms of production trading differ from those considered in the studies of Rodriguez (1987), De Zen (2002), Pizzol (2002) and Fasiaben (2002). In their analysis the authors consider only the product price in the spot market and do not discriminate the trade of the combined crop production in the composition of the gross revenue of the farms.

As the representative farm works with a double crop, a 24-month cash flow regime was used. This allowed recording the gross revenue entry of the agricultural products of the typical farm with soybeans in two trading modes (anticipated and spot market) and also with corn. In addition, it records the money used to pay

Table 3
Parameter and constraint of the seeding and harvesting area for the representative farm in Sorriso – MT. *Source:* Research data.

Month	Days of month	Useful days for mechanical operation (%)	Seeding			Harvest		
			Technical coefficient – h/ha		Total available hours	Technical coefficient – h/ha		Total available hours
			Soybean	Corn	Grain	Soybean	Corn	Grain
1	31	68.0	0.29	0.34	465	0.25	0.43	465
2	28	63.3	0.31	0.36	420	0.27	0.46	420
3	31	73.0	0.27	0.31	465	0.23	0.40	465
4	30	87.9	0.22	0.26	450	0.19	0.33	450
5	31	96.5	0.20	0.24	465	0.18	0.30	465
6	30	98.5	0.20	0.23	450	0.17	0.30	450
7	31	98.8	0.20	0.23	465	0.17	0.30	465
8	31	99.1	0.20	0.23	465	0.17	0.29	465
9	15	92.1	0.21	0.25	225	0.18	0.32	225
10	31	79.5	0.25	0.29	465	0.21	0.37	465
11	30	77.6	0.25	0.30	450	0.22	0.38	450
12	31	65.4	0.30	0.35	465	0.26	0.45	465
13	31	68.0	0.29	0.34	465	0.25	0.43	465
14	28	63.3	0.31	0.36	420	0.27	0.46	420
15	31	73.0	0.27	0.31	465	0.23	0.40	465
16	30	87.9	0.22	0.26	450	0.19	0.33	450
17	31	96.5	0.20	0.24	465	0.18	0.30	465
18	30	98.5	0.20	0.23	450	0.17	0.30	450
19	31	98.8	0.20	0.23	465	0.17	0.30	465
20	31	99.1	0.20	0.23	465	0.17	0.29	465
21	15	92.1	0.21	0.25	225	0.18	0.32	225
22	31	79.5	0.25	0.29	465	0.21	0.37	465
23	30	77.6	0.25	0.30	450	0.22	0.38	450
24	31	65.4	0.30	0.35	465	0.26	0.45	465

the operating costs of the farm's agricultural products (Table 4). The 24-month cash flow attempts to better portray the farm's financial regime regarding the input and output variation of resources. This condition sets this article apart from the research of Rodriguez (1987), De Zen (2002), Pizzol (2002) and Fasiaben (2002), who evaluated the revenue flow and annual and quarterly costs.

Therefore, this condition was structured for each month, with the average real income of the ten crops years, and also of the costs. In Sorriso, the operating cost (OC) of early soybean (ES) was of R$ 3.23/ha in month 1. In the same period, the OC was R$ 3.2/ha for normal soybeans and R$ 3.27/ha for corn (Table 4). The same procedure was performed to determine the average value of the following 23 months for the farms with soybean and corn cultivations.

The model assumes that capital is not constrained to decision making regarding the products, with the initial available value of R$ 1700/ha for the representative farm in Sorriso. In turn, the balance of the previous month will be used the following month to finance the farm's production.

The negative cash flow balance was not corrected with financial interests. This situation was not verified with the availability of capital considered in the model assumption. At any rate, it is assumed that this amount is not significant enough to change the results of this study. In the period investigated (2000/01–2009/10), the typical property could borrow money from the government to pay for the agricultural costs at an average monthly interest rate of 0.6548% per month and the average loan period is of 8 months. However, the amounts of interest paid by the producers were not obtained during the field visit. The explanation given is that the average interest rate value varies for each borrower, because it depends on factors such as the amount of outstanding debt, extended debt, capacity to pay, the producer's background records and other requirements required by financial agents.

Finally, the model studied considers in the calculation the absolute deviation of total average gross margin as a measure of risk. This condition seeks to capture the cost variation in the production and gross revenue.

Table 4
Mean revenue and cost values of the ten seasons (2000/01–2009/10) for the products found in the representative farm in Sorriso – R$/ha. *Source:* Cepea – elaborated by researchers.

	Sorriso					
	ES		SN		SC	
	OC	RB	OC	RB	OC	RB
1	3.23	0	3.52	0	3.27	0
2	3.21	0	3.51	0	3.26	0
3	14.18	0	14.47	0	3.24	0
4	77.71	0	6.15	0	2.44	0
5	2.37	0	73.19	0	2.43	0
6	107.33	0	130.57	0	25.7	0
7	39.06	0	38.16	0	3.84	0
8	5.02	0	6.66	0	3.81	0
9	37.94	0	38.24	0	2.36	0
10	55.83	0	56.16	0	2.34	0
11	68.07	0	70.64	0	2.31	0
12	32.94	457.87	14.25	0	151.34	0
13	47.27	496.79	5.84	0	260.62	0
14	67.95	152.13	51.67	0	52.35	0
15	36.46	0	60.88	338.99	72.92	0
16	802.09	626.99	828.04	1075.77	8.53	0
17	47.12	0	53.56	238.75	1.19	0
18	1.75	0	2.26	28.4	67.2	83.33
19	1.74	0	2.25	28.36	76.6	244.53
20	1.73	0	2.24	28.29	79.05	291.03
21	1.71	0	2.01	21.62	10.95	178.8
22	1.7	0	1.73	14.69	6.82	42.26
23	1.68	0	1.52	6.21	3.55	38.17
24	1.67	0	1.3	0	3.54	20.64

ES: Early soybean, SN: Normal soybean, SC: Second corn crop.

This measure differentiates this work from the many others carried out. It should be noted that it is extremely difficult for researchers to obtain reliable cost series of agricultural production in Brazil. This fact helps to explain, for example, why Peres (1981), Rodriguez (1987), De Zen (2002), Pizzol (2002) and Fasiaben (2002) considered only the absolute deviation of total gross revenue as a measure of risk.

2.3. Application of Minimization of Total Absolute Deviations – MOTAD

The MOTAD method applied in linear programming was implemented to evaluate the change in the combined activity associated with the income variability in the farm. The values used in the calculations were based on the absolute deviations of crop's contribution margins. To determine the absolute deviation value, we have calculated the difference between the average contribution margin effectively observed and the value of the expected contribution margin (ECM) condition for that production. The variable ECM was obtained from the linear regression of the contribution margin of the cultivation in relation to time. The value of the intercept and the line slope generated in the regression allow estimating the value of the expected contribution margin (ECM) of the crop year, which refers to the value that farmers expect to earn at the end of each crop year. For this paper, the linear regression of the average contribution margin of early soybean from 2000/01 to 2009/10 generates an intercept value of 137.71 and line slope of 24.71. In regard of the case of regular soybeans, the intercept was 178.06 and line slope, 24.39; as for corn, the intercept was 128.17 and line slope, −14.38 in the same period of research. To calculate the expected contribution margin of early soybean in the period 1, the intercept value of 137.71 with line slope of 24.71 multiplied by 1 (period 1) should be added, resulting in 162.49. The absolute deviation was obtained with a difference between 242.88 (ACM) and 162.49 (ECM), resulting in 80.39. The same figures were adopted for normal soybeans and corn, with respective values found in the linear regression below, resulting in ECM of 202.45 for soybean and 113.79 for corn in the period 1. As for regular soybeans, the absolute deviation was 18.33 in the period 1, and, for corn, it was −106.12 (Table 5).

The data processing was performed using the LINDO software version W32. The variables considered in the restrained planning model with maximum gross margin contribution were: use of area under cultivation in the harvest period, availability of machine-hours for sowing and harvesting and cash flow of the farm. The second part was to minimize uncertainties, considering the above-mentioned restrictions and the absolute deviation of the gross margin of the farm.

2.4. Model used

2.4.1. Maximization of operating net revenue or gross contribution margin

The objective function, Eq. (1), which reflects the maximization of the gross contribution margin of the typical farm in R$/ha is given by:

$$z = \sum_{j=1}^{m} mb_{ij}X_j \quad j(1,\ldots,m) \tag{1}$$

$$X_j \geqslant 0 \quad j(1,\ldots,m)$$

where X_j is the area of j product (ha); mb_{IJ} the gross contribution margin of j product in (R$/ha) in period i, and m is the number of products.

The maximization of the objective function is subject to the restriction that the representative farms studied should cultivate two crops in the same year.

Eq. (2) represents the amount of cultivation area for early soybean, normal soybean and second corn crop, in hectare, in period i should not exceed the total cultivation area of the farm.

(a) Land use – ha

$$\sum_{i=1}^{n}\sum_{j=1}^{m} a_{ij}X_j \leqslant ATC_i \quad i(1,\ldots,n) \text{ and } j(1,\ldots,m) \tag{2}$$

$$X_j \geqslant 0 \quad j(1,\ldots,m)$$

where a_{ij} is the agricultural area available for j product in the farm in period i; if $a_{ij} = 1$ in period i, then the land can be occupied with product j. Otherwise, if $a_{ij} = 0$ in the period i, the area is unavailable for the cultivation of product j. ATC_i the total cultivation area of the farm in period i; m the number of products; and n is the number of periods.

The increased use of the area requires greater availability of machine-hours for sowing the crop in the recommended time period. Thus, Eq. (3) shows that the quantity of machine-hours for seeding product j, in hours per hectare, in period i does not exceed the total available hours for sowing (*THAS*) also in period i.

(b) Availability of machinery for sowing – h/ha

$$\sum_{i=1}^{n}\sum_{j=1}^{m} s_{ij}X_j \leqslant THAS_{ij} \quad i(1,\ldots,n) \text{ and } j(1,\ldots,m) \tag{3}$$

$$X_j \geqslant 0 \quad j(1,\ldots,m)$$

where n is the number of periods; m the number of products; s_{ij} the hour-machine per hectare for sowing product j in period i; and $THAS_{ij}$ is the total hours available for sowing product j in period i.

The introduction of the second crop depends on the harvest pace of the previous crop. Thus, Eq. (4) expresses the number of machine-hours for the harvest of product j, in hours per hectare, in period i should not exceed the total available hours for harvesting (*THAH*) in period i.

Table 5
Absolute deviation of total gross production – R$/ha. *Source:* Research data.

Crop year	ES			SN			SC		
	ACM (observed)	ECM	Absolute deviation (ACM–ECM)	ACM (observed)	ECM	Absolute deviation (ACM–ECM)	ACM (observed)	ECM	Absolute deviation (ACM–ECM)
1	242.88	162.49	80.39	220.79	202.45	18.33	7.68	113.79	−106.12
2	210.91	187.28	23.63	218.45	226.85	−8.40	197.67	99.42	98.25
3	420.69	212.06	208.63	363.72	251.24	112.47	115.58	85.05	30.54
4	311.79	236.85	74.94	527.01	275.64	251.37	129.82	70.67	59.15
5	120.10	261.63	−141.53	193.00	300.03	−107.03	51.25	56.30	−5.04
6	−167.54	286.42	−453.96	−190.70	324.42	−515.12	−92.29	41.92	−134.21
7	90.62	311.20	−220.58	205.40	348.82	−143.42	73.03	27.55	45.48
8	476.30	335.99	140.31	585.74	373.21	212.53	95.44	13.17	82.27
9	442.78	360.77	82.00	605.08	397.61	207.47	−139.77	−1.20	−138.57
10	591.73	385.56	206.17	393.79	422.00	−28.21	52.67	−15.58	68.25

ES: Early soybean, SN: Normal soybean, SC: Second corn crop.

(c) Availability of machinery for harvesting – h/ha

$$\sum_{i=1}^{n}\sum_{j=1}^{m} h_{ij}X_j \leqslant THAH_{ij} \quad i(1,\ldots,n) \text{ and } j(1,\ldots,m) \tag{4}$$

$$X_j \geqslant 0 \quad j(1,\ldots,m)$$

where n is the number of periods; m the number of products; h_{ij} the hour-machine per hectare for harvesting product j in period i; and $THAH_{ij}$ is the total hours available to harvest product j in period i.

Eq. (5) shows the cash flows of the farm, in which the gross revenue of product j per ha in period i minus the operating cost of product j in R$ per hectare in period i should not exceed the total available credit for product j in period i.

(d) Balance of production cash flow for activities – R$/ha.

$$\sum_{i=1}^{n}\sum_{j=1}^{m} gr_{ij}X_j - \sum_{i=1}^{n}\sum_{j=1}^{m} oc_{ij}X_j + TC_i - TC_{i-1} \leqslant 0 \quad i(1,\ldots,n) \text{ and } j(1,\ldots,m) \tag{5}$$

$$X_j \geqslant 0 \quad j(1,\ldots,m)$$

where n is the number of periods; m the number of products; gr_{ij} the gross revenue of product j in period i; oc_{ij} the operating cost of product j in period i; TC_{i-1} the total Credit for the production of goods in period $i-1$; and TC_i is the total credit for the production of goods in period i.

Corn sowing occurs after early soybean harvest and to prevent occupancy disorganization in the area, the constraint of Eq. (6) is added;

(e) Restrictions of product 3 area on product 1 area – ha

$$-X_1 + X_3 \leqslant 0 \tag{6}$$

$$X_1, X_3 \geqslant 0$$

where X_1 is the product 1 area and X_3 is the product 3 area.

2.4.2. Minimizing the contribution margin risk

Eq. (7) expresses the search to minimize the contribution margin deviation of the representative farm

$$\min W = \sum_{i=1}^{n} -D_i^+ + D_i^- \quad i(1,\ldots,n) \tag{7}$$

The minimization of the objective function (7) is subject to

$$z^* - \sum_{j=1}^{m} mb_{ij}X_j \leqslant W \quad j(1,\ldots,m) \tag{8}$$

and Eqs. (2–6). Moreover, the following equation is added

$$\sum_{i=1}^{n}\sum_{j=1}^{m} d_{ij}X_j - D_i^+ + D_i^- = 0 \quad i(1,\ldots,n) \text{ and } j(1,\ldots,m) \tag{9}$$

$$X_j, -D_i^+, +D_i^- \geqslant 0 \quad i(1,\ldots,n) \text{ and } j(1,\ldots,m)$$

where n is the number of periods; m the number of products; d_{ij} the absolute deviation of the contribution margin of product j in period i; z^* the value of the optimal contribution margin of the farm; mb_{ij} the contribution margin of product j in period i; and W is the largest set of regret of an agricultural planning over all of nature.

3. Result and discussion

The first evaluation refers to the gross margin maximization conditions (used as a proxy of the economic result) of the representative farm in Sorriso with two crops in the same agricultural year. The assessment uses the objective function of Eq. (1) and the constraints of Eqs. (2–6). Next, the objective function is minimized, Eq. (7), with the absolute deviation of the total gross margin (risk) of the farm. The results were organized to understand the levels of risk and returns taken by the farmers according to the different decisions they may take in relation to the various uses of the cultivation area.

The optimal planning of the agricultural property at risk was obtained by adding the total gross absolute deviation of the farm. In the second step of the result analysis, the absolute deviation of the farm's total gross margin is minimized, Eq. (7). The maximum profit of the farm, then, becomes the constraint problem in question (8).

The application of the model reveals that the representative farm maximizes the use of production factors when they allocate 1000 ha (76.92%) of the total area under cultivation to early soybean, and 300 ha (23.08%) to normal soybean at first harvest, and 1000 ha (76.92%) to second corn crop (Table 6). With this combination, which assumes the maximum profit of R$ 416799.00, the farmer is exposed to a risk of R$ 64430.11. This means that the decision of the producer to plan agricultural production with maximum profit in the farm assumes taking the risk of losing R$ 64430.11 in relation to the farm's average gross margin, which is equivalent to 15.46% of the gross margin.

However, it is not always possible to carry out agricultural production planning with the maximum profit. Even with the availability of machinery and equipment to perform all the sowing and harvesting, unfavorable weather conditions, such as the lack of or excess of rains, might limit the mechanical planting of early soybean and corn. Moreover, availability of labor during the sowing and harvesting decreases due to the increase in demand for workers to do the same activities in neighboring farms. To keep the work team, the farmer may encourage workers with better wages or other benefits. It is worth noting that for double crop farms simultaneous mechanical operation and labor availability between planting and harvest are crucial.

To understand the return and the risk the producer takes to decide each specific area combination in the agricultural planning, some results were organized in Table 6 and Fig. 1. Table 6 groups a small sample of the possible combinations of the area for soybean (early and normal) and corn, the return, absolute deviation and the risk. The efficient frontier is obtained by minimizing, using MOTAD, the expected contribution margin ratio (ECM). The construction of the efficient frontier curve starts with the maximum return, and this value is reduced until it reaches the value of maximum return and minimal risk by means of linear programming. Thus, from the value of maximum profit (R$ 416,799), which assumes the highest risk and is represented by the farthest point of the axis, a given value is subtracted until achieving a return of R$ 407,299, which represents the farm's maximum return with the lowest risk.

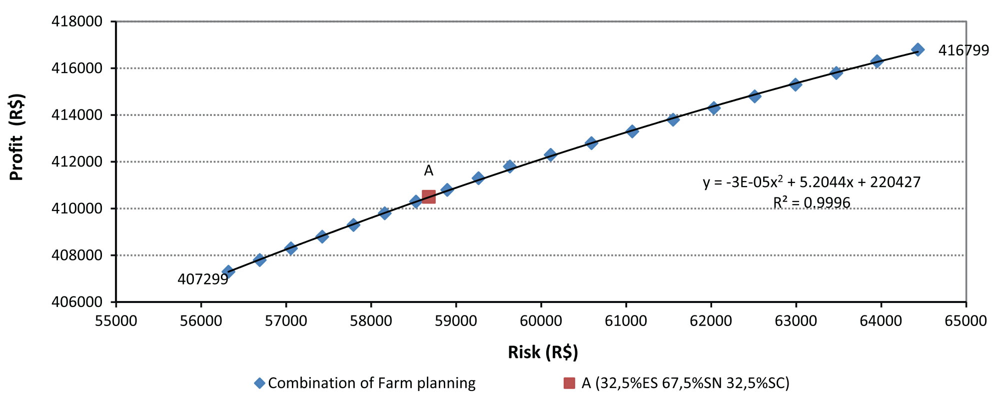
In the range of these extreme points we have a broad combination of production systems for a determined return and risk. The construction of the efficient frontier curve is represented by a small sample of the possible farm production combinations and it should generate a sufficient number of points to allow to adequately visualize the behavior of the efficient frontier curve. This procedure was adopted by Peres (1976), Peres (1981), Rodriguez (1987), De Zen (2002), Pizzol (2002) and Fasiaben (2002).

To determine the different types of agricultural planning, R$ 500.00 are subtracted from the average gross margin of the farm in the theoretical model, reducing the planting area of the early soybean and second corn crop and expanding the normal soybean area. In the first part, there is the farm's highest gross margin of R$ 466,299, using 953.13 ha of the agricultural area for early soybean

Table 6
Result of optimal planning of the representative farm in Sorriso – MT. *Source:* Research data.

Use of agricultural area in summer (ha)	Cultivation area – ha			Mean gross margin of the farm – R$	Sum of total deviation – R$	Average negative deviation of gross margin – R$ (semi-sum)	Risk (%)
	ES	SN	SC				
1300	1000	300	1000	416799.00	1159742.00	63950.17	15.458
1300	954	346	954	416299.00	1151103.00	63950.17	15.362
1300	908	392	908	415799.00	1142464.00	63470.22	15.265
1300	862	438	862	415299.00	1133825.00	62990.28	15.167
1300	817	483	817	414799.00	1125186.00	62510.33	15.070
1300	771	529	771	414299.00	1116547.00	62030.39	14.972
1300	725	575	725	413799.00	1107908.00	61550.44	14.874
1300	679	621	679	413299.00	1099269.00	61070.50	14.776
1300	633	667	633	412799.00	1090630.00	60590.56	14.678
1300	587	713	587	412299.00	1081991.00	60110.61	14.579
1300	541	759	541	411799.00	1073352.00	59630.67	14.481
1300	495	805	495	411299.00	1066714.00	59261.89	14.408
1300	450	850	450	410799.00	1060096.00	58894.22	14.337
1300	404	896	404	410299.00	1053478.00	58526.56	14.264
1300	358	942	358	409799.00	1046861.00	58158.94	14.192
1300	312	988	312	409299.00	1040243.00	57791.28	14.120
1300	266	1034	266	408799.00	1033625.00	57423.61	14.047
1300	220	1080	220	408299.00	1027007.00	57055.94	13.974
1300	174	1126	174	407799.00	1020389.00	56688.28	13.901
1300	128	1172	128	407299.00	1013771.00	56320.61	13.828

ES: Early soybean, SN: Normal soybean, SC: Second corn crop.



Legend: ES: Early soybean, SN: Normal soybean, SC: Second corn crop.

Source: Research data.

Fig. 1. Efficient frontier curve of farm in Sorriso – MT. Legend: ES: Early soybean, SN: Normal soybean, SC: Second corn crop. *Source:* Research data.

and 345.87/ha for normal soybeans in the first season, and 954.13 ha for second corn crop. In this scenario, the producer takes a risk of up to R$ 63950.17 in the harvest, which represents 15.36% of the average gross margin (Table 6).

The agricultural planning with lower risk exposure occurs when the producer chooses to earn a maximum farm gross margin with a harvest value close to R$ 407,299, allocating 128.44 ha of the cultivation area to early soybean, 1171.56 ha to normal soybean (first crop), and 128.44 ha to second corn crop. This scenario corresponds to a risk of R$ 56320.11 in the harvest, or 13.83% gross margin (Table 6).

Fig. 1 shows the efficient frontier curve of the representative farm in Sorriso – MT, in which each point represents a combination of farm production for a particular return and risk. These points are the same values obtained by parameterization, using MOTAD, of the expected contribution margin described in Table 6. In the efficient frontier curve, the quadratic trend line appears well adjusted with the coefficient of determination (R^2) of 99.93% (Fig. 1), meaning that the combination of the variables analyzed in the theoretical model can satisfactorily explain the producer's decision making in Sorriso. The efficient frontier curve shows that the return increases with the risk assumed by the farmer.

The efficiency curve allows to assess the level of risk and return for the representative property studied in the period covered by the study. During the 6 years of data collection in the field, there was progress in the corn area under the production system. However, this intensification has increased the risk of the farms, a factor still overlooked by many producers. Point A refers to the average allocation of the cultivation area between the crop years 2004/05 and 2009/10. In this case 32.5% was allocated to early soybean and 67.5% to normal soybean in the first season and an additional 32.5% to second season corn. This production system takes a risk (semi-sum of absolute deviation) of R$ 58676.72, accounting for 14.29% of the farm's gross margin.

The production systems adopted between the harvest of 2004/05 and 2009/10, point A, are on the efficient frontier curve. The results show that the current production is being performed in maximum efficiency conditions in the relationship between risk and return. The farmers have managed to, even if intuitively, minimize the risk for a given level of income, or alternatively, maximize income for a given level of risk, which is by definition the efficient frontier curve.

With the efficient frontier curve of the Sorriso farm, one can extract the risk aversion rate for alternative agricultural planning.

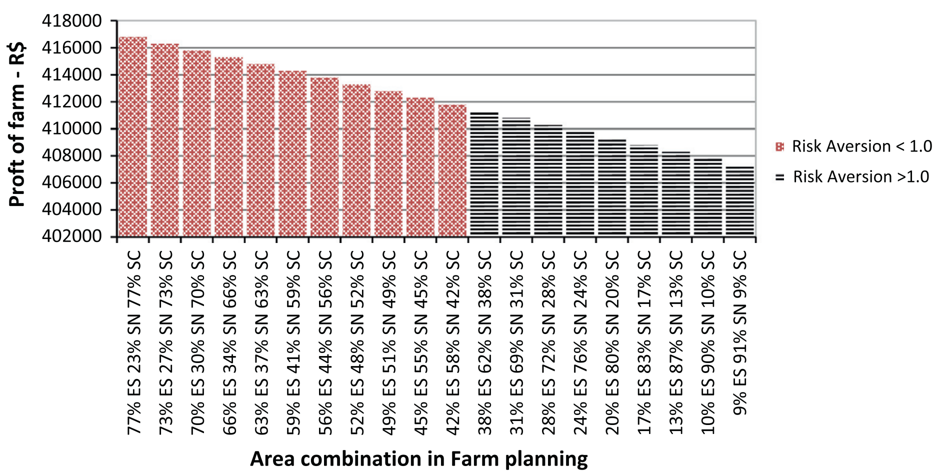
Point A is the geometric space in which the utility function curve is tangent to the quadratic function curve. The value of the risk aversion rate refers to the geometric space given by the risk measured by the semi-sum of absolute deviations relative to the average and the gross margin average return. The average allocation of the six seasons in the agricultural planning has a risk aversion rate of 1.0504, which is the amount required by the producer to add R$ 1.0504 to the average gross margin for each risk unit (Fig. 1).

Fig. 2 shows the allocation options in the cultivation area of the agricultural products in the representative farm, in percentage, in relation to the different levels of profit and Fig. 3 shows the allocation options in the cultivation area of the agricultural products in relation to the different levels of risks. The results of the theoretical model suggest a production system that combines early soybean, normal soybean and corn in different proportions.

The optimal agricultural planning pointed to the cultivation of maximum risk and profit when it chooses to allocate most of the production area to early soybeans in the first season and to corn in the second season. However, the risk will be reduced when it allocates the majority of the area under cultivation to normal soybean. Figs. 2 and 3 show that there are two agricultural production planning groups within a production system in the representative farm of Sorriso.

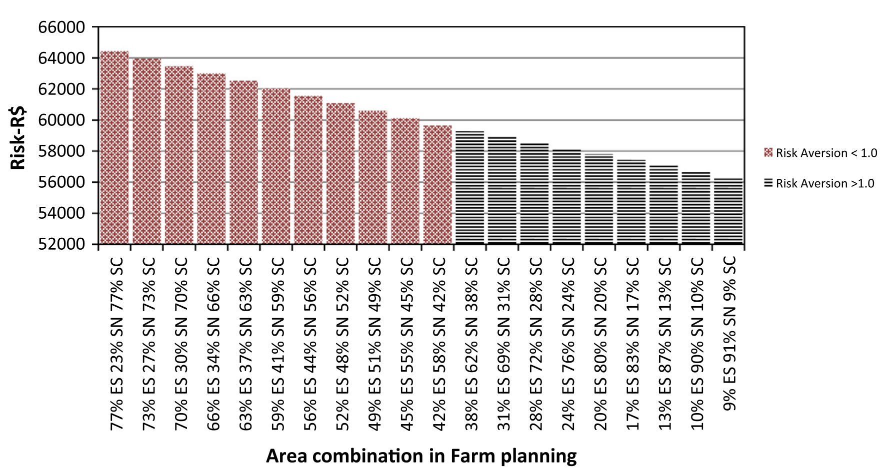
The first group refers to the interval between the gross margin of R$ 411799.00 and R$ 416799.00 under risk conditions of R$ 59630.67 and R$ 64430.11, respectively, Figs. 2 and 3. Regarding the farm planning for using the agricultural area, the allocation comprises between 41.6% and 76.9% for early soybean and 23.1–58.4% for normal soybean in the first season. For corn, the area varies between 41.6% and 76.9% in the second season. This group combines the agricultural planning options with a risk aversion rate less than 1, meaning that the amount of revenue required by the producer is smaller than a risk unit. In this group, the measure that seeks the maximum gross margin becomes indifferent to the risk aversion rate.

The second group regards the interval between the average gross margin of R$ 407299.00 and R$ 410799.00 under risk conditions of R$ 56320.61 to R$ 58894.22, respectively, Fig. 2 and 3. In



Legend: ES: Early soybean, SN: Normal soybean, SC: Second corn crop.
Source: Research data

Fig. 2. Profit of farm for different area combination in farm planning of the representative farm in Sorriso – MT. Legend: ES: Early soybean, SN: Normal soybean, SC: Second corn crop. *Source:* Research data.



Legend: ES: Early soybean, SN: Normal soybean, SC: Second corn crop.
Source: Research data

Fig. 3. Risk for different area combination in farm planning of the representative farm in Sorriso – MT. Legend: ES: Early soybean, SN: Normal soybean, SC: Second corn crop. *Source:* Research data.

the case of the agricultural planning interval, it allocates the cultivation area between 9.9% and 34.6% for early soybean and 65.4–90.1% for normal soybean in the first season. For corn, the area also varies between 9.9% and 34.6% in the second corn season. This group assembles the agricultural planning options with a risk aversion rate greater than 1.

The difference between the two groups is the risk that the producer is willing to take. In the first group, the agricultural planning options allow to intensify the land use, machinery and manpower, resulting in an increase in the producer's production scale and a reduction in the fixed cost of the farm. However, the *risk aversion rate* of this group is less than 1, that is, the more the producer intensifies the land use with early soybean and second corn crop, the higher the return, but under high-risk conditions.

In the second group, the allocation alternatives for the cultivation area maximize the use of the production factors, at an aversion rate greater than 1. This shows that reducing the early soybean and second corn crop production system, the risk of the representative farm decreases.

But since the 2008/09 season, the producers have intensified land use and have practiced above average combinations in the last six seasons. The results of the model showed that the strategy of increasing the corn area in the second season implies taking a relatively high risk. At the same time, this risk can be minimized if for example corn prices increase by improving infrastructure, developing regional agribusiness, introducing new mechanism to hedge corn price and also drought, pest and disease resistant cultivars.

The double crop agricultural planning model under risk conditions for Sorriso pointed out that the production system with 76.9% of early soybean and 23.1% of normal soybean in the cultivation area of the first season and 76.9% of corn in the second season takes the greatest risk. On the other hand, the production area with mostly normal soy (90%) and early soybean (10%) takes a lesser risk. Furthermore, diversification in the farming area with early and normal soybean in the first season and corn in the second season proved to be an interesting allocation, but the decision will depend on how much risk the producer is willing to take. Agricultural planning with the option of reducing early soybean and corn in the production system shows a decrease in the gross margin and also in the risk.

4. Final remarks

The efficient frontier curves revealed that the representative farm under study maximized the use of its production factors. In Sorriso, the average crop area allocated between the crop years 2004/05 and 2009/10 was on the efficient frontier curve, showing that the production system chosen by the producers (32.5% of early soybean and 67.5% of normal soybean in the first season and 32.5% in the second corn crop season) has maximized the production factors used with a risk aversion rate of 1.05. Although the production diversification is usually viewed as a strategy to reduce risk (De Zen, 2002; Vilckas, 2004), the results found for Sorriso show that this is not always true.

This study provides farmers a tool to support decision making in order to improve agricultural planning under risk conditions. It helps to choose the best products to comprise the set of agricultural products and especially to determine the production proportion of each product (soybean, corn and cotton), which translates into higher returns and lower risks. The right production choices can result in obvious, direct and important financial and administrative gains for farmers, for the region and for the country.

The results can also be very useful to all those who participate in the funding of agricultural production in the region. Financing conditions can be adapted to the risk conditions assumed by the producer. The combination of very high risks with the occurrence of unanticipated events can compromise the producers' ability to comply with the production contacts. Producers who take higher levels of risk will have more restrictive credit conditions. The results achieved in this study may also help the government to establish crop insurance policies based on the region's production reality.

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