A STUDY ON THE SELECTION OF AGRICULTURAL ADAPTIVE DEVELOPMENT AREAS USING GENETIC ALGORITHMS APPLIED TO MORE THAN ONE CROP

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ABSTRACT

Geographical information on large areas can be obtained in a macroscopic way based on image data of natural resource satellites. Application examples in agriculture, with experiments for selection of areas for agricultural development have been based on geographical information, and others related with soils and existing research on climate. However, the existent methods were efficient for a small number of areas, and for one crop only. This work selected areas for agricultural development for more than one crop using a genetic algorithms approach. With these algorithms, that are part of computational models inspired by nature, and used to solve search and optimization problems, maximization of the total net income of the planted crops was sought. The study area is located in the district of *Iraí de Minas*, and the production of two crops: soybean and corn was studied. In this model, the production of crops is a function of the application of basic inputs: lime and the fertilizer, as well as production costs. The quantities of these inputs were adjusted to the cost of the production systems of that region. The introduction of irrigation systems to avoid loss of production by drought was considered. With the evolution of genetic research, productivity of new varieties

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was also considered. The results show that the selection of agricultural adaptive development areas using genetic algorithms for more than one crop was made operational.

Key words: genetic algorithm, optimization, selection of agricultural adaptive development areas

1 Introduction

The question of where and how to develop agricultural areas and its products can be treated as an optimization problem solved through the selection of adaptive areas to the agricultural development.

Recently, geographical information of large areas can be obtained in a macroscopic way using image data of natural resource satellites. In agriculture, experiments of selection of adaptive areas for agricultural development can be seen in large areas, based on geographic information and information related with soil and data of existent research on climate. For example, a study conducted by Inagaki (1986) models and clarifies a selection method for rice. This study defined eight characteristics of the soil, and conditions of these characteristics, where they express the relationship between these soil characteristics and rice productivity with the minimum pathvector of the reliable theory of the multi-conditional coherent system. Later on, the cost of improvement of the conditions of these characteristics is estimated, and to face the general problem of optimization of the agricultural production and also minimize the total cost of development, a *Pareto* curve of the best solution is obtained (Inagaki, 1987). Inagaki's method is efficient when the number of divided areas is small; but in large regions where the number of divided areas is very large, it is difficult to find solution, due to an increase in the number of calculations. Consequently, even observing the problem of large-scale optimization, the fusion with methods that solve the optimization by approximation becomes indispensable. As an optimization method to solve such problem, the study of Yamamoto & Hoshi (1996) shows an experiment with the use of genetic algorithms.

In this new methodology using genetic algorithms, each chromosome has several genes that represent the variables corresponding to the characteristics of the soil at the study area. With the introduction of some phenotypes to increase the applicability of the genetic algorithms, and the evaluation function controlling the restricting conditions, the results, compared with those obtained by Inagaki, were considered tolerable. However, the referred study was not applied for more than one crop.

2 Objective

The objective of this study is to select adaptive areas for agricultural development by optimizing the total net income of planted crops through the use of genetic algorithms applied to more than one crop[3] .

3 Methodology

This research selects adaptive areas for agricultural development using evolutionary computational methods called Genetic Algorithms (GAs). These algorithms are very efficient in the search of optimal solution, or approximately optimal solutions, in a great variety of problems, because they do not impose many of the limitations found in the traditional search methods. The advantages of using GAs are that: a) they require no knowledge or gradient information about response surface; b) discontinuities present on response surface have little effect on overall optimization performance; c) they are resistant to becoming trapped in local optima; d) they perform very well for large-scale optimization problems; and e) they can be employed for a wide variety

[3] This study includes soybean and corn. Other crops are already being studied.

of optimization problems (Schaffer, 1999).

A rigorous definition of genetic algorithms accepted by the whole community of the evolutionary computation does not exist. According to Goldberg (1989), Whitley (1993), and Beasley (1993), GAs have been defined as being "search algorithms based on the mechanisms of natural selection and genetics", "a family of computational models inspired by the evolution", and "adaptive methods that can be used to solve search and optimization problems", respectively.

GAs form part of systems study inspired by nature, simulating the natural processes and applying to the solution of real problems. They are generalized search and optimization methods that simulate the natural processes of evolution, applying Darwin's idea of selection. Combined with other genetic operators, these methods produce great robustness and applicability. These algorithms are based on genetic processes of the biological organisms, by coding possible solution to a problem with chromosome composed by bit and character strings. Such chromosomes represent individuals that are taken along several generations, in a similar form to the natural problems, developed according with the principles of natural selection and survival of the fittest, described for the first time by Charles Darwin (1958 and 1994) in his book "On the Origin of Species" published by John Murray in 1859. Emulating these processes, GAs are able of evolve solutions to the real world problems. GAs were initially proposed by John Holland (1975) of the University of Michigan, and systematized by David E. Goldberg (1989), that modeled the biological evolution. Recently, several papers, covering a variety of topics, have been published (Back, 1996; Mitchell, 1997; Schaffer, 1999; Welstead, 1994; e Whitley, 1993).

The chromosomes, in a population of GAs, typically take the form of bit strings. Each locus of the chromosome has two possible alleles: 0 and 1. Each chromosome can be thought as being a point in the search space of solution of candidates. GAs processes the candidates' populations successively, substituting a population for another. Very frequently, GAs request an adaptation function, also called evaluation (fitness) function that scores each chromosome of the current population. The adaptation of a chromosome depends on how well it solves the problem in hand.

The basic principle of the operation of GAs is that a selection criterion will generate more capable chromosomes, after many generations. The natural selection guarantees that the most adapted chromosomes will spread to future populations. Besides the selection criterion, the most adapted chromosomes are also sought through genetic operators: mutation and recombination.

The simple form of a genetic algorithm involves three basic types of operators: selection, crossover (simple point), and mutation.

Selection: this operator selects chromosomes in the population for reproduction. The most adapted ones are selected more frequently to reproduce.

Crossover: this operator chooses randomly a locus, and exchanges the sequences before and after this locus among two chromosomes in order to create two offsprings. For example, the strings 10000100 and 11111111 could cross after the second locus, producing two offspring, 10111111 and 11000100. This crossover operator grossly imitates the biological recombination among two simple chromosomes (haploid). The crossover is generally not applied to all mated individuals selected. A random choice is made, where the likelihood of crossover (p_c) being applied is typically between 0.6 to 1.0 (Beasley, 1993). If crossover is not applied, the offsprings are produced simply by duplicating the parents, giving to each individual a chance of passing on its genes without the disruption of crossover.

Mutation: this operator randomly flips some bits in a chromosome. For example, the string 00000010 could be mutated in the third position, producing 00100010. Mutation can happen in each position of a string of bits under some probability (p_m), generally very small (typically, 0.001) (Beasley, 1993). Mutation is applied for each individual after the crossover. The traditional point of view is that the crossover is more important for the speed in exploring a search space, while mutation provides a small random search, ensuring that no point of the search space has a zero probability of being examined.

Given a defined problem clearly to be solved and a representation of bit strings for solution candidates, a simple genetic algorithm works in the following way:

i) start with a random generation of a population of n chromosomes with m-bits;

ii) evaluate the value of the adaptation of each chromosome in the population;

iii) repeat the following steps until n offspring have been created:

a) Select a pair of chromosome parents inside the current population, with the selection probability being directly proportional to its adaptation. The same chromosome can be selected more than one time to be a parent.

b) With crossover probability p_c, cross mated pair at a randomly chosen point to form two offsprings. If there is no crossing, two offspring are copied exactly as their parents.

c) Mutate the two offsprings at each locus with mutation probability p_m, and place the resulting chromosomes in the new population.

If n is odd, a new population member can be randomly discarded.

iv) Replace the current population with the new one;

v) Go to step ii).

Appendix 1 shows a flowchart of a simplified genetic algorithm with basic principles of the evolution of the individuals' population through time, applying the criterion of the most adapted individuals' selection, and crossover and mutation operators.

Each iteration of this process is called generation. The whole set of generations is called a run. At the end of a run there will be one or more chromosomes highly adapted in the population. If GAs are correctly implemented, the population evolves in successive generations in such a way that the adaptation of the best and the average score of the individuals in each generation increases in direction to a global optimum.

The problem of selecting areas for agricultural development is expressed by the following equations:

$$Y = \sum_{i=1}^{n} a_i y_i \quad (1)$$

$$R = \sum_{i=1}^{n} a_i r_i \quad (2)$$

$$C = \sum_{i=1}^{n} a_i c_i \quad (3)$$

Conditions: $(r_i - c_i) > 0 \quad (i = 1, \ldots, n) \quad (4)$

$$C < C_{disp} \quad (5)$$

Where:

Y: total production of the cultivated products
R: total gross profit of the cultivated products
C: total cost of the cultivated products
i: index of the cultivated product, where (i = 1,... n), and n = number of products
a_i: planted area of the product i
y_i: productivity per unit of area of the product i
r_i: gross income per unit of area of the product i
c_i: cost of the production per unit of area of the product i
C_{disp}: available capital of investment

The conditions are that the net income of the crops has to be positive (4), and that the total cost of production be smaller than the available capital of investment C_{disp}, expressed in the equation (5).

4 Materials

The study area of this work is the *Cerrado* region, specifically some plots of municipal district of *Iraí de Minas*, located in *Alto Paranaíba*, in the middle west of the State of *Minas Gerais*, with area of 358 km^2 and 4801 inhabitants (IBGE, 2000), at approximately 100 km east of the city of *Uberlândia*. Two crops were studied: soybean and corn. Productivity is considered to be a function of the quantity of lime applied for soil pH correction, besides the nutrients necessary to crop development, the new plant varieties developed by genetic research, and the cost of the construction of an irrigation system, to avoid losses with the *veranico*, that is, the prolonged drought days in rainy season in *Cerrado*.

The coding method for GA defines four variables for each plot in the *Iraí de Minas*, as shown in Figure 1, where a_i represents the percentage of area planted with product *i* in the cultivable area, and p_i is the quantity of phosphorus to produce *i*, at different productivity levels. With the existence of 21 plots, the whole area is represented by 84 variables. As each variable is expressed with 3 bits, a chromosome of the total region is represented by 252 bits.

|---|---|---|---|

a_1 p_1 a_2 p_2

Figure 1: four variables regarding to a plot

The *Iraí de Minas* was part of the Program for Development of the *Cerrados* (PRODECER), created to explore the development of new agricultural regions in Brazil, with the settling down that occurred between 1979 and 1982. The information about the plots, cultivable area, livestock area, and reserve areas (Table 1) were extracted from the map provided by the Company of Agricultural Promotion - Campo (1992/93).

As the soil treatment depends on its analysis, the initial data about soil for this region was obtained by contacting Campo, and later on with the Cooperative Copamil of *Iraí de Minas*. Since the original data was not accessible, the rightmost column of Table 1 was filled with the type of soil in each plot, referenced in studies conducted by Vilela (1978). Thus, the numbers 0 (zero) and 1 (one) represent two types of the most common soil in the region: Dark Red Latosol (LVE) and Yellow Red Latosol (LVA), respectively.

Table 1. Identification of plots, areas, and soil type.

Identification	Cultivable [ha]	Livestock [ha]	Reserve [ha]	Soil Type
lote-6	230.0	77.7	20.0	0
lote-7	289.0	0.0	0.0	0
lote-8	230.0	105.3	0.0	0
lote-9	204.5	87.9	20.0	0
lote-10	239.0	67.5	20.0	0
lote-11	240.0	11.0	20.0	0
lote-12	262.0	77.0	20.0	0
lote-13	256.0	81.0	0.0	0
lote-14	262.0	75.0	20.0	0
lote-15	265.0	79.3	0.0	1
lote-16	210.0	110.3	30.0	0
lote-17	216.0	66.1	20.0	1
lote-18	223.0	64.5	20.0	1
lote-19	211.0	61.5	47.0	1
lote-20	226.0	76.0	20.0	1
lote-21	244.0	70.5	20.0	1
lote-22	262.0	71.5	20.0	1
lote-23	255.0	73.5	20.0	1
lote-24	292.0	75.1	20.0	1
lote-25	240.0	43.6	31,5	1
lote-26	210.0	75.8	30.0	1

Source: Campo, 1992/3; and Vilela, 1978

Table 2 shows the amount of lime applied according to the soil's chemical characteristics. The amounts of corrective fertilization are: 240 kg of P_2O_5, and 100 kg of K_2O (Souza, 1984).

Table 2. Data of chemical analysis of Dark Red Latosol (LVE) and Yellow Red Latosol (LVA) in natural conditions, and after respective application of 4 ton of limes/ha in LVE and 2,5 ton/ha in LVA.

Chemical characteristics	Natural soil		Soil after limes and phosphor applications		
			6 months		12 months
	LVE	LVA	LVE	LVA	LVE
pH	4,5	4,7	5,2	5,2	5,2
Al3+ (meq/100g)	0,90	0,43	0,20	0,05	0,05
Ca2+ + Mg2+ (meq/100g)	0,40	0,25	2,90	2,20	2,50
K (ppm)	25	21	52	21	38
P (ppm)	0,5	traces	1,0	1,5	traces
Sat.Al(%)	66	59	6	2	7

Source: Vilela, 1978

The soybean yield varying as a function of the quantity of phosphorus applied is presented in Table 3.

Table 3. Yield of soybean in function of quantity of phosphor applied.

seed variety: UFV-1	
P_2O_5 [kg/ha]	Yield [kg/ha]
0	77
150	2020
300	2488
600	2993
1200	3159

Source: Vilela, 1978

The present study uses the production system of soybean related to the region of *Cerrado* (EMBRAPA-a, 1998). The production cost per hectare, excluding those with the application of lime, phosphorus, and potassium, amounts to R$ 479.43 (US$ 1.00 = R$ 1.80 (reais)). The amount of lime indicated for this system is of 800 kg, and the quantities of phosphorus and of potassium are both equal to 60 kg.

Table 4 shows the adjustment of the productivity of the soybean with this new quantity of phosphorus, centralized on 2.020 kg per hectare; which means that in this productivity row, the originally applied phosphorus (150) is transformed to the new value of the production system (60). All other original phosphorus quantities are analogously adjusted according to the production system data, resulting in new quantities that are presented in column two of Table 4.

Table 4. Adjustment of the yield of the soybean in function of the phosphor quantity.

Original quantity of phosphor [kg]	Adjusted quantity of phosphor [kg]	Yield [kg/ha]
0	0	77
150	60	**2020**
240	96	2300
300	120	2488
600	240	2993
1200	480	3159

Here, one more crop is included - the corn – such that its yield is a function of the quantity of phosphorus applied as shown on Table 5 (Miranda, 1980).

Table 5. Corn yield, according to the quantity of phosphorus applied

phosphor quantity [kg/ha]	Yield [kg/ha]
40	2260
160	5230
320	6270
640	6790
1820	7960
2000	8300

Source: Miranda, 1980

The study has also used data of the corn production system for the *Cerrado* region (EMBRAPA-b, 1998). The production cost per hectare, excluding lime, nitrogen, phosphorus, and potassium inputs, is equal to R$ 238.36. The quantity of lime indicated for this system is of 1 tone, and the amount of fertilizers are of 10 kg for nitrogen, 50 kg for phosphorus, and 50 kg for potassium. Table 6 shows the corn yield readjusted with this new amount of phosphorus, centralized in 2.260 kg per hectare; that is, in this yield row, the originally applied phosphorus (40) is transformed to the new value of the production system (50). All other original phosphorus quantities are analogously readjusted, resulting in the new quantities in central column.

Table 6. Adjustment of the yield of corn in function of the phosphorus quantities.

Phosphor quantity [kg]	Readjusted quantity [kg]	Yield [kg/ha]
40	50	**2260**
160	200	5230
320	400	6270
640	800	6790
1820	2275	7960
2000	2500	8300

The input and products prices obtained at the FNP site (2000), regarding the city of *Uberlândia*, are listed in Table 7. The researcher Dr. Edson Lobato, from Embrapa Cerrados Research Center supplied the percentage amounts of nutrients inside of the marketed fertilizers.

Table 7. Prices of input and products of the region of Uberlândia at July 6, 2000.

Product	Price per ton [R$]	Price per kg [R$]
Nitrogen (*Uréia Agrícola* : 45%)	385.00	0.86
Phosphor (*Fosfatado Supertriplo* : 45%)	357.00	0.79
Potassium (*Cloreto de Potássio*: 60%)	376.00	0.63
Limes (*Dolomílico*)	8.50	
Corn		0.18
Soybean		0.27

Source: FNP, 2000

The agricultural production loss caused by the *veranico* in the *Cerrado* could reach 40% for corn, and 20% for soybean, according to Brazilian Agricultural Research Corporation – EMBRAPA (1984). The *veranico* frequency, verified on 42 years of historical data for the Federal

District area (Wolf, 1977) is shown in Table 8. Here, the irrigation system is introduced to the model as one more variable to be controlled by the evaluation function of GA, with the cost of US$ 600.00 per hectare. These information were provided by Dr. Edson Eiji Matsura, of the Department of Water and Soil of the Faculty of Agricultural Engineering of the University of Campinas. It is assumed that the irrigation system can be used for 20 years, such that its cost was first divided by 20 years, and also for two crops a year. As the largest production loss occurs with 22 or more days of drought, this work adopts losses of 13 or more days as an average frequency for a year. As a result, the production loss is about 23,6% of corn, and 11,8% of soybean, in case of not considering the use of irrigation system.

Table 8. *Veranico* frequency in *Distrito Federal.*

Drought period	frequency
8 or more days	3 per year
10 or more days	2 per year
13 or more days	1 per year
18 or more days	2 in 7 years
22 or more days	1 in 7 years

Source: Wolf, 1977

Considering the evolutions in genetic research for seeds, the productivity of these new varieties of soybean was used in this analysis. By taking the average of two varieties: BR 91-8762, with average productivity of 3672 kg/ha and EMBRAPA 65, with average productivity of 3540 kg/ha (Silva, 1998), an average productivity of about 3606 kg/ha was obtained for the new variety of soybean. This adjustment is shown in Table 9, centralized in the maximum productivity value of 2993 kg/ha; which is the original productivity (2993) readjusted for the new productivity (3606). All other productivity values were adjusted proportionally, resulting in the new productivity values in the rightmost column.

Table 9. Readjustment of the soybean productivity using a new variety

Phosphor quantity [kg]	Original productivity [kg/ha]	Readjusted productivity [kg/ha]
96	2300	2760
120	2488	2985
240	**2993**	3606

5 Results

The parameters for running the genetic algorithm, in this study, were maintained as population of 1,000 chromosomes; number of generations = 1,000,000; probability of crossover pc = 0.05; and probability of mutation pm = 0.0001. The percentages of area considered adequate for cultivation were restricted to values of 0, 10, 20, 30, 40, 50, 75 and 100%.

Table 10 presents the summary of the results obtained with GA in this model, using the existing published data about soybean productivity as a function of lime and fertilizer application that were shown in the Tables 1, 2 and 3. The leftmost column indicates the phosphorus quantity per hectare. The 'cost per ha' is the value of the amount of phosphorus multiplied by its unit value. The third column indicates the cost per hectare of lime, phosphorus, and potassium input. The following column indicates the total cost, including the cost of soybean production. The soybean yield indicated in column 5, multiplied by the unit value of soybean, results in the column of the 'gross income per ha'. The net income is therefore the value of the difference between the gross income and the total cost.

Table 10. The result of the run of GA with original data of soybean.

Phosphor [kg]	Cost per ha [R$]	Cost (Lime+ + NPK)/ha [R$]	Cost per ha [R$]	Yield [kg/ha]	Gross income per ha [R$]	Net income per ha [R$)]
0	0.00	121.44	600.87	77	20	-580
150	119.00	2064.44	2543.87	2020	545	-1998
240	190.39	2344.44	2823.87	2300	621	-2203
300	237.99	2532.44	3011.87	2488	671	-2340
600	475.98	3037.44	3516.87	2993	808	-2709
1200	951.96	3203.44	3682.87	3159	852	-2830

Source: A summarized report from the run of GA for soybean.

It can be noticed that all results of net income are negative. Thus, adjustments for the phosphorus quantities according to the production system for soybean, are indicated in Table 4, and the summary of the new run of GA is shown in Table 11.

Table 11. The result of the run of GA with readjusted data of soybean.

Phosphor [kg]	Cost per ha [R$]	Cost (Lime+ +NPK)/ ha [R$]	Cost per ha [R$]	Yield (kg/ha)	Gross Income per ha (R$)	Net Income per ha (R$)
60	47.60	92.04	571.47	2020	545	-26,07
96	76.16	120.60	600.03	2300	621	20,97
120	95.20	139.64	619.07	2488	671	52,69
240	190.39	234.83	714.26	2993	808	93,85
480	380.78	425.22	904.65	3159	852	-51,72

Source: A summarized report of the new run of GA for soybean.

It can be noticed that positive and negative net incomes are expressed by the results obtained. The evaluation function of the genetic algorithm is adjusted to the condition of the methodology of this study. Equation (4) is satisfied, limiting the quantity of phosphorus applied to the amounts of lucrative incomes. Next, a GA with the original corn data, shown in the Table 5. The results are presented in Table 12.

Table 12. Result of the run of GA with corn original data.

Phosphor [kg]	Yield [kg/ha]	Net income /ha [R$]
40	2,260	-1,998
160	5,230	-1,556
320	6,270	-1,495
640	6,790	-1,655
1,820	7,960	-2,379
2,000	8,300	-2,461

Source: A summarized report of the run of GA for corn.

These results show that negative net incomes may also be obtained. Adjusting the amounts of phosphorus according to the production system for corn, as indicated in the Table 6, one obtains the results presented in Table 13.

Table 13. Results of the run of GA with readjusted data of corn.

Phosphor [kg]	Cost per ha [R$]	Cost (lime+ + NPK)/ha [R$]	Cost per ha [R$]	Yield [kg/ha]	Gross income per ha [R$]	Net income per ha [R$]
50	39.67	88.05	326.41	**2020**	408.70	82
100	79.33	127.72	366.07	3311	598.76	233
200	158.66	207.05	445.40	5230	945.79	500
300	237.99	286.38	524.73	5808	1050.32	526
400	317.32	365.71	604.06	6270	1133.87	530
800	634.64	683.03	921.38	6790	1227.90	307
2275	1804.76	1853.14	2091.50	7960	1439.49	-652
2500	1983.25	2031.64	2269.99	8300	1500.97	-769

Source: A summarized report of the new run of GA for corn.

The existence of positive and negatives net incomes can also be verified in these results. The evaluation function of genetic algorithm is therefore adjusted to the condition of the methodology of this study. Equation (4) is also satisfied, such that the quantities of phosphorus application is limited to the amount of profitable incomes.

Several levels of profit realized with soybean according to the quantities of phosphorus applied to the soil, and consequently due the losses with the *veranico*, are shown in Table 14.

Table 14. Net profit /ha of the soybean with several days of drought(R$).

Phosphor	Without loss	Loss of 20% of the production	Loss 10% of the production	Loss 5% of the production	With irrigation
96 kg/ha	21.01	-103.19	-41.09	-10.04	-5.99
120 kg/ha	52.73	-81.62	-14.45	19.14	25.73
240 kg/ha	93.89	-67.73	13.08	53.48	66.89

Source: A summarized report for soybean, with losses due to *veranico.*

The profitability of soybean considering the phosphorus application, the losses with *veranico*, and using new variety of soybean (Table 9), is shown in Table 15.

Table 15. Net profit/ha with the new variety of soybean (R$).

Phosphor	Without loss	Loss of 20% of the production	Loss 10% of the production	Loss 5% of the production	With rrigation
96 kg/ha	145.21	-3.83	70.69	107.95	118.21
120 kg/ha	186.92	25.73	106.33	146.62	159.92
240 kg/ha	259.40	64.68	162.04	210.72	232.40

Source: A summarized report for the new variety of soybean, and with losses due to the *veranico*

Table 16 presents the profitability of corn according to amount of phosphorus applied in the soil, and due to the losses with *veranico.*

Table 16. The net profit/ha of the corn with several days of drought(R$).

Phosphor (kg/ha)	Without loss	Loss of 40% of the production	Loss of 20% of the production	With irrigation
50	82.29	-81.19	0.55	55.29
100	232.69	-6.81	112.94	205.69
200	500.39	122.07	311.23	473.99
300	525.59	105.46	315.52	498.59
400	529.81	76.26	303.03	502.81

Source: A summary of the run of GA with corn, and with losses due to *veranico.*

The result of the run of GA including corn and soybean is shown in Table 17. To avoid risks of crop losses due to the veranico, mainly with the single crop, the planting area can be restricted in many levels (10%, 20%, ..., 90%), and this work adopted to plant a maximum of 60% of corn. The average year loss of the production of the crops due to the veranico is also included in this result.

Table 17. Net profit (without irrigation) in function of the available capital of investment (in thousand R$). Considering losses of 23.6% in corn, and 11.8% in soybean due to the *veranico* of 13 days.

Available capital [R$]	Expenses [R$]	Gross profit [R$]	Net profit [R$]
3,000	2,654	4,327	1,673
2,000	1,998	3,384	1,386
1,000	997	1,692	695
500	497	847	350
100	98	168	70

Source: A summary of the run of GA, in case of not existing irrigation systems

The result of the run of GA including two crops, corn and soybean, subject to the restriction of planted area of corn, including the cost of irrigation system considering that there are no crop production losses due to the *veranico*, is shown in Table 18.

Table 18. Net profit (with irrigation) in function of the capital of investment (in thousand R$).

Available capital [R$]	Expenses [R$]	Gross profit [R$]	Net profit [R$]
3,000	2,990	5,041	2,051
2,000	1,998	3,447	1,449
1,000	999	1,725	728
500	497	862	365
100	98	170	72

Source: A summarized result of the run of GA, with the existence of the irrigation system.

The Appendixes 2a and 2b show the results of the run of GA for an available capital of R$ 2,000,000.00, and when irrigation systems do not exist. The losses with the *veranico* happen with 11.8% in the production of the soybean, and 23.6% in the production of the corn. The Appendixes 3a and 3b show the results of GA for an available capital of R$ 3,000,000.00, with the existence of irrigation systems. The leftmost column identifies the plots of the area of this study, with total cultivable area together. The next column, *area*, is the planted area, in hectare; the *dsp/ha* indicates the expenses of this product; the *despesa* indicates the total expenses; the *rec./ha* indicates the gross income; the *receita* indicates the total gross income; *Rd/ha* indicates the net income per hectare; and *Renda* indicates the total net income, all in the same plot.

6 Conclusion and Recommendations

The area selection for agricultural development, considering net income optimization of total production, with the use of genetic algorithms applied on more than one crop was made operational.

It was necessary to adjust the fertilizers and lime quantities based on production systems to the respective agricultural products, such that the results became realizable values. The new soybean variety was also introduced, since yield changes with the evolution of genetic research. The losses with *veranico* in *Cerrado* were also considered, since the occurrence is not rare.

The model was restricted to the application of basic inputs, such as lime and fertilizers, and more specifically dependent on the levels of quantities of phosphorus applied to the soil, since these nutrients are very important for the agricultural cultivation in *Cerrado*. The other limitation was the percentage use for cultivable area that was predefined to use only the values 0, 10, 20, 30, 40, 50, 75 and 100%. For planting two crops, it was placed inside of the evaluation function the restriction of planting at most 60% of the area with corn. Without this restriction, the GA would choose to plant only the product with best profitability. This last restriction can be defined with other percentile values, and the larger its value, the larger the risk of loss of the crop with the veranico.

In this work it was also tried several values of parameters for the operation of GAs, which were standardized to be run with a population of 1,000 chromosomes, in 1,000,000 generations, with values of 0.05 for crossover probability, and of 0.0001 for mutation probability. The variation of these parameters results in some small variation in the total profit, but among several variations of these values, such parameter values were the most effective in presenting the results, and also in the time consumption of computational processing.

The number of variables was small for the potential use of genetic algorithms, and can be increased: in the number of new variables that can influence the productivity of the product; in the number of plots or areas of agricultural development; in the flexibility in choosing land use percentile of corn and soybean, that values can be amplified by the number of divisions; and mainly with the increase of the number of crops.

Many articles have been written about the advantages of the GAs in comparison to other optimization methods, and it is not seen many practical advantages of some on the other ones (Schaffer, 1999). To have an optimization method that works in the best performance it is necessary to make some experiments with its configurations or with the optimization parameters, and a poor choice of these parameters can result in poor search performance. In this work, the possibility of using genetic algorithms for the selection of adaptive areas for agricultural development for more than one crop was evidenced.

The flexibility in choosing planted areas, the incorporation of new variables that determine the productivity, the more detailed characteristics of soils of different geographical areas, the capacity of the production administration, and addition of new crops, are objects of future studies.

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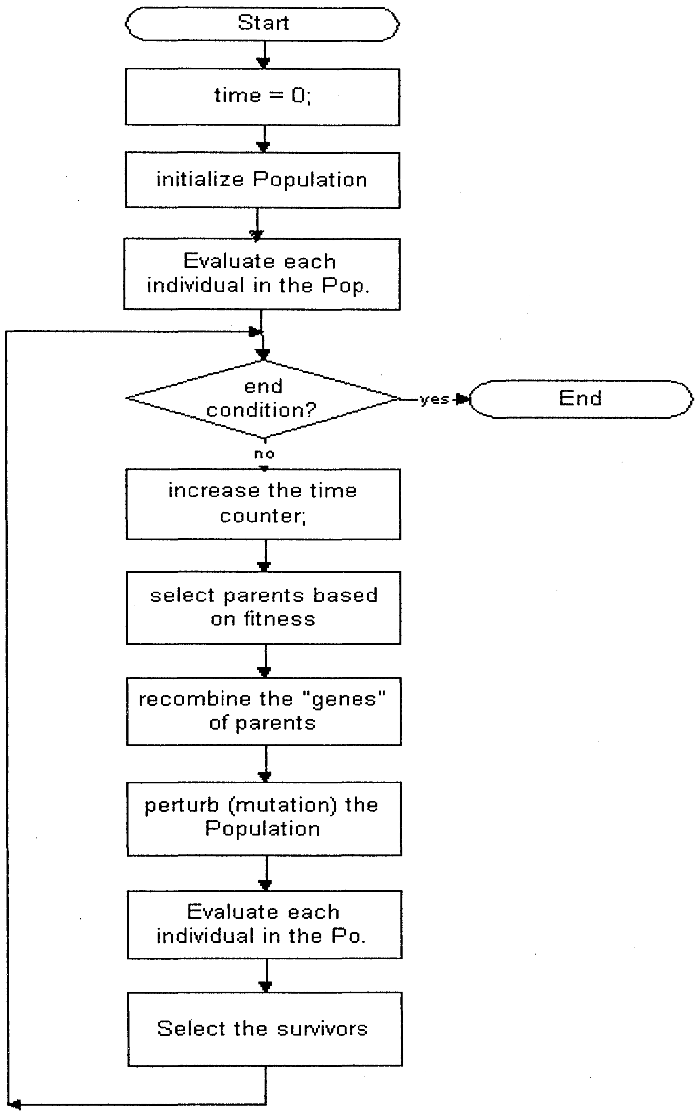
Appendix

Appendix 1: A Simplified Genetic Algorithm



Appendix 2a- Report for Soybean (for R$ 2,000,000.00 of available capital of investment)

lotenn[a.lav]:	*area*	*dsp/ha*	*despesa*	*rec./ha*	*receita*	*Rd/ha*	*Renda*
lote 1[289.0]:	115.6	619.03	71559.87	710.85	82174.02	91.82	10614.15
lote 2[230.0]:	92.0	619.03	56950.76	710.85	65398.01	91.82	8447.25
lote 3[204.5]:	81.8	599.99	49079.18	657.27	53764.39	57.28	4685.21
lote 4[239.0]:	38.2	599.99	22943.62	657.27	25133.87	57.28	2190.25
lote 5[240.0]:	96.0	619.03	59426.88	710.85	68241.40	91.82	8814.52
lote 6[262.0]:	104.8	619.03	64874.34	710.85	74496.86	91.82	9622.52
lote 7[256.0]:	102.4	619.03	63388.67	710.85	72790.83	91.82	9402.16
lote 8[262.0]:	104.8	619.03	64874.34	710.85	74496.86	91.82	9622.52
lote 9[265.0]:	106.0	619.03	65617.18	710.85	75349.88	91.82	9732.70
lote10[210.0]:	84.0	599.99	50399.16	657.27	55210.38	57.28	4811.22
lote11[216.0]:	86.4	599.99	51839.14	657.27	56787.82	57.28	4948.68
lote12[223.0]:	89.2	619.03	55217.47	710.85	63407.63	91.82	8190.16
lote13[211.0]:	84.4	619.03	52246.13	710.85	59995.56	91.82	7749.43
lote14[226.0]:	90.4	619.03	55960.31	710.85	64260.65	91.82	8300.34
lote15[244.0]:	97.6	619.03	60417.32	710.85	69378.76	91.82	8961.43
lote16[262.0]:	104.8	599.99	62878.95	657.27	68881.52	57.28	6002.57
lote17[255.0]:	102.0	619.03	63141.06	710.85	72506.48	91.82	9365.43
lote18[292.0]:	116.8	619.03	72302.70	710.85	83027.04	91.82	10724.33
lote19[240.0]:	38.4	599.99	23039.62	657.27	25239.03	57.28	2199.42
lote20[210.0]:	71.4	619.03	44198.74	710.85	50754.54	91.82	6555.80

Appendix 2b- Report for corn (for R$ 2,000,000.00 of available capital of investment)

lotenn[a.lav]:	*area*	*dsp/ha*	*despesa*	*rec./ha*	*receita*	*Rd/ha*	*Renda*
lote 1[289.0]:	173.4	445.40	77232.53	722.59	125296.41	277.18	48063.88
lote 2[230.0]:	138.0	445.40	61465.34	722.59	99716.87	277.18	38251.53
lote 3[204.5]:	122.7	445.40	54650.70	722.59	88661.30	277.18	34010.60
lote 4[239.0]:	57.4	445.40	25548.20	722.59	41447.54	277.18	15899.33
lote 5[240.0]:	144.0	445.40	64137.74	722.59	104052.38	277.18	39914.64
lote 6[262.0]:	157.2	445.40	70017.04	722.59	113590.52	277.18	43573.48
lote 7[256.0]:	153.6	445.40	68413.59	722.59	110989.21	277.18	42575.62
lote 8[262.0]:	157.2	445.40	70017.04	722.59	113590.52	277.18	43573.48
lote 9[265.0]:	159.0	445.40	70818.76	722.59	114891.17	277.18	44072.41
lote10[210.0]:	126.0	445.40	56120.53	722.59	91045.84	277.18	34925.31
lote11[216.0]:	129.6	445.40	57723.97	722.59	93647.15	277.18	35923.18
lote12[223.0]:	133.8	445.40	59594.66	722.59	96682.01	277.18	37087.36
lote13[211.0]:	126.6	445.40	56387.77	722.59	91479.38	277.18	35091.62
lote14[226.0]:	135.6	445.40	60396.38	722.59	97982.66	277.18	37586.29
lote15[244.0]:	146.4	445.40	65206.70	722.59	105786.59	277.18	40579.88
lote16[262.0]:	157.2	445.40	70017.04	722.59	113590.52	277.18	43573.48
lote17[255.0]:	153.0	445.40	68146.35	722.59	110555.66	277.18	42409.30
lote18[292.0]:	175.2	445.40	78034.26	722.59	126597.06	277.18	48562.81
lote19[240.0]:	57.6	445.40	25655.10	722.59	41620.95	277.18	15965.86
lote20[210.0]:	107.1	445.40	47702.45	722.59	77388.96	277.18	29686.51

Appendix 3a- Report for Soybean (for R$ 3,000,000.00 of available capital of investment)

lotenn[a.lav]:	*area*	*dsp/ha*	*despesa*	*rec./ha*	*receita*	*Rd/ha*	*Renda*
lote 0[230.0]:	92.0	714.22	65708.23	973.62	89573.04	259.40	23864.80
lote 1[289.0]:	115.6	714.22	82563.83	973.62	112550.47	259.40	29986.64
lote 2[230.0]:	92.0	714.22	65708.23	973.62	89573.04	259.40	23864.80
lote 3[204.5]:	81.8	619.03	50636.65	805.95	65926.71	186.92	15290.06
lote 4[239.0]:	95.6	714.22	68279.43	973.62	93078.07	259.40	24798.64
lote 5[240.0]:	96.0	714.22	68565.12	973.62	93467.52	259.40	24902.40
lote 6[262.0]:	104.8	619.03	64874.34	805.95	84463.56	186.92	19589.22
lote 7[256.0]:	102.4	714.22	73136.12	973.62	99698.69	259.40	26562.56
lote 8[262.0]:	104.8	619.03	64874.34	805.95	84463.56	186.92	19589.22
lote 9[265.0]:	106.0	599.99	63598.94	745.20	78991.20	145.21	15392.26
lote10[210.0]:	84.0	714.22	59994.48	973.62	81784.08	259.40	21789.60
lote11[216.0]:	86.4	714.22	61708.61	973.62	84120.77	259.40	22412.16
lote12[223.0]:	89.2	714.22	63708.42	973.62	86846.90	259.40	23138.48
lote13[211.0]:	84.4	714.22	60280.17	973.62	82173.53	259.40	21893.36
lote14[226.0]:	90.4	714.22	64565.49	973.62	88015.25	259.40	23449.76
lote15[244.0]:	97.6	714.22	69707.87	973.62	95025.31	259.40	25317.44
lote16[262.0]:	104.8	619.03	64874.34	805.95	84463.56	186.92	19589.22
lote17[255.0]:	102.0	714.22	72850.44	973.62	99309.24	259.40	26458.80
lote18[292.0]:	116.8	619.03	72302.70	805.95	94134.96	186.92	21832.26
lote19[240.0]:	96.0	619.03	59426.88	805.95	77371.20	186.92	17944.32
lote20[210.0]:	84.0	619.03	51998.52	805.95	67699.80	186.92	15701.28

Appendix 3b- Report for Corn (for R$ 3,000,000.00 of available capital of investment)

lotenn[a.lav]:	*area*	*dsp/ha*	*despesa*	*rec./ha*	*receita*	*Rd/ha*	*Renda*
lote 1[289.0]:	173.4	445.40	77232.53	945.79	164000.53	500.39	86768.01
lote 2[230.0]:	138.0	445.40	61465.34	945.79	130519.46	500.39	69054.12
lote 3[204.5]:	122.7	604.06	74118.28	1133.87	139125.45	529.81	65007.18
lote 4[239.0]:	143.4	524.73	75246.42	1050.32	150615.70	525.59	75369.27
lote 5[240.0]:	144.0	604.06	86984.78	1133.87	163276.83	529.81	76292.04
lote 6[262.0]:	157.2	445.40	70017.04	945.79	148678.69	500.39	78661.66
lote 7[256.0]:	153.6	604.06	92783.77	1133.87	174161.95	529.81	81378.18
lote 8[262.0]:	157.2	524.73	82487.71	1050.32	165110.09	525.59	82622.38
lote 9[265.0]:	159.0	604.06	96045.70	1133.87	180284.83	529.81	84239.13
lote10[210.0]:	126.0	524.73	66116.11	1050.32	132340.16	525.59	66224.05
lote11[216.0]:	129.6	604.06	78286.30	1133.87	146949.14	529.81	68662.84
lote12[223.0]:	133.8	604.06	80823.36	1133.87	151711.39	529.81	70888.02
lote13[211.0]:	126.6	445.40	56387.77	945.79	119737.42	500.39	63349.65
lote14[226.0]:	135.6	524.73	71153.53	1050.32	142423.22	525.59	71269.70
lote15[244.0]:	146.4	524.73	76820.62	1050.32	153766.66	525.59	76946.04
lote16[262.0]:	157.2	524.73	82487.71	1050.32	165110.09	525.59	82622.38
lote17[255.0]:	153.0	524.73	80283.84	1050.32	160698.77	525.59	80414.92
lote18[292.0]:	175.2	445.40	78034.26	945.79	165702.97	500.39	87668.71
lote19[240.0]:	144.0	524.73	75561.27	1050.32	151245.89	525.59	75684.63
lote20[210.0]:	126.0	524.73	66116.11	1050.32	132340.16	525.59	66224.05