IOSR Journal of Business and Management (IOSR-JBM)
e-ISSN:2278-487X, p-ISSN: 2319-7668. Volume 26, Issue 4. Ser. 1 (April. 2024), PP 57-65
www.iosrjournals.org

Optimization in Agricultural Management: Exploring Linear Programming for Rural Properties

Bianca Jupiara Fortes Schardong[1], Roberto Portes Ribeiro[2]
Nelson Guilherme Machado Pinto[3], Paloma De Mattos Fagundes[4]
[1]*(Postgraduate Program in Agribusiness/ Federal University of Santa Maria, Brazil)*
[2]*(Department of Production Engineering/ Federal University of Santa Maria, Brazil)*
[3]*(Postgraduate Program in Agribusiness/ Federal University of Santa Maria, Brazil)*
[4]*(Postgraduate Program in Agribusiness/Federal University of Santa Maria, Brazil)*

Abstract:
Background:*Rural organizations often operate with limited resources, which means that managers are faced with strategic decision-making situations in rural operations. A case study was therefore carried out on a rural property located in the northwestern region of the state of Rio Grande do Sul, with the aim of evaluating the contribution margin of growing three winter crops on this property, using linear programming.*
Materials and Methods:*A survey was carried out of the gross revenue per hectare planted of the three winter crops (wheat, oats and ryegrass) on the farm, the calculation of the farm's costs, the calculation of the contribution margin of each crop using the variable costing method and, finally, the application of linear programming to work out how much area of the farm should be set aside for planting each crop in order to maximize the contribution margin, using the free LibreOffice software.*
Results: *The result made it possible to change the area planted to each crop, eliminating ryegrass, and achieving a contribution margin 39.53% higher than the contribution margin historically achieved.*
Conclusion: *It can be concluded that the use of linear programming can make a significant contribution to managing the resources of a rural property.*

Key Word:*Linear programming; Rural management; Costs; Decision making.*[5]

Date of Submission: 22-03-2024 Date of Acceptance: 02-04-2024

I. Introduction

Agribusiness has established itself as an important sector in the national economy, accounting for 24.1% of the country's GDP in 2023 (Cepea, 2023). Since the 1990s, its productivity has experienced remarkable growth, accompanied by a reduction in production costs, reflected in more affordable prices for consumers. In this context, studying agribusiness is justified as it is one of the most important services for the population, since it provides food, which is one of the basic resources for development.

Along these lines, Khan and Arif (2023) point out that aspects such as the productivity and efficiency of agribusiness are essential for meeting the growing demand for food. In addition, the authors argue that this sector plays a key role in reducing extreme poverty (Khan & Arif, 2023). Within this context, agribusiness also plays an important role in rural development, providing employment and income opportunities for farmers and rural workers. This, in turn, boosts the economic and social development of these regions, as highlighted by Khan and Arif (2023).

Such relevance demands efficient management of rural properties based on useful tools for decision-makers. In this way, it is essential to look for solutions that optimize the production process, reducing costs for rural producers, especially small and medium-sized producers, who are less favored in terms of management and innovation (Bjerk & Johansson, 2022) when compared to large producers.

The aim of this research was to carry out a case study on a rural property located in the northwestern region of the state of Rio Grande do Sul - Brazil, with the aim of analyzing the contribution margin of growing three winter crops on this property, using Linear Programming (LP). In order to do this, it was necessary to survey the following aspects: gross revenue per hectare planted with wheat, oats and ryegrass, determine the costs of the rural property and calculate the contribution margin of each crop using the variable costing method. Based on this, the aim was to answer the following question: how much of the farm should be allocated to planting each crop in order to maximize the contribution margin?

[5]This article comes from the Project for the Center for Technological Innovation in Agribusiness: a proposal for entrepreneurship, research and regional development, which was included in Call 16/2022, supported by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) - Finance Code 001.

Given the effectiveness of using linear programming for this type of problem, as it is a deterministic method that allows the best solution to be found for a given objective such as the allocation of available resources under constraints, this study results in an application of the linear programming tool to agricultural activity, more specifically to the problem of allocating land resources for cultivation.

In order to achieve the proposed objective, this work is structured as follows: first, there is the introduction, which clarifies the objectives and the relevance of the topic. This is followed by the second section, which includes a reference on cost management in rural properties and its relationship with Linear Programming. The third part deals with the research method used. The fourth section presents the results found, while the fifth section discusses these results. The sixth section explores the final considerations and finally the references.

II. Literature Review

Cost Management in Rural Properties and Linear Programming

With the expansion of the agricultural sector, the need to monitor the activities carried out on rural properties has become imperative, demanding a more professionalized approach to the rural environment (Viégas & Nogueira, 2019). This implies treating the rural area as a business, even if it is not formally registered as such. Consequently, "increased competition and the scarcity of available resources have contributed to constant changes in business management [...]" (Crepaldi, 2012, p. 3), highlighting the importance of using effective controls to manage the various activities carried out within the property.

From this perspective, managing a rural property is one of the indispensable factors for achieving good performance. Lourenzani et al. (2008) state that the management of a rural activity consists of a decision-making process that evaluates the allocation of scarce resources among various production possibilities. These decisions are usually made against a backdrop of risks and uncertainties that permeate the agricultural sector, thus highlighting the importance of using tools to support rural management.

With particular regard to the costs of rural activities, the cost of the crop consists of all the expenses associated directly or indirectly with the crop, such as fertilizers, seeds and others (Oliveira, 2010). In agriculture, direct costs are those directly related to agricultural products, which can be measured in terms of consumption, labor, inputs, fuel, depreciation and electricity (Crepaldi, 2009). Allied to this, Martins (2010, p. 48) says of direct costs that "some costs can be directly appropriated to products, all that is needed is a measure of consumption. These are direct costs in relation to products". The kilograms of materials consumed, packaging used, hours of labor used and even the amount of force consumed are examples of direct costs.

Indirect costs, on the other hand, according to Silva (2009), are those costs that need to be estimated or apportioned to the activities carried out. Depreciation of machinery that is used for different crops, the salary of the administrator who manages more than one production, taxes, property fees and maintenance are typical examples of indirect costs in agriculture. Cost accounting on rural properties has several uses for farmers, generally seeking better management control based on the information obtained. According to Callado and Callado (2009), the producer can use this information to make decisions about agricultural practices in different periods, and the government and trade associations can use the information for public policies to maintain competitive conditions for the products sold.

In addition, according to Viégas and Nogueira (2019), the current agricultural scenario, characterized by increasingly advanced agricultural implements and an increasingly demanding consumer market, has led farmers to constantly seek ways to modernize the management of the crops they grow. As part of this modernization, it is essential that farmers adopt cost control and management practices that are in line with these demands, allowing them to remain competitive. It is therefore essential that farmers plan their businesses using tools associated with rural accounting that not only facilitate control and planning, but also help with decision-making.

In this sense, with regard to decision-making, it is clear that the Linear Programming method is a tool that supports the decision-making process. Furthermore, in the specific context of this research, which involves a rural property and its accounting aspects, both Dossa (1994) and Bressan and Ramos (2020) argue that the LP method enables a mathematical analysis of agricultural property, although it does not directly incorporate economic content. Therefore, the choice to apply Linear Programming arises from several fundamental concerns, including the modeling of the property, which makes it possible to develop simulations and adjustments based on an initial model (Dossa, 1994). To this end, the first step in the process of studying linear programming is to formulate or define the problem.

According to Andrade (2015), outlining the problem involves three essential factors: a precise description of the study's objectives, identification of the different decision options available and a survey of the system's limitations, restrictions and requirements. Once the problem has been defined, the next step is to draw up the mathematical model to be used to solve it.

For Goldbarg and Luna (2005), Linear Programming, which belongs to the field of Operational Research, uses linear equations in its formulation. In this way, the authors elucidate that the mathematical model of LP aims to maximize or minimize a linear objective function, subject to a set of inequalities that are also linear, which represent the technical constraints (Goldbarg & Luna, 2005). According to Bressan and Ramos (2020), Linear Programming can be characterized as a field that applies scientific methods to solve problems related to control and optimization, such as the management of agricultural systems, offering more effective solutions aimed at maximizing profits and minimizing costs, taking into account the specific constraints of the context in question (Bressan & Ramos, 2020). In addition, Caixeta Filho (2009) highlights the application of Mathematical Programming techniques, particularly Linear Programming, in problems, applications and models related to the agro-industrial sector.

In view of this, Linear Programming (LP) has emerged as an essential tool for addressing issues related to agricultural production planning. In particular, the optimization of crop rotation stands out, which has been commonly carried out using Linear Programming mathematical models (Haneveld & Stegeman, 2005). In a study conducted by Fey et al. (2000), for example, an 8.8% increase in the property's annual net income was observed.

Similarly, Bressan et al. (2019) used Linear Programming in problems related to agricultural production, aiming to maximize profits in both agricultural production and a reforestation property. It can be seen that these and other studies highlight the ability of numerical optimization methods to help reduce costs and, consequently, improve profits for both small and large farmers, taking into account different agricultural crops and different growing seasons.

III. Material And Methods

According to Vergara (2014), it is descriptive in nature, as it describes a situation in which a tool is implemented to solve a management problem. The data was collected from a small rural property located in the northwest region of Rio Grande do Sul. The gross revenue and production costs of three winter crops typical of the region were surveyed: wheat, oats and ryegrass on the rural property that is the subject of the study, which is owned by the manager, who provided the data through documents and unstructured interviews. Based on this data, the contribution margin of each crop was calculated using the variable costing method.

This study is also classified as a case study, which, according to Gil (2010), is when it involves the in-depth and exhaustive study of one or a few objects in a way that allows for broad and detailed knowledge. In addition, this research has a quantitative approach according to the classification of Miguel (2012), as a mathematical model was developed to solve the production mix problem of the rural property studied, applying the linear programming technique that falls within the area of Operational Research, which operates with data treated as information to be analyzed in decision-making.

The use of linear programming models can be an important tool for analyzing decisions (Munhoz & Murabito, 2010). Thus, linear programming consists of a method that seeks to optimize a given problem that has many possible solutions, by maximizing or minimizing a linear function, in the case of this study, the aim is to optimize the available planting resources.

Finally, the modeled problem was solved using the Solver tool in the LibreOffice software. This software is a free and easily accessible tool, which also offers small farms the possibility of obtaining quantitative solutions in their daily lives using this type of tool. According to the Regional Labor Court of the 4th Region (2007), in a corporate environment, the use of free software makes it possible to integrate new operational and strategic concepts, making the management of the technological environment more flexible and providing increasingly better solutions for the user.

IV. Result

The results were structured in such a way as to present a survey of gross revenue per hectare planted with three winter crops (wheat, oats and ryegrass) on the farm, calculate the farm's costs, calculate the contribution margin of each crop using the variable costing method and, finally, apply linear programming to solve the problem using LibreOffice software.

Gross Revenue Survey

Gross sales revenue is directly related to the productivity of each of the three winter crops (wheat, oats and ryegrass) per hectare and the selling price of each bag on the market. Table 1 shows the gross revenue per hectare of each crop as a function of the yield of bags per hectare and the selling price of each bag.

Table no 1: Gross revenue per hectare.

Culture	Bags per hectare	Bag Price (R$)	Total (R$)
Wheat	55	R$ 29,00	R$ 1.595,00
Oats	60	R$ 18,00	R$ 1.080,00
Ryegrass	45	R$ 15,00	R$ 675,00

Source: Surveyed rural property.

Calculating Farm Costs

The process of preparing and planting each of the three winter crops: wheat, oats and ryegrass was analyzed to begin the survey of the farm's costs. Based on these processes, the costs of production inputs per hectare for each crop were calculated, as shown in Tables 2, 3 and 4, corresponding to wheat, oats and ryegrass, respectively. Table 2 shows the costs of wheat production inputs per hectare according to the items used in each process.

Table no2: Wheat production input costs per hectare.

Process	Input	Quantity	Unit price (R$)	Total (R$)
Soil preparation	Agrotoxics	1.5 Kg	R$ 20,00	R$ 30,00
Treatment	Fungicide	0,5 l	R$ 99,00	R$ 49,50
Planting	Fertilizer	200 Kg	R$ 1,50	R$ 300,00
Planting	Seed	200 Kg	R$ 1,20	R$ 240,00
Post-emergent	Fungicide	2 l	R$ 65,00	R$ 130,00
Post-emergent	Insecticide	0,05 l	R$ 200,00	R$ 10,00
Post-emergent	Urea	120 Kg	R$ 1,00	R$ 120,00
Total				**R$ 879,50**

Source: Surveyed rural property.

The total costs of wheat production inputs amount to R$879.50 per hectare cultivated. Table 3 shows the oat production costs per hectare according to the inputs used in each process.

Table no3: Costs of oat production inputs per hectare.

Process	Input	Quantity	Unit price (R$)	Total (R$)
Soil preparation	Agrotoxics	1.5 Kg	R$ 20,00	R$ 30,00
Treatment	Fungicide	0,05 l	R$ 290,00	R$ 14,50
Planting	Fertilizer	200 Kg	R$ 1,50	R$ 300,00
Planting	Seed	50 Kg	R$ 0,45	R$ 22,50
Post-emergent	Fungicide	0,5 l	R$ 65,00	R$ 32,50
Post-emergent	Insecticide	0,05 l	R$ 200,00	R$ 10,00
Post-emergent	Urea	100 Kg	R$ 1,00	R$ 100,00
Total				**R$ 509,50**

Source: Surveyed rural property.

The total costs of oat production inputs amount to R$509.50 per hectare cultivated. Table 4 shows the ryegrass production costs per hectare according to the inputs used in each process.

Table no 4: Ryegrass production input costs per hectare.

Process	Input	Quantity	Unit price (R$)	Total (R$)
Soil preparation	Agrotoxics	1.3 Kg	R$ 20,00	R$ 26,00
Treatment	Fungicide	0,04 l	R$ 290,00	R$ 11,60
Planting	Fertilizer	200 Kg	R$ 1,50	R$ 300,00
Planting	Seed	90 Kg	R$ 0,65	R$ 58,50
Post-emergent	Fungicide	1 l	R$ 65,00	R$ 65,00
Post-emergent	Insecticide	0,08 l	R$ 200,00	R$ 16,00
Post-emergent	Urea	100 Kg	R$ 1,00	R$ 100,00
Total				**R$ 577,10**

Source: Surveyed rural property.

Table 4 shows the costs of ryegrass production inputs per hectare, totaling R$577.10. Fertilizer was found to be the most representative cost in the production of the three crops. The cost of seed was representative for wheat.

In addition to calculating the costs of production inputs for the three crops, annual labor costs and expenses were also calculated, as shown in Table 5, including labor charges.

Table no 5: Annual labor costs and expenses on the far.

Labor item	Number of employees	Total (R$)
Permanent workforce	20	R$ 275.260,00
Temporary labor	4	R$ 5.620,00
Specialized technician	1	R$ 18.000,00
Labor charges		R$ 96.135,00
Total	25	**R$ 395.015,00**

Source: Surveyed rural property.

Annual labor costs and expenses amount to R$395,015.00. The farm's other fixed annual costs and expenses are listed in Table 6.

Table no 6: Fixed annual costs and expenses of the rural property.

Item	Total (R$)
Fuels and lubricants	R$ 264.000,00
Depreciation	R$ 333.666,33
Freight and transportation	R$ 26.500,00
Rural Property Tax	R$ 6.255,35
Maintenance	R$ 27.150,00
Other costs	R$ 6.000,00
Insurance	R$ 12.500,00
Water, electricity and telephone charges	R$ 24.943,00
Total	**R$ 701.014,68**

Source: Surveyed rural property.

The farm's fixed annual costs and expenses total R$701,014.68, with depreciation and fuel and lubricant expenses accounting for the majority of the farm's fixed costs.

Contribution Margin for each Crop using the Variable Costing Method

Based on a survey of the gross revenue per hectare planted to the three winter crops (wheat, oats and ryegrass) on the farm and the calculation of the farm's costs, the Income Statement was prepared using the variable costing method for each hectare cultivated. The only sales deduction from gross revenue is Funrural, an annual rural social contribution, which was apportioned proportionally to the months and hectares of cultivation. From this deduction, net revenue is obtained, from which variable costs and expenses are subtracted.

Table 7 shows the details of the calculation of the contribution margin for each crop using the variable costing method, which represents how much the farm earns from each crop, net income minus variable costs and expenses, to pay its fixed costs.

Table no 7: Contribution margin for each crop calculated using the variable costing method.

	Wheat	Oats	Ryegrass
Gross revenue	R$ 1.595,00	R$ 1.080,00	R$ 675,00
Sales deduction	R$ 11,25	R$ 11,25	R$ 11,25
Net revenue	R$ 1.583,75	R$ 1.068,75	R$ 663,75
Variable costs and expenses	R$ 879,50	R$ 509,50	R$ 577,10
Contribution margin	**R$ 704,25**	**R$ 559,25**	**R$ 86,65**

Source: Authors.

It can be seen that the contribution margin is positive for all three crops and, based on this, the annual fixed and labor costs and expenses will be paid. According to the results shown in Table 7, wheat cultivation has the highest contribution margin and ryegrass cultivation has the lowest contribution margin.

By analyzing the results of the contribution margin alone, it could be inferred that it is better to plant only wheat; however, there are production and financial capacity restrictions that were not taken into account when calculating the contribution margin. Although the variable costing method provides this information on the contribution margin, it is necessary to use linear programming, because by taking into account the restrictions, you have a more complete analysis on which to base the decision as to how many hectares should be planted with wheat, oats and/or ryegrass on the rural property under study.

Using Linear Programming

The use of linear programming seeks to evaluate the profitability of three possible winter crops on a rural property. To do this, it is necessary to initially define the decision variables to model the system under study in order to maximize the contribution margin of the crops. The decision variables corresponding to these crops are:

- X_1 = number of hectares of wheat to be cultivated;
- X_2 = number of hectares of oats to be cultivated;
- X_3 = number of hectares of ryegrass to be cultivated.

Once the decision variables have been defined, the mathematical model for maximizing the contribution margin can be designed based on the data researched on the rural property under study.

The objective function seeks to maximize the contribution margin according to the number of hectares cultivated for each crop, so the coefficients of the objective function are the unit contribution margins for each of the three crops: wheat, oats and ryegrass. Thus, the objective function is given by:

$$Z_{máx} = 704.25\ X_1 + 559.25\ X_2 + 86.65\ X_3$$

The constraints refer to the total variable costs, the input costs in each production process, the number of hectares available, as well as the non-negativity conditions, for the wheat, oat and ryegrass crops respectively. The values that appear on the right-hand side of the inequality relate to the quantity defined in the pre-planting project, as well as representing the financial constraints faced by the farm manager.

Constraint (1) refers to the total variable costs for wheat, oats and ryegrass crops respectively:

$$879.5\ X_1 + 509.5X_2 + 577.1\ X_3 \leq 701.080 \quad (1)$$

Restriction (2) refers to the soil preparation process, more specifically the amount of pesticides used:

$$1.5\ X_1 + 1.5\ X_2 + 1.3\ X_3 \leq 1,505 \quad (2)$$

Constraint (3) corresponds to the soil treatment process, more specifically the amount of fungicides used:

$$0.5\ X_1 + 0.05\ X_2 + 0.04\ X_3 \leq 402.5 \quad (3)$$

Constraint (4) refers to the planting process, more specifically the amount of fertilizer used:

$$200\ X_1 + 200\ X_2 + 200X_3 \leq 223.100 \quad (4)$$

Constraint (5) refers to the planting process, more specifically the quantity of seeds used:

$$200\ X_1 + 50\ X_2 + 90\ X_3 \leq 121.066 \quad (5)$$

Constraint (6) corresponds to the post-emergent process, more specifically it refers to the amount of fungicides used:

$$2\ X_1 + 0,5\ X_2 + 1\ X_3 \leq 1.248 \quad (6)$$

Constraint (7) corresponds to the post-emergent process, more specifically it refers to the amount of insecticides used:

$0.05 X_1 + 0.05X_2 + 0.08 X_3 \leq 100$ (7)

Constraint (8) corresponds to the post-emergent process, more specifically it refers to the amount of urea used:

$120 X_1 + 100 X_2 + 100 X_3 \leq 115.000$ (8)

Constraint (9) refers to the number of hectares available for planting any of the crops.

$X_1 + X_2 + X_3 = 1,000$ (9)

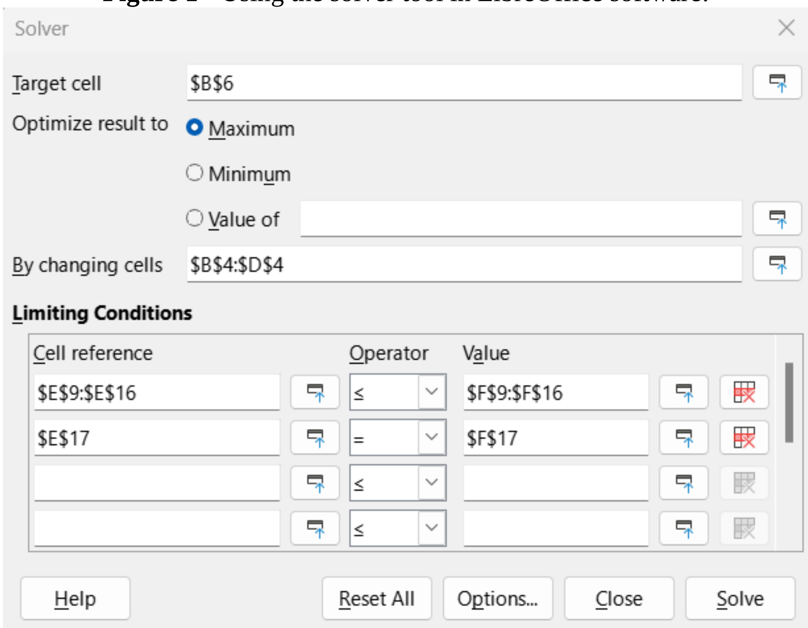
Constraint (10) corresponds to the conditions of non-negativity:

$X_1 \geq 0; X_2 \geq 0; X_3 \geq 0.$ (10)

Thus, the mathematical model consisting of three decision variables, the objective function and ten constraints was entered into the LibreOffice software, where the solver function was used to find the optimal solution, i.e. the solution that maximizes the contribution margin according to the number of hectares cultivated for each crop.

Figure 1 shows the use of the solver tool in the LibreOffice software and Table 1 shows the result found by the LibreOffice software for the mathematical model for maximizing the contribution margin on a rural property.

Figure 1 - Using the solver tool in LibreOffice software.



Source: LibreOffice.

Table no 7: Results from the LibreOffice software for the mathematical model to maximize the contribution margin.

	X1	X2	X3		
Objective Function Coefficients	704,25	559,25	86,65		
Variables	**473,77**	**526,23**	**0,00**		
Result Objective Function	**627.947,13**				
Restrictions:				LHS	RHS
Restriction 1	879,5	509,5	557,1	684.796	701.080

Restriction 2	1,5	1,5	1,3	1.500	1.505
Restriction 3	0,5	0,05	0,04	263	402,5
Restriction 4	200	200	200	200.000	223.100
Restriction 5	200	50	90	121.066	121.066
Restriction 6	2	0,5	1	1.211	1.248
Restriction 7	0,05	0,05	0,08	50	100
Restriction 8	120	100	100	109.475	115.000
Restriction 9	1	1	1	1.000	1.000

Source: Authors.

According to the results of the mathematical model presented in Table 1, the maximum contribution margin considering the restrictions was R$ 627,947.13, with 473.77 hectares of wheat and 526.23 hectares of oats. Given these conditions, it is not necessary to grow ryegrass for marketing.

The constraint (9) regarding the number of hectares available for planting any one crop is an important limiting factor in this situation. In addition, the constraint (5) referring to the planting process, more specifically corresponding to the quantity of seeds used, was the main limiting factor in terms of the financial aspect, so if the producer had more financial resources available, he could use them to buy seeds, however, other restrictions that are redundant in this situation could become limiting in terms of financial resources.

V. Discussion

Based on this structure, i.e. a survey of the gross revenue per hectare planted of three winter crops (wheat, oats and ryegrass) on the rural property, the calculation of the rural property's costs and the calculation of the contribution margin of each crop using the method of variable costing, it was possible to calculate the contribution margin according to the area usually cultivated on the farm in previous years.

According to historical data provided by the owner, the cultivation area was divided equally between wheat, oats and ryegrass, i.e. 333.33 hectares for each of the three winter crops, without any calculation of costs or contribution margin.

After structuring the farm, it was possible to calculate the contribution margin of R$ 450,045.50 that would be earned if the cultivated area were divided equally between the three crops.

The mathematical modeling of the management problem and the application of linear programming to solve this problem using free and easily accessible software made it possible to change the area cultivated for each crop, eliminating the cultivation of ryegrass, and obtaining a contribution margin of R$ 627,947.13.

The difference in contribution margin between historical production and the production suggested by the linear programming model is R$177,901.63, which represents an increase in contribution margin of 39.53%. Of course, producing two crops increases business risk, but this significant difference in contribution margin led the farm manager to choose to grow only wheat and oats in the quantities established by the linear programming model.

VI. Conclusion

The main contribution of this study was to optimize the profitability of growing winter crops on a rural property, by surveying the gross revenue per hectare planted of three winter crops (wheat, oats and ryegrass) on the rural property, calculating the costs of the rural property in detail, calculating the contribution margin of each crop using the variable costing method and, finally, applying linear programming to solve the problem using the free LibreOffice software.

The variable costing method provided important information that made it possible to model the constraints of the problem studied in terms of financial resources and the coefficients of the objective function, which facilitated the subsequent analysis of what should be cultivated using linear programming.

The manager of the rural property under study can follow this entire process that was developed in order to establish the optimum production mix, which will allow this type of analysis to continue in subsequent years on that property, given that the manager has learned how to use the software and will not have to spend any money to obtain it. In addition, the manager has become aware of the need to make better use of resources in order to optimize them.

The 39.53% increase in contribution margin proved the effectiveness of the linear programming model, which proved to be relevant to the management decision-making process. Therefore, the manager can use this linear programming model to decide mainly on the amount of financial resources to be used on the farm, avoiding wasteful use of resources.

A limiting factor of this study is precisely its nature, i.e. it is a specific case study, which does not allow full generalization of its results in terms of the use of this linear programming model for other rural properties. Therefore, it is hoped that future studies will be carried out that analyze a greater number of rural properties and bring similar benefits to a more significant number of rural properties, especially smaller ones, and consequently to society, as it can help the performance and development of these rural properties to be analyzed.

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