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AN EVOLUTIONARY STUDY ON CROP PRODUCTION IN SMALL FARM SYSTEMS IN THE MID-WEST REGION OF BRAZIL BASED ON A LINEAR PROGRAMMING MODEL

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ABSTRACT. Based on an agro-technical study for the mid-west region of Brazil, and considering financial conditions like monthly expenses and long-term investments, a mixed integer and dynamic linear model has been proposed for representing crop production systems. This model establishes a monthly dynamic treatment of production and financial activities over a long-term planning horizon for small and medium farm systems. In this paper, by considering more recent government financial policies for the Brazilian agricultural sector related to the *Pronaf* and *Proger* credit lines, a mathematical model is updated for distinct situations derived from the use of short and long-term loans which were defined for small and medium farmers. In this way, new versions of the original model are obtained by separately implementing into the production systems economic and financial conditions of credit lines for the years 2006 and 2009. Computational tests are performed and the results obtained are presented in several scenarios. Also, an evolutionary analysis on the socio-economic and financial feasibility of the agricultural farm system is drawn over the last decade by comparing the results obtained to one known from the year 2002.

Keywords: agricultural production planning, family farming systems, linear programming.

1 INTRODUCTION

The economic and social importance of small and medium Brazilian farms has been drawing attention in the last decades. Particularly, the participation of small agricultural systems in the rural economy has improved when considering gross production and exportation (*IBGE – Instituto Brasileiro de Geografia e Estatística*, 2006). An explanation for this can be found in the fact that Brazilian small farms have received special attention with the creation in 1995 of *Pronaf* – National Program for Family Farming – a Brazilian governmental program that offers financial support for family farms. A qualitative and quantitative analysis on the evolution of total loans that *Pronaf* gave to farms in the whole country and in rural regions is presented in Guanziroli (2007). This analysis, however, does not take into consideration the financial problems of farm system production as a problem related to planning decisions.

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In order to search for farm-system oriented decisions in the mid-west region of Brazil, some quantitative studies, in the area of operational research, have concentrated attention on modeling a mathematical problem for crop production planning. This has been done by presenting a financial emphasis and proposing technical policies. Among these, it is important to cite the works of Veloso (1990) and Veloso et al. (1997). Based on earlier studies in the literature on agricultural systems (Dalton 1982, Dent et al., 1986 and Dent, 1990), the authors of the former and latter works present a crop production planning study of farm systems in the cities of Paracatu and Formoso, respectively, both in the state of Minas Gerais, Brazil. In these studies, they consider conventional planting techniques. Moreover, the authors propose financial-economic policies for crop production systems which are based on the following suppositions: just one family member works full time; the farmer has an initial capital contribution for the first investments; and there are three hypothetical long-term credit lines which can be used, under certain financial conditions, along a planning horizon of ten years and five months. Also, these studies supposed the farmer hires seasonal labor in the months of intensive agricultural activities and accounts are balanced monthly during the first four years and annually computed for the remaining years of the planning horizon. The entire production of the farm's crops is supposed to be sold to a cooperative group, as the farmer is a cooperative member.

Based on agro-technical aspects proposed in the studies mentioned above, and considering financial aspects like monthly expenses and long-term investments, a mixed integer linear mathematical model was presented by Biagio et al. (2007) for representing small and medium farm system crop production in the District of Paracatu. This model establishes a monthly dynamic treatment of production and financial activities on a long-term planning horizon for a system based on the production of soybeans, wheat, corn and rice, which are produced in a particular rotational scheme. Computational results were presented for financial data related to the year 2002.

In the present study, by considering government financial policies for small and medium farmers in the last decade, the last cited mathematical model is updated for distinct situations derived from the use of short and long-term loans for the Brazilian agricultural sector. New model versions are obtained by implementing into the original programs credit lines available in the years 2006 and 2009, separately. Simulation tests are performed for distinct scenarios and results are obtained. Also, a discussion on the socio-economic and financial feasibility of the agricultural farm system is drawn from the results obtained and additionally, those results from the year 2002 which were already presented in the literature (Biagio et al., 2007).

Within this context this article is organized in the following way: Section 2 presents a summary of the original mathematical model of the crop production planning problem in the *Cerrado* (2007); Section 3 describes the necessary system updates for implementing the financial conditions of Brazilian credit lines in the years 2006 and 2009; Section 4 shows and describes the obtained results; Sections 5 and 6 present a discussion and conclusions, respectively, based on the results attained.

2 MATHEMATICAL MODEL SUMMARY

The original mathematical model (2007) describes a planning problem in crop production by using mixed linear mathematical programming. It is constituted of constraints on the use of

land, machinery, man-power, short-term and long-term loans which strongly influence the values of total income, general expenses, in addition to credits and debts that may be monthly and annually made.

During an agricultural year the work activities on the farm are determined monthly by their type of production. Consequently, once crop production is considered as a business, the farmer may control the cash of the farm in every month along the planning horizon, which also includes transference of the cash surplus, or debts, to the next monthly account balance. This last condition defines a monthly dynamic structure for the mathematical model of farm production planning. The objective of the farmer is to maximize cash surplus and to minimize the use of his credit card every month over the entire planning horizon.

Subsections 2.1, 2.2 and 2.3 below, present a general formulation of constraints on production and financial activities and the objective function, respectively, as they are considered in the original model.

2.1 System Production Conditions

As mentioned in the earlier section, the farm systems in reference are located in the mid-west region of Brazil, which is denominated as the *Cerrado Biome*. This is an important region for the agricultural sector of the country because it has a good climate with no strong temperature changes or rainstorms and plant infestation problems are under control. Traditionally considered inappropriate for intensive cultivation, is today the area largely responsible for the agricultural exports of the country.

The *Cerrado* climate is characterized by two seasons: dry and rainy. The dry season occurs in the period from May to September, and the rainy season happens from October to April. In accordance with the seasons, the agricultural year in this region begins in May and finishes in the following April. Savanna is the typical regional vegetation and is marked by large areas of acid and low fertility soils, which are classified into three main types of oxisols (*Latossolos*): the *LVA*, the *LV* and the *LHI* soils representing 20%, 60% and 20% of the *Cerrado* area, respectively. Soils corresponding to type *LV* are more argillaceous and better for straining than the other types.

As crop yield generally depends on both season and type of soil, with this problem it is supposed that rice, corn and soybean crops are produced in *LVA* and *LV* soils in rainy seasons, and wheat and soybean crops are produced in irrigated *LV* and *LHI* soils during dry and rainy seasons, respectively. In this way, the calendar of the agricultural year is defined as follows: rice, corn and soybeans may be planted in the months of October and November, and may be harvested in the months of January, March and April. Wheat crops may be planted in May and harvested in September. Moreover, soybean crop is planted in a rotation scheme with any of the other three grains in order to reach productivity improvements for the soils.

There is the possibility of buying agricultural machinery and irrigation systems through specific loan requirements (see Section 3). The farmer can employ a maximum number of two permanent workers (drivers) in the case of owning a tractor and/or harvester. Soil preparations for planting

may be done between seasons when the farmer may use (owned and/or rented) machinery such as a tractor and/or harvester. Direct costs of inputs include expenditures on fertilizer, herbicides, seeds, packaging, electric energy and also permanent workers.

Just one family member manages and operates the farm full-time; i.e., he may dedicate 200 hours a month to manage and to operate production activities, which include sowing and harvesting. An additional 200 hours of seasonal family labor is foreseen for the months of intensive sowing and harvesting activities, together with the necessity of hiring seasonal working labor.

Considering the aforementioned conditions above, the planning problem is described below, which considers the production of four different types of crops subject to six necessary monthly resources and five financial instruments, along a planning horizon. The monthly resources are: tractor, harvester, management and seasonal labor working time, direct costs of inputs and gross income. The financial instruments are presented in the next section.

Costs related to soil fertility correction may be computed among the costs of inputs in the months of May and October. For notational simplicity, considered in the constraints below, there are no fertility differences among soil types (for details, see Biagio et al., 2007). In this way, the parameters and variables used for the mathematical model description are defined as follows.

Parameters:

- T is the planning horizon;
- $a_{i,j}(k)$ is the coefficient related to the j-th necessary resource, $j = 1, \ldots, 6$, for the i-th crop production/hectare, $i = 1, \ldots, 4$, in the k-th month, $k = 1, \ldots, 12$;
- L_r is the loan upper bound for the r-th credit line, $r = 1, \ldots, 5$;
- I_5 is the monthly interest rate of the credit card and I_r is the percentage on loan debts updated, and related to r-th credit line, $r = 1, 2, 3, 4$;
- I_D is the amount of money that the farmer may provide to be spent monthly on the family's discretionary consumption;
- I_w is the interest rate due to monetary correction on investments made with the cash surplus of the previous month.

Decision variables:

- $x_i(k, t)$ is the land area producing the i-th crop in the month k and year t, where rice, corn, soybeans and wheat crops are represented by varying the i index from 1 to 4, respectively;
- $x_{3I}(k, t)$ is the land area producing soybeans in irrigated soils, in the month k and year t;
- T_{L1} and T_{L2} are the land area of *LVA* and/or *LV* soils, and *LV* and/or *LHI* irrigated soils, respectively, designed for planting in the year t;

- $y_j(k,t)$ is the j-th necessary resource in the month k and year t, which varies in accordance with worked land area. Particularly, the problem description, below, considers the following necessary resources, for $j = 1, 2, \ldots, 6$, respectively: tractor working time, harvester working time, management working time, working time of seasonal labor, direct costs of inputs and gross income;
- $z_r(k,t)$ is the amount of money withdrawn from the r-th credit line, $r = 1, \ldots, 5$, in the month k and year t;
- $w(k,t)$ is the cash surplus in the month k and year t;

The inequalities (1) below, represent the constraints related to each of the necessary resources.

$$\begin{gathered} a_{1,j}(k)x_1(k,t) + a_{2,j}(k)x_2(k,t) + a_{3,j}(k)x_3(k,t) + a_{4,j}(k)x_4(k,t) \leq y_j(k,t), \\ \text{for any } j = 1, 2, \ldots 6, \text{ any } k \text{ and } 0 \leq t \leq T \end{gathered} \tag{1}$$

where $a_{1,j}(k)$, $a_{2,j}(k)$, $a_{3,j}(k)$ and $a_{4,j}(k)$ are the coefficients related to the j-th resource necessary for the i-th crop production/hectare ($i = 1, 2, 3$ and 4), respectively, in the month k.

With the aim of obtaining improvement in production, the soybean crop is produced in a rotation scheme with any of the other three cereal grains. Also, the land area used for planting in one year may remain with at least the same size in the next agricultural year. The rotation constraints can be written as in (2):

$$\begin{gathered} x_1(k,t) + x_2(k,t) \leq x_3(k,t+1) \\ x_3(k,t) \leq x_1(k,t+1) + x_2(k,t+1) \\ x_{3I}(k,t) \leq x_4(k,t+1) \end{gathered} \tag{2}$$

for any year t, and month k in accordance with the calendar of the agricultural year described above and satisfying the constraint on land availability, i.e., $x_1(k,t) + x_2(k,t) + x_3(k,t) \leq T_{L1}$, and $x_{3I}(k,t) + x_4(k,t) \leq T_{L2}$.

All of the aforementioned activities depend on financial investments. The next section explains how the financial conditions of the problem are formulated in the model.

2.2 Financial Conditions

In the crop production planning problem in reference, the farmer is assumed to be a cooperative member, and can sell the total crop production to a cooperative group. A tax of 2,5% is retained by a rural government fund, namely *FUNRURAL*.

The financial problems of crop production are mainly dealt with in the mathematical model by considering government financial packages created for small and medium farmers, separately. Small farmers must have up to 60 ha of land available and can employ up to two permanent workers. In this paper, a medium farmer is considered to own a land area of up to 100 ha and larger than 60 ha. For the former, the problem considers a financial package that is composed of

Pronaf (National Program for Family Farming) long-term credit lines and for the second it considers a financial package that includes *Proger* (Program for Rural Employnment and Revenues Generation) long-term credit lines. These credit lines allow users to pay debts along a planning horizon of T years and also to pay small percentages of debts during the first four years from the draft date.

A short-term credit line is included in every financial package. This type of credit line may finance costs with inputs and/or investments for soil preparation, and credit amounts may be withdrawn in the months of May, July, September, October, November, and/or February, which depend on both the type of crops to be produced and the land area used for that. Short-term credit lines may also finance maintenance costs of machinery. Loans can be requested every two years, and debts may be paid in full in July of the year following the loan date.

The *Pronaf* and *Proger* financial packages considered in this work are presented in the next section. They are composed of one short-term and up to three long-term credit lines.

In order to have a general representation of the financial conditions cited above, it is considered, in the constraints below, three long-term credit lines, which can vary according to the use of *Pronaf* or *Proger* (Biagio et al., 2007). In this way, let $z_r(k,t)$, $r = 1,\ldots,5$, be as in the following order: the amount of money withdrawn from short-term, the first, second and third long-term credit lines, and credit card, respectively. So, the constraints on short-term and long-term credit limits can, respectively, be represented as in (3).

$$\begin{aligned} \sum_{k} \sum_{t=t1+1}^{t1+2} z_1(k,t) \leq L_1, \quad \text{for} \quad t1 = 0,2,4,6 \\ \sum_{k} \sum_{t=1}^{T} z_r(k,t) \leq L_r, \quad \text{for} \quad r = 2,3,4 \end{aligned} \tag{3}$$

where k is defined according to the calendar of the agricultural year t mentioned in subsection 2.1. The credit card upper bounds are represented as $z_5(k,t) \leq L_5$ for any month k and year t, $0 \leq t \leq T$.

In relation to the farmer, the problem also considers the possibility of the farmer using his/her own initial capital contribution for investment purposes and credit card for balancing the monthly accounts of the farm. The last situation may be interpreted as a monthly debt in the farm's account balance. Decisions about the amount of machinery acquired along the planning horizon are dependent on loans from long-term credit lines and the feasibility of constraints on the account balance, which are described below.

$$\begin{aligned} y_5(k,t) + \sum_{j=1}^{4} c_j(k,t) y_j(k,t) + I_5 z_5(k-1,t) + \sum_{r=1}^{4} I_r z_r(k,t-1) + w(k,t) = \\ = \quad y_6(k,t) + z_5(k,t) + \sum_{r=1}^{4} z_r(k,t) + I_w w(k-1,t) - I_D \end{aligned} \tag{4}$$

for any month k and year t, $0 \leq t \leq T$,

where $c_j(k,t)$ is the cost related to the j-th resource unit, $j = 1, \ldots, 4$, in the month k and year t. The percentage on loan debts updated, and related to i-th credit line, I_i, $i = 2, 3, 4$, may be paid in the month of September for $i = 2, 3, 4$ (i.e., $I_i = 0$ for $k \neq 9$, $i = 2, 3, 4$). It is assumed that the short-term loan debt may be paid in the month of July of the forthcoming year (i.e., $I_1 = 0$ for $k \neq 7$).

As described in the sections above, the problem presents decision variables such as land area for planting rice, corn, soybeans and wheat, besides several others which are dependent on the land area worked and the type of crop production, like the following: amount of loans to be taken out from short and long-term credit lines, necessary working time of tractor, harvester, management and hiring seasonal labor, and also direct costs of inputs and gross income. The amount of acquired machinery and permanent employees hired along the planning horizon are integer decision variables in the problem. The goal of the crop production problem presented is described in the next subsection.

2.3 Objective Function

As already mentioned in the earlier section, the objective of the problem is to maximize the monthly cash surplus and minimize the monthly loan amount taken from the credit card. So, the objective function can be written as:

$$Maximize \sum_{t=1}^{T} \sum_{k=1}^{12} w(k,t) - \sum_{t=1}^{T} \sum_{k=1}^{12} z_5(k,t) \tag{5}$$

for all k and all t, since the account balance is made in every month of the planning horizon.

The next section presents the upgrading requirements for obtaining new versions of the original model.

3 UPGRADING THE MODEL

In this paper, the original model (2007) is adapted from *Pronaf* and *Proger* financial packages for the years 2006 and 2009, separately, which correspond to governmental policies for the agricultural sector implemented throughout the last decade. To do this, several model updates are carried out, ranging from simple but important parameters to those for a partial reformulation of farm systems.

Subsections 3.1 and 3.2 respectively describe the financial conditions of the *Pronaf* and *Proger* packages in reference and subsection 3.3 summarizes the updates implemented.

3.1 *Pronaf* Financial Package

As mentioned earlier, the Brazilian *Pronaf* financial package was created to help small farmers. In both the years 2006 and 2009, the *Pronaf* packages considered are composed of just a long-term credit line designed for investment purposes, including acquiring machinery and irrigation systems (specifically designed for farm systems which have already been producing), and a short-

term one, namely *Pronaf Custeio*, for soil input purposes. Loans taken out from either long-term or short-term credit lines must be paid within eight years and five months or two years, respectively. It is possible to take out loans from both of them simultaneously.

For requesting credit from *Pronaf*, the user must prove that his farm had an annual gross income average ranging from 2,564.10 u.m. to 3,846.15 u.m. in 2006 and from 1,153.84 u.m. to 7,051.28 u.m. in 2009 where u.m. is a monetary unit equivalent to US$ 7.72. Table 1, below, shows the required annual interest rates and total credit allowed by the financial packages in both 2006 and 2009.

Table 1 – Financial conditions of *Pronaf* in the years 2006 and 2009 (credits are in u.m.).

Pronaf	Long-Term		Short-Term	
	credit	rate (%)	credit	rate (%)
2006	2,307.7	7.25	1,794.87	7.25
2009	2,307.7	1.0 to 5.0	2,564.10	1.5 to 5.5

In 2009, the annual interest rates varied from 1,0% to 5,0% and from 1,5% to 5,5%, according to the amount of money taken from the long-term and short-term credit lines, respectively.

3.2 Proger Financial Package

As already reported, the *Proger* financial package was created to help medium farmers and, in this study, it is supposed that medium farmers own a land area with size ranging from 60 ha to 100 ha. For both years 2006 and 2009, the *Proger* packages considered are composed of *Moderfrota* long-term credit lines for acquiring machines, *Moderagro* and *Proger Rural,* both for general investments, and the short-term credit line *Proger Custeio* for land inputs assistance. Time limits for debt payments are the same as *Pronaf*. Table 2 below shows the amount of credit available from the *Moderagro* and *Proger Rural* long-term credit lines and their respective annual interest rates in the years considered.

Table 2 – Financial conditions for the *Proger* package in the years 2006 and 2009 (credits are in u.m.).

Proger	Long-Term				Short+Term
	Moderagro		Proger Rural		credit
	credit	rate (%)	credit	rate (%)	
2006	12,820.50	8.75	3,076.92	8.00	3,846.15
2009	16,025.64	6.75	12,820.51	6.25	12,820.00

In 2006 and 2009, the credit amount allowed by *Moderfrota* did not have an upper bound, and its annual interest rate was equal to 9.75% in 2006 and of 7.5% in 2009. This credit line was defined to assist farms that have a gross income with an annual average of up to 9,615.38 u.m.

The *Proger Rural* credit line, which includes the short-term credit line *Proger Custeio*, was defined to help farms with a gross income annual average of up to 5,128.20 u.m. in 2006 and between 7,051.28 u.m. and 32,051.28 u.m. in 2009. Loans that could be taken out simultaneously from both *Proger Rural* and *Proger Custeio* were up to 3,846.15 u.m. and 12,820.0 u.m. in the years 2006 and 2009, respectively.

These financial rules of *Pronaf* and *Proger* required modifications in the original mathematical model (2007). The necessary changes are explained in the next subsection.

3.3 Reformulating the Systems

As described in subsections 3.1 and 3.2, the credit lines belonging to the 2006 and 2009 *Pronaf* and *Proger* financial packages offered larger loans than those in the year 2002 (see Appendix 1), bringing about the possibility of testing the feasibility of production systems in a real planning horizon. Also, they required some different financial conditions, which have to be considered in the mathematical model.

As a consequence, system reformulations must be done in the following way:

- New versions of the original mathematical model are formulated with a planning horizon of eight years and five months. As the original model (2007) was formulated with an extended planning horizon of ten years and five months, the upgraded versions present smaller systems as the number of decision variables and number of constraints in equations (1), (3) and (4) above, depend on the value of parameter T;
- Constraints related to an upper bound on joint loans from *Proger* short-term and long-term credit lines are added to the mathematical system. These constraints are described by the inequalities (6) below:

$$\sum_{t=t1+1}^{t1+2} \sum_{k=1}^{12} \sum_{r=1}^{2} z_r(k,t) \leq L, \qquad t1 = 0, 2, 4, 6 \tag{6}$$

  where $z_r(k,t)$ is the amount of money taken from the r-th credit line, $r = 1, 2$ as described in Section 2, and L is the upper bound on joint loans from *Proger Rural* and *Proger Custeio*, as depicted in Table 2.

Additionally, updates on financial parameters are required and the main changes are in the following:

- For the *Pronaf* and *Proger* user, an amount of 67.3 u.m. is supposed to be withheld monthly for a family's consumption in the year 2006. In 2006, this value corresponds to three times the monthly minimum salary in Brazil, which was of 22.43 u.m.;
- For the year 2009, the amounts of 79.42 u.m. and 89.42 u.m. are supposed to be set aside monthly by users of *Pronaf* and *Proger*, respectively, for a family's consumption. The first and second values represent 266% and 300%, respectively, of the monthly minimum salary in Brazil, which was of 29.81 u.m.;

- The cost of hiring seasonal work is equal to 0.12 u.m. and 0.17 u.m. an hour for the years 2006 and 2009, respectively. These values are determined by dividing the respective monthly minimum wage by 176 hours – the monthly workload in Brazil;
- The interest rates of the short and long-term credit lines are changed to the values as mentioned in subsections 3.1 and 3.2; consequently, updates on the computations of payments and debt amounts are necessary;
- Credit card interest rate was 7,9% monthly in both years 2006 and 2009.

In consequence of the first change mentioned above, the upgraded systems present smaller dimensions than their original ones (see Section 4 and Appendix 1), considering that the number of constraints and variables decreased, despite the addition of constraints (6) in the *Proger* programs. The obtained results are presented in the next section.

4 RESULTS

New versions of the mathematical model are obtained by applying the financial packages described above for the years 2006 and 2009, separately. They were programmed in MPS format and present systems with the following dimensions: about 1424 constraints and 2190 variables for the programs which included *Pronaf* packages, and about 1356 constraints and 2019 variables for those including *Proger* packages. The computational tests were performed on a *PC Pentium*® 4, 1.80 GHz, by using the software CPLEX 9.0. The optimal values of decision variables as land area designed to each crop and seasonal main labor along the planning horizon, and the computational times for running the scenarios, are showed in the tables from 9 to 20, Appendix 2. For the results, the parameter I_w, in equation (4) was assumed to be 1%.

In the subsections below, tables show the results through the following notations: IC is the initial capital resource that the farmer may have for obtaining the indicated solution; TF is the total credit amount taken from the financial package long-term credit lines; ST is the annual average taken from the short-term credit line during a specified period; CC is the monthly average loan amount he may take from his credit card during a specific period of time; TL is the area of land annually used for planting, and LI is the land area annually irrigated; GI is the annual average of the gross farm income; and CS is the cash surplus of the farm at the end of the planning horizon.

In order to attain results on the economic and financial participation of the seasonal family labor in the production systems, simulation tests are also performed for two distinct supposed situations: in one of them, the farmer has up to 200 monthly hours of family labor available for managing; in the second situation he has an additional 200 hours of seasonal family labor. The results are presented in the following subsections 4.1 and 4.2.

4.1 Pronaf Financial Packages

This subsection presents results attained from running the new versions of the programs when applying the *Pronaf* financial packages described in subsection 3.1. In Tables 3 and 4 below,

the financial packages considered for the years 2006 and 2009 are denominated *Pronaf_06* and *Pronaf_09*, respectively.

4.1.1 No surplus family labor

By supposing there is no additional seasonal family labor available in the months of intensive agricultural activities, the results obtained are depicted in Table 3 and described below. The word "all", below column TF in this table, represents the maximum acceptable value shown in Table 1. Detailed information about planting area for each crop and need of hiring seasonal workers is presented in Tables 9, 10 and 11, Appendix 2.

Table 3 – Financial and production results for farmers using *Pronaf* financial packages.

Package	IC	TF	ST	CC	TL	LI	GI	CS
Pronaf_06	968.	all	897.43 (8 years)	0.0	49.82	10.82	3,953.92	5,035.41
Pronaf_06	100.	all	897.43 (8 years)	87.47 (5 years)	49.82	10.82	3,368.82	1,126.76
Pronaf_09	100.	all	1,282.04 (8 years)	21.13 (5 years)	50.03	11.03	3,670.52	977.37

As it is possible to observe, if the initial capital contribution is 968 u.m. for investments, the solution obtained for the year of 2006 indicates that the farmer could take out the whole loan amount from the *Pronaf* long-term credit line and also an annual average of 897.43 u.m. from the short-term credit line along the eight years. In this way, by annually using a land area of 49.82 ha for planting corn, soybeans and wheat in a rotation system, the gross farm income could present an annual average of 3,953.92 u.m. and the account balance of the farm could be closed with an amount of 5,035.41 u.m. at the end of the planning horizon.

In the case of a farmer with just 100 u.m. of an initial capital contribution, the obtained solution indicates that the farmer could take the same amount of credit from the *Pronaf_06* financial package of the first case. For a land area of 49.82 ha used annually for planting rice, corn, soybeans and wheat crops, the annual average of gross farm income obtained could be 3,368.82 u.m., and the account balance of the farm could be closed with an amount of 1,126.76 u.m. at the end of the planning horizon. Additionally, in order to obtain these results, the farmer would have to use a monthly average amount of 87.47 u.m. from his credit card over the first five years for balancing the monthly accounts of the farm.

In the year 2009, if an initial capital contribution is 100 um. for investments, the solution attained indicates the user of *Pronaf_09* could take the total amount from the *Pronaf* long-term credit line and an annual average of 1,282.04 um. from the *Pronaf Custeio* short-term credit line along the eight years. By annually using a land area of 50.03 ha the farmer could plant wheat, rice, corn and soybeans in a rotation system in order to obtain an annual average of gross farm income of 3,670.52 um. and to close the account balance of the farm with the amount of 977.37 um. at the

end of the planning horizon. To do that, he would have to take a monthly average of 21.13 um. from his credit card during the first five years.

4.1.2 With surplus family labor

The results obtained from supposing there is 200 additional hours available of seasonal family labor in the months of intensive activities are shown in Table 4 and described as the following. As in the earlier section, the word "all", below column TF in this table, represents the maximum acceptable value shown in Table 1. Information on planting area for each crop and need of hiring seasonal workers is presented in Tables 12, 13 and 14, Appendix 2.

Table 4 – Production and financial results for farmers using both *Pronaf* financial packages and surplus family labor.

Package	IC	TF	ST	CC	TL	LI	GI	CS
Pronaf_06	968.	all	897.43 (8 years)	0.0	49.82	10.82	3,955.06	5,234.84
Pronaf_06	100.	all	897.43 (8 years)	68.55 (6 years)	49.82	10.82	3,383.50	1,362.27
Pronaf_09	100.	all	1,206.63 (8 years)	38.50 (3 years)	50.03	11.03	3,729.60	1,263.10

If an initial capital contribution is 968 u.m. for investments in the year 2006 the farmer could take the whole loan amount from the *Pronaf* long-term credit line and an annual average of 897.43 u.m. from the short-term credit line throughout the planning horizon. In this case, by annually using a land area of 49.82 ha for planting corn, soybeans and wheat in a rotation system, the gross farm income could present an annual average of 3,955.06 u.m. and the account balance of the farm could be closed with an amount of 5,234.84 u.m. at the end of the planning horizon.

If there is an initial capital contribution of just 100 u.m., the farmer could take the same amount of credit from the *Pronaf_06* financial package in the earlier case. The results obtained indicate that by using a land area of 49.82 ha for annually planting rice, corn, soybeans and wheat crops, the farmer could get a gross farm income with an average of 3,383.5 u.m. a year and the account balance of the farm could be closed with 1,362.27 u.m. at the end of planning horizon. Also, he would have to take a monthly average of 68.55 u.m. from his credit card over the first six years for balancing the monthly accounts of the farm.

With an initial capital contribution of 100 u.m., the user of *Pronaf_09* could take the total amount from the *Pronaf* long-term credit line and an annual average of 1,206.63 u.m. from the *Pronaf Custeio* short-term credit line, along the planning horizon, in order to annually use a land area of 50.03 ha for planting wheat, rice, corn and soybean crops. In this way, the obtained annual average of gross farm income could be 3,729.60 u.m. and the account balance of the farm could be closed with 1,263.10 u.m. at the end of the planning horizon. Additionally, to balance the monthly account, the farmer would have to take a monthly average of 38.50 u.m. from his credit card during the first three years.

For all cases shown in both Tables 3 and 4, the user of credit from *Pronaf_06* and/or *Pronaf_09* could pay off his debts during the real planning horizon of eight years and five months.

4.2 Proger Financial Packages

This subsection presents results attained from running the new versions of the programs when applying the *Proger* financial packages described in 3.2. In Tables 5 and 6, below, the financial packages considered for the years 2006 and 2009 are denominated *Proger_06* and *Proger_09*, respectively.

4.2.1 No surplus family labor

The results obtained by supposing there is no use of additional seasonal family labor in the months of intensive activities are depicted in Table 5 and described below. Detailed information on planting area for each crop and need of hiring seasonal workers is showed in Tables 15, 16 and 17, Appendix 2.

Table 5 – Production and financial results for farmers using *Proger* financial packages.

Package	IC	TF	ST	CC	TL	LI	GI	CS
Pronaf_06	5,000.	6,845.84	384.61 (8 years)	0.0	79.33	14.33	6,018.31	19,902.74
Pronaf_06	600.	4,764.72	797.78 (8 years)	184.89 (5 years)	55.02	10.82	3,708.80	2,952.46
Pronaf_09	600.	12,085.60	2,655.53 (8 years)	196.12 (1st year)	100.00	35.00	9,153.62	14,128.48

With an initial capital contribution of 5,000 u.m. in the year 2006, the obtained solution indicates that the user of credits from the *Proger* financial package could take the amount of 6,845.84 u.m. from both *Proger Rural* and *Moderagro* credit lines. Furthermore, an annual average of 384.61 u.m. could be taken from the *Proger Custeio* short-term credit line throughout the entire planning horizon. In this way, the farmer could use 65 ha of land area in the first two years, and 79.33 ha from the third year for annually planting corn, soybeans and wheat in a rotation system to get an annual average of gross farm income of 6,018.31 u.m. and to close the account balance of the farm with 19,902.74 u.m. at the end of the planning horizon of eight years and five months.

If there is an initial capital contribution of 600 u.m., the user of the *Proger_06* package could take the amount of 4,764.72 u.m. from the *Proger Rural* and *Moderagro* credit lines and an annual average of 797.78 u.m. from the *Proger Custeio* short-term credit line throughout the planning horizon. With this capital, the producer could use a land area of 45 ha in the first year, and 55.02 ha from the second year for annually planting rice, corn, soybeans and wheat in a rotation system, to get an annual average of gross farm income of 3,708.80 u.m. and to close the account balance with 2,952.46 u.m. at the end of the planning horizon. For attaining these results, he

would have to use a monthly average amount of 184.89 u.m. from his credit card over the first five years.

In the year 2009, if there is an initial capital contribution of 600 u.m., the user of *Proger_09* could take the amount of 12,085.60 u.m. from the *Moderagro* and *Proger Rural* credit lines, and an annual average of 2,655.53 u.m. from the *Proger Custeio* credit line over the entire planning horizon. With this capital, the farmer could use 95.90 ha in the first year, and from the second year 100 ha of land to annually plant corn, soybeans, rice and wheat in a rotation system in order to obtain an annual gross farm income average of 9,153.62 u.m. and to close the account balance of the farm with the amount of 14,128.48 u.m. at the end of the planning horizon. For attaining these results, the farmer would have to take a monthly average of 196.12 u.m. from his credit card in the first year of the planning horizon.

4.2.2 With surplus family labor

The results obtained by supposing the use of additional seasonal family labor in the months of intensive activities are depicted in Table 6 below, and described as the following. Information about planting area for each crop and need of hiring seasonal workers is showed in Tables 18, 19 and 20, Appendix 2.

Table 6 – Production and Financial results for farmers using both *Proger* financial packages and surplus seasonal family labor.

Package	IC	TF	ST	CC	TL	LI	GI	CS
Pronaf_06	5,000.	6,841.49	404.61 (8 years)	0.0	79.25	14.25	5,569.40	20,847.65
Pronaf_06	600.	4,751.96	810.07 (8 years)	147.92 (6 years)	54.92	9.92	3,696.80	3,374.37
Pronaf_09	600.	12,085.60	2,655.53 (8 years)	196.12 (1st year)	100.00	35.00	9,153.62	14,503.72

With an initial capital contribution of 5,000 u.m., the user of credit from the *Proger_06* financial package could take an amount of 6,841.49 u.m. from both *Proger Rural* and *Moderagro* credit lines, and an annual average of 404.61 u.m. from the *Proger Custeio* short-term credit line throughout the entire planning horizon. In this way, he could use a land area of 65 ha in the first year, and 79.25 ha from the second year for annually planting corn, soybeans and wheat in a rotation system, to get an annual gross farm income average of 5,569.40 u.m., and to close the account balance of the farm with 20,847.65 u.m. at the end of the planning horizon.

It is also possible to observe from Table 6 that if there is an initial capital contribution of 600 u.m., the user of *Proger_06* could take a credit amount of 4,751.96 u.m. allowed by this financial package, and also take money from the *Proger Custeio* short-term credit line over the planning horizon, with an annual average of 810.07 u.m. With this capital, the farmer could use a total area of 45 ha in the first year, and 54.92 ha of land from the second year for annually planting rice, corn, soybeans and wheat in a rotation system, in order to get an annual gross farm income

average of 3,696.80 u.m. and finish the planning horizon with 3,374.37 u.m. in the account balance of the farm. For that, he would have to take money from his credit card during the first six years with a monthly average of 147.92 u.m.

In the year 2009, if there is an initial capital contribution of 600 u.m., the user of *Proger_09* could obtain results that only differ to those displayed in Table 5 in the value of the final account balance surplus, which could be of 14,503.72 u.m. at the end of the planning horizon.

For all cases shown in both Tables 5 and 6, the user of credit from *Proger_06* and/or *Proger_09* could pay his debts over the real planning horizon of eight years and five months.

5 DISCUSSION

In order to include in this discussion results related to the year 2002, it is important to underscore some differences existing among the initial conditions of the *Pronaf* and *Proger* programs considered for that time and those ones considered in the present work.

As the authors mentioned in their work (Biagio et al., 2007), in the year 2002 the long-term credit lines had the period for debt payments extended to ten years and five months due to system feasibility purposes. Furthermore, parameters like the amount of money monthly set aside for the family's consumption, costs with seasonal labor and interest rates are upgraded for all implemented programs in the present study. The first two parameters are strongly related to the Brazilian minimum wage, so their values have changed as described in subsection 3.3 above (see Appendix 1 for the year 2002) and below:

- for the *Pronaf* programs, the parameter related to the family's consumption was considered to be 16.65% and 37.66%, respectively in the years 2006 and 2009, larger than that in the year 2002;
- for the *Proger* programs, respectively in the years 2006 and 2009, the family's consumption parameter was 16.65% and of 55.00% larger than the one in the year 2002;
- in the year 2009, and for both programs, seasonal labor costs were considered to be 41.66% larger than the one in the years 2002 and 2006.

By taking into account the differences cited above, it is possible to observe from the results shown in both Tables 3 and 4, subsection 4.1, and Table 7 in the Appendix 1, for the user of *Pronaf* financial packages:

(i) In the year 2002, if the initial capital contribution is 1,500 u.m. and additional seasonal family labor is being used, it would be necessary to take the total loan from the *Pronaf* credit line and part of the credit allowed by *Proger Rural* with a high interest rate in the first year. Furthermore, in order to achieve financial feasibility, the farmer would have to take out money from a hypothetical short-term credit line during the first seven years, with an interest rate of 15,25% a year;

(ii) Different from the situation in the year 2002, the farmer who took money from *Pronaf* in the years 2006 and/or 2009, could pay his debts over a planning horizon of eight years and five months. Furthermore,

- in the year 2006, the user of *Pronaf_06* could take a larger loan amount and invest a smaller initial capital contribution amount than those in the year 2002; also, in all scenarios shown the farmer could achieve a good gross income and surplus in the account balance of the farm at the end of the planning horizon. If investing just 100 u.m. of an initial capital contribution, the farmer would have to use his credit card monthly over five or six years depending on the use of seasonal family labor;
- in the year 2009, with a larger loan amount from the short-term credit line, the Pronaf_09 user could initially invest a small amount of his/her capital contribution of 100 u.m. and attain better production and financial results along the planning horizon than those obtained from *Pronaf_06*. Moreover, given that 50.03 ha of land could be used for planting, the annual farm income average could increase and the average amount of money taken monthly from the credit card decreases.

From the results shown in both Tables 5 and 6, subsection 4.2, and Table 8 in the Appendix 1, it is possible to see that for the user of *Proger* financial packages:

(i) In the year 2002, if investing 5,000 u.m. of initial capital, the user of the *Proger_02* package could achieve good production and gross farm income, with exception to the final account balance surplus; if investing just 100 u.m. of a capital contribution, the farmer must use surplus seasonal family labor and his credit card in order to get feasible financial results from the production system;

(ii) Different from the situation in the year 2002, the farmer who took money from *Proger* in the years 2006 and/or 2009, could pay off his debts during a planning horizon of eight years and five months. Besides this,

- with an amount of 5,000 u.m. of an initial capital contribution in the year 2006, the *Proger_06* package user could get much better results than in the year 2002 since he could take out a larger loan amount and consequently, attain increases in both annual average farm income and final account balance surplus;
- if investing 600 u.m. of an initial capital contribution, the user of *Proger_06* could take a somewhat bigger loan than in the second scenario of the year 2002 and obtain financial feasibility for the production system by planting in a reduced area of land, using a larger credit card amount and sustaining decreased values of gross farm income and final account balance surplus;
- in the year 2009, the *Proger_09* financial package allowed significant improvements in credit amounts. In consequence of this, the farmer could invest an initial capital contribution of just 600 u.m. and obtain much better annual averages of gross farm income and final account balance surplus than in the earlier cases by planting 100 ha of land.

In relation to the financial benefits of seasonal family labor participation in the production systems, it can be observed from the results shown in Tables 3 to 8 that:

- When applying *Pronaf_02* in the year 2002 (see Appendix 1), the farmer could obtain an increase in the annual average of gross farm income with a decreased amount of initial capital contribution. For the user of the *Proger_02* package, production and financial feasibility of the system could be obtained from a small initial capital contribution;
- In the year 2006, the farmer who took money from the *Pronaf_06* package could obtain a little larger account balance surplus than that one obtained with no surplus seasonal family labor. For the user of the *Proger_06* package, it could be possible to attain a slight increase in the final account balance surplus and a decrease in the monthly loan average taken from the credit card when using a small amount of initial capital contribution;
- In the year 2009, the user of *Pronaf_09* could obtain some financial system improvements, given the modest increase in the values of both the annual average of gross farm income and the final account balance surplus. For the user of the *Proger_09* package, the financial results shown did not indicate significant improvements in any case, given only the relatively small increase attained in the value of the final account balance surplus.

With respect to the bank requirements on annual average of gross farm income mentioned in subsections 3.1 and 3.2, some additional observations on economic and financial feasibility improvements of farm systems during the last decade can also be made based on the results shown in the last section:

- All cases related to the use of loans from *Pronaf_06* and *Pronaf_09* present possible solutions for the production system, which also satisfy the financial bank constraints;
- For medium farmers, despite the favorable solutions provided by *Proger_06*, the annual average of gross farm income could not satisfy the upper bound established by the banks when investing an initial capital contribution of 5,000 u.m. and planting in a larger land area;
- The *Proger_09* financial package considered in this work could guarantee financial solutions for the production systems in accordance to bank criteria.

6 CONCLUSIONS

In this paper, new versions of mathematical programs for crop production planning problems in farm systems with up to 100 ha of land area were implemented and several scenarios were successfully run. They generated solutions from which it is possible to affirm that:

- Differently from the financial packages considered in the year 2002, both *Pronaf* and *Proger* packages allowed credit amounts, in the years 2006 and 2009, which could improve the financial conditions and feasibility of both small and medium (with up to 100 ha of land) crop production systems;

- For small systems, besides the increased amounts of credit, in the years 2006 and 2009, good results were possible to observe when the farmer having some amount of an initial capital contribution for investments and, additionally, using a credit card to balance the monthly accounts of the farm, independent of using additional seasonal family labor;
- The increased amount of credits available for medium farmers, in the year 2009, could provide the agricultural systems with better solutions than those obtained for the years 2002 and 2006. Also, the limits on gross farm income established by financial institutions improved the feasibility between production and bank constraints;
- For all systems tested in this study, the results obtained showed that the financial importance of surplus seasonal family labor decreased during the last decade and could be substituted by seasonal workers.

For the Brazilian agricultural sector, these are favorable results since they indicate production and financial improvements for small systems during the last decade, which are also accomplished by the socio-economic improvements given by the feasibility of hiring seasonal workers.

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A APPENDIX 1

This appendix summarizes, in the subsections below, a description of the *Pronaf* and *Proger* financial packages for the year 2002 and results obtained from the original programs (Biagio et al., 2007). As described in this last study, the original mathematical systems presented the

following matrix dimensions: 1758 constraints and 2722 variables when applying *Pronaf*, and 1677 constraints and 2508 variables when applying *Proger*.

By using the notations defined in section 4, Tables 7 and 8 below, depict results that were attained for an extended planning horizon of ten years and five months. For these results, the parameters related to a family's consumption and costs with seasonal labor were assumed to be equal to 57.69 u.m. and 0.12 u.m. an hour, respectively, for both *Pronaf* and *Proger* packages.

A.1 *Pronaf* Package

In the year 2002, the *Pronaf* financial package was composed of the long-term *Pronaf_D*, *Pronaf Agregar* and *Proger Rural Tradicional* credit lines, the last one being a long-term credit line with a high annual interest rate of 19,25% (known as *Proger* with *TJLP*). The *Pronaf_D* and *Pronaf_Agregar* were proposed to help farm infrastructure improvements, including acquiring irrigation systems and machinery. Each of these credit lines had an annual interest rate of 4% and, for feasibility purposes it was supposed that each of them allowed credit amounts of 1,105.77 u.m. which were 15% larger than the real ones. In this year, the *Pronaf* package did not offer a short-term credit line and the farmer had no available credit card. The results are shown in Table 7 below.

Table 7 – Financial and production results for users of *Pronaf* financial packages.

Family labor	IC	TF	CC	TL	LI	GI	CS
No	7,500.	2,211.54	0.0	45.60	0.60	2,402.38	252.08
Yes	1,500.	2,760.09	0.0	47.76	2.76	2,715.75	147.58

As it is depicted in the table above, without using additional seasonal family labor, it was necessary for the *Pronaf* user to have an initial capital contribution of 7,500.00 u.m. and to take an amount of 2,211.54 u.m. from the credit lines in order to obtain production system feasibility. Furthermore, for attaining the results, the farmer must take 408.23 u.m. from a hypothetical short-term credit line in the 10th year.

If using 200 additional hours of seasonal family labor, an initial capital contribution of 1,500.00 u.m. was required by the farmer in order for the production system to be feasible. Besides this, the farmer needs to take an amount of 2,760.09 u.m. from the *Pronaf* credit line and part of the credit allowed by *Proger* with *TJLP* in the first year. In addition, the farmer must take an annual average of 247,52 u.m. from a hypothetical short-term credit line over the first seven years, paying an interest rate of 15,25% a year.

A.2 *Proger* Package

The *Proger* financial package considered for the year 2002 was composed of three long-term credit lines and one short-term. The long-term were the following: *Modefrota*, *Prosolo* and *Proger Rural*. The first offered unlimited credit for acquiring machinery such as a tractor and a harvester, and credit amounts of up to 5,128.2 u.m. and 1,923.07 u.m. were allowed by the second

and third credit lines for soil input expenses and investments in irrigation systems, respectively. An interest rate of 8.5% a year was pre-determined for each of these credit lines.

The *FCO* (Brazilian Constitutional Funds for the Mid-West Region) short-term credit line considered allowed an amount of up to 3,205.13 u.m. with an interest rate of 8.5% a year. The *FCO* credit line also offered a discount of 15% on the interest rate for users with no overdue debt payments. There was an 8,3% monthly credit card interest rate in the year 2002. The results are shown in the table below.

Table 8 – Financial and production results for users of *Proger* financial package.

Family labor	IC	TF	CC	TL	LI	GI	CS
No	5,000.	5,431.44	0.0	73.90	8.90	4,679.29	513.49
Yes	100.	4,483.34	78.46	65.26	8.90	3,958.14	1,773.67

Without using additional seasonal family labor as depicted in Table 8, the user of the *Proger* financial package must have an initial capital contribution of 5,000.00 u.m. and needs financing in the first year of 5,431.44 u.m. from both *Proger* and *Prosolo* credit lines for obtaining production system feasibility. For the results attained, the farmer also needs to take money from the short-term FCO credit line every year with an annual average of 1,602.56 u.m..

By using 200 hours of surplus seasonal family labor, and an initial capital contribution of 100 u.m., the farmer could take the amount of 4,483.34 from both *Proger* and *Prosolo* credit lines in the first year. In order to obtain the results, the farmer needs to use a monthly average of 78.46 u.m. from his credit card in the first six years and take an annual average amount of 1,602.57 u.m. from the FCO short-term credit line along the extended planning horizon.

B APPENDIX 2

This appendix presents, in the tables from 9 to 20, the optimal solutions on crop planting areas and contracted man-hours, which are related to the scenarios depicted in tables from 3 to 6, Section 4.

Table 9 – Pronaf_06, without seasonal family labor, IC = 968.00 u.m. and family's consumption of 67.31 u.m. (CPU = 0.19 sec.).

Year / Solution	1	2	3	4	5	6	7	8
Land area (ha)								
Rice	—	—	—	—	—	—	—	—
Corn	39	—	39	—	39	—	39	—
Wheat	10.82	10.82	10.82	10.82	10.82	10.82	10.82	10.82
Soy-been	10.82	49.82	10.82	49.82	10.82	49.82	10.82	49.82
Man-hours	176.55	54.67	176.55	54.67	176.55	54.67	176.55	54.67

Table 10 – Pronaf_06, without seasonal family labor, IC = 100.00 u.m. and family's consumption of 67.31 u.m. (CPU = 0.30 sec.).

Year / Solution	1	2	3	4	5	6	7	8
Land area (ha)								
Rice	—	39	—	39	—	15.26	—	—
Corn	—	—	—	—	—	23.74	—	39
Wheat	10.82	10.82	10.82	10.82	10.82	10.82	10.82	10.82
Soy-been	49.82	10.82	49.82	10.82	49.82	10.82	49.82	10.82
Man-hours	49.80	59.55	49.80	59.55	49.80	129.78	52.77	181.32

Table 11 – Pronaf_09, without seasonal family labor, IC = 100.00 u.m. and family's consumption of 79.42 u.m. (CPU = 0.34 sec.).

Year / Solution	1	2	3	4	5	6	7	8
Land area (ha)								
Rice	3.43	29.33	—	35.56	—	4.8	—	—
Corn	—	6.23	3.43	—	3.43	30.76	3.43	35.56
Wheat	11.03	11.03	11.03	11.03	11.03	11.03	11.03	11.03
Soy-been	46.60	14.47	46.60	14.47	46.60	14.47	46.60	14.47
Man-hours	50.89	77.61	61.96	59.35	61.18	151.63	65.03	166.06

Table 12 – Pronaf_06, with seasonal family labor, IC = 968.00 u.m. and family's consumption of 67.31 u.m. (CPU = 0.14 sec.).

Year / Solution	1	2	3	4	5	6	7	8
Land area (ha)								
Rice	—	—	—	—	—	—	—	—
Corn	39	—	39	—	39	—	39	—
Wheat	10.82	10.82	10.82	10.82	10.82	10.82	10.82	10.82
Soy-been	10.82	49.82	10.82	49.82	10.82	49.82	10.82	49.82
Man-hours	0.	0.	0.	0.	0.	0.	0.	0.

Table 13 – Pronaf_06, with seasonal family labor, IC = 100.00 u.m. and family's consumption of 67.31 u.m. (CPU = 0.16 sec.).

Year / Solution	1	2	3	4	5	6	7	8
Land area (ha)								
Rice	—	39	—	39	—	11.71	—	—
Corn	—	—	—	—	—	27.29	—	39
Wheat	10.82	10.82	10.82	10.82	10.82	10.82	10.82	10.82
Soy-been	49.82	10.82	49.82	10.82	49.82	10.82	49.82	10.82
Man-hours	0.	0.	0.	0.	0.	0.	0.	0.

Table 14 – Pronaf_09, with seasonal family labor, IC = 100.00 u.m. and family's consumption of 79.42 u.m. (CPU = 0.34 sec.).

Year / Solution	1	2	3	4	5	6	7	8
Land area (ha)								
Rice	—	24.14	—	29.72	—	—	—	—
Corn	9.30	5.58	9.30	—	9.30	29.72	9.30	29.72
Wheat	11.03	11.03	11.03	11.03	11.03	11.03	11.03	11.03
Soy-been	40.73	20.31	40.73	20.31	40.73	20.31	40.73	20.31
Man-hours	0.	0.	0.	0.	0.	0.	0.	0.

Table 15 – Proger_06, without seasonal family labor, IC = 5,000.00 u.m. and family's consumption of 67.31 u.m. (CPU = 0.16 sec.).

Year / Solution	1	2	3	4	5	6	7	8
Land area (ha)								
Rice	—	—	—	—	—	—	—	—
Corn	65	—	65	—	65	—	65	—
Wheat	—	14.33	14.33	14.33	14.33	14.33	14.33	14.33
Soy-been	—	65	14.33	79.33	14.33	79.33	14.33	79.33
Man-hours	276.25	87.44	290.57	87.44	290.57	87.44	290.57	87.44

Table 16 – Proger_06, without seasonal family labor, IC = 600.00 u.m. and family's consumption of 67.31 u.m. (CPU = 0.19 sec.).

Year / Solution	1	2	3	4	5	6	7	8
Land area (ha)								
Rice	6.49	32.68	—	38.51	6.49	—	—	—
Corn	—	5.83	6.49	—	—	38.51	6.49	38.51
Wheat	—	10.02	10.02	10.02	10.02	10.02	10.02	10.02
Soy-been	38.51	16.51	48.53	16.51	48.53	16.51	48.53	16.51
Man-hours	46.61	82.14	76.80	65.44	56.61	180.19	80.89	181.00

Table 17 – Proger_09, without seasonal family labor, IC = 600.00 u.m. and family's consumption of 89.42 u.m. (CPU = 0.17 sec.).

Year / Solution	1	2	3	4	5	6	7	8
Land area (ha)								
Rice	—	—	—	20	—	—	—	—
Corn	45	20	45	-	45	20	45	20
Wheat	30.9	35	35	35	35	35	35	35
Soy-been	50.9	80	55	80	55	80	55	80
Man-hours	242.14	170.62	248.75	110.62	246.25	170.62	248.75	170.62

Table 18 – Proger_06, with seasonal family labor, IC = 5,000.00 u.m. and family's consumption of 67.31 u.m. (CPU = 0.24 sec.).

Year / Solution	1	2	3	4	5	6	7	8
Land area (ha)								
Rice	—	—	—	—	—	—	—	—
Corn	65	—	65	—	65	—	65	—
Wheat	—	14.25	14.25	14.25	14.25	14.25	14.25	14.25
Soy-been	—	79.25	14.25	79.25	14.25	79.25	14.25	79.25
Man-hours	27.5	0.	31.06.	0.	31.06.	0.	31.06.	0.

Table 19 – Proger_06, with seasonal family labor, IC = 600.00 u.m. and family's consumption of 67.31 u.m. (CPU = 0.19 sec.).

Year / Solution	1	2	3	4	5	6	7	8
Land area (ha)								
Rice	5.40	31.98	—	38.53	6.47	—	—	—
Corn	1.07	6.55	6.47	—	—	38.53	6.47	38.53
Wheat	—	9.92	9.92	9.92	9.92	9.92	9.92	9.92
Soy-been	38.53	16.39	48.45	16.39	48.45	16.39	48.45	16.39
Man-hours	0.	0.	0.	0.	0.	0.	0.	0.

Table 20 – Proger_06, with seasonal family labor, IC = 600.00 u.m. and family's consumption of 89.42 u.m. (CPU = 0.19 sec.).

Year / Solution	1	2	3	4	5	6	7	8
Land area (ha)								
Rice	—	—	—	20	—	—	—	—
Corn	45	20	45	—	45	20	45	20
Wheat	30.9	35	35	35	35	35	35	35
Soy-been	50.9	80	55	80	55	80	55	80
Man-hours	0.	0.	0.	0.	0.	0.	0.	0.