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Using Genetic Algorithms to Outline Crop Rotations and a Cropping-System Model

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***Abstract*—**The idea of cropping-system is a method used by farmers. It is an environmentally-friendly method, protecting the natural resources (soil, water, air, nutritive substances) and increase the production at the same time, taking into account some crop particularities. The combination of this powerful method with the concepts of genetic algorithms results into a possibility of generating sequences of crops in order to form a rotation. The usage of this type of algorithms has been efficient in solving problems related to optimization and their polynomial complexity allows them to be used at solving more difficult and various problems. In our case, the optimization consists in finding the most profitable rotation of cultures. One of the expected results is to optimize the usage of the resources, in order to minimize the costs and maximize the profit. In order to achieve these goals, a genetic algorithm was designed. This algorithm ensures the finding of several optimized solutions of cropping-systems possibilities which have the highest profit and, thus, which minimize the costs. The algorithm uses genetic-based methods (mutation, crossover) and structures (genes, chromosomes). A cropping-system possibility will be considered a chromosome and a crop within the rotation is a gene within a chromosome. Results about the efficiency of this method will be presented in a special section. The implementation of this method would bring benefits into the activity of the farmers by giving them hints and helping them to use the resources efficiently.

***Keywords*—**Genetic algorithm, chromosomes, genes, cropping, agriculture.

I. INTRODUCTION

CROPPING-systems, low or no-tillage, ecological methods, low usage of pesticides, organic fertilizers are the new directions of the development in agriculture, leaving behind the industrial type of agriculture, which had a main and only purpose: obtaining a higher production by all means. In this matter, it can be seen a recurrence of “communion with nature” in the mentality of farmers, taking into account the relation with environmental factors. As well as protecting nature, these methods bring an increase in productivity, with the advantage of obtaining healthier products and a higher profit. Cropping-systems are presented in detail in the book [1].

The need of information in this domain is vast. The association of agriculture with technology and new discoveries in exact sciences creates new opportunities for developing mathematical structures and technologic implementations for agricultural issues. So, besides the traditional sources of information, there is contoured a modality of obtaining and modeling concepts in agriculture from a different point of view, with more and more optimized results. This is a reason for which we chose to approach the issue of crop rotation using genetic algorithms. Because this method is used in optimization problems and has many practical applications in solving various problems, genetic algorithms were a good choice of generating rotations of cultures. The optimization refers to finding the highest profit from a cropping-system possibility. The major challenge is to find this profit by respecting the cropping-system rules, which represents quite major restrictions for the method.

This paper will present the generation of rotation possibilities using algorithms inspired from genetics and we will focus on the order of crops within the cropping-system. Section II will contain reasons and experimental data for supporting the choice of cropping-systems in agriculture from an environmental point of view (effects on nutritive substances and physical proprieties of the soil). In Section III, we will shortly introduce and sketch concepts about genetic algorithms, followed by other research about cropping-systems and genetic algorithms made in the scientific world in Section IV. We will describe in the Section V the way we applied genetics for generating crop rotations. Section VI will contain some results obtained using the implementation described in the previous section and we will show the performance of the structure of genetic algorithms. In the end, we will draw some conclusions and outline some future work for this direction.

We choose this theme for the paper because the importance of the rotation within the methods of improving the productivity in agriculture, among other important measures and methods. It is also part of a sequence of papers that study the rotation of cultures using various methods, such as backtracking generation [2] and random generation [3].

II. THE EFFECTS OF CROPPING-SYSTEM ON THE ENVIRONMENT

The cropping-system and the rotation of the cultures are studied in various papers. The effects on the environment are beneficial, influencing the fertility of the soil, the pests, the diseases and other variables. Effects of cropping systems are studied and presented in paper [4]. An important term which can be introduced in this paper is the durable agriculture, which, in few words, means that the soil, the base of the agriculture, and the environment in its integrality must be used rationally and kept usable for future generations. The durable

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agriculture is an integrant part of a bigger concept which includes the durable development in all areas of work.

The cropping-system can be used on all types of soils. In paper [5], a study made on acid soils shows the beneficial effects of the rotation of cultures for the production and the fertility of the soil. The rotation of cultures also has positive effects on the fertility of the soil.

Another important effect of the cropping-system over the soil is reducing the weed percentage and the attack of pests and diseases within the parcel. Different crops have different weeds, different pests and different diseases, thus their rotation reduces the attack of pests over the plants needed. Cropping system effects over the environment are studied more in the paper [6]. A study regarding rotation and minimum tillage effects over the cultures are presented in paper [7].

The economic aspect of the cropping-systems is represented by the higher of productivity than in case of mono-culture. This aspect is a result of the reduced effect of pests and diseases, thus remaining a better potential for the crop to grow nicely and richer in mass and quality. Economic aspects of a corn-beans cropping-system are shown in [8] and [9].

Simulations of cropping systems and mineral substances budget are made in various papers. One of them is made in [10]. Another experiment which shows the production increase as a result of cropping-system usage is shown in [11].

Generally, when the rotation is applied, the production increases. As a result, the profit in the holding increases too, because the quantity of product is higher.

III. About Genetic Algorithms

Genetic algorithms were firstly designed in early 1950s, being inspired from biology and genetics [12]. They use structures and methods from nature integrated and translated in a computer language. In this matter, these types of algorithms use chromosomes and genes as structures, mutations and crossovers as genetic operators in the same way a live cell uses them to carry information.

The genetic algorithms are used in various domains, from agriculture to irrigation system, [13], web applications [14], for generating an institution schedule [15], in combinatorics [16], [17].

A genetic algorithm has a general structure which contains several components:

- An initial population of individuals (also called chromosomes)
- A fitness function, which is the function to be minimized or maximized
- Data structures (chromosomes and genes)
- Genetic operators (mutation, crossover, selection)
- The solutions are heuristically formed and the optimal one is found after a number of generations. Now, we will shortly present the components.

The initial population contains data structures, also called chromosomes. After using operators, the individuals are modified (obtain descendants from parents), which can maximize / minimize the fitness function. It can be obtained by generating.

The fitness function helps in selecting chromosomes. It has a form of a mathematical function which helps at the calculation of the fitness of every chromosome.

Individuals are usually in a binary form, containing data converted form other bases. There are cases when the information carried is not binary, such as in our example. A gene is a bit from a chromosome.

Operators are used to modify chromosomes and select those which have the greatest fitness. Mutation is the modification of one gene and its shift with another one within the same chromosome. Crossover is the shift between a part of a chromosome with the correspondent part of another chromosome, using one or more crossover points. Selection is the sorting operation of the chromosomes based on their fitness and has different methods. Yet, we must keep the proportions, because the complexity of the natural principles and operations are hard to be reached. Even so, genetic algorithms are used to solve NP-complete problems in various domains such as in agriculture, in our case.

GAs were chosen in this case, compared to other algorithms based on methods such as backtracking and random generation.

IV. Description of the Genetic Algorithm and the Mathematical Model

The genetic algorithm we used has several components. Firstly, we will describe the input data used by the algorithm, then we will show the process of obtaining solutions and then we will give examples of output data.

The structures we need for starting the process are:

- the number of crops, denoted in the paper by n;
- the number of parcels = the number of crops used in the rotation, denoted by m;
- the number of solutions to be output (k);
- the surface of the area (denoted by HA);
- the crops, represented in the paper as numbers from 1 to n; every crop is associated with a number (e.g. wheat – 1, corn – 2 etc.);
- the costs for every culture expressed in lei (represented by an array with n double-type elements):
- cost[n] = (cost1, cost2, …, costn), costk = the cost made for the culture k
- the selling price for every culture expressed in lei / kg, (also a double-type array)
- price[n] = (price1, price2, …, pricen), pricek = the selling price for culture k
- the production for every culture expressed in kg (a double-type array)
- prod[n] = (prod1, prod2, …, prodn), prodk = the production for culture k

In this paper, we introduce the notion of leaping sola, which has important role in the holding, because it also protects the soil and provide food for animals. The leaping sola is cultivated with perennial plants (e.g. alfalfa, clover) or left uncultivated as pasture. These types of culture help the soil to rest and redo its reserve in nutritive substances. For

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introducing this notion, we also have special containers of data. In this matter, we use:

- leap, representing the number of crops used for the leaping sola;
- the name of the crops used for cultivating the leaping sola.

The leaping sola will not generate direct profit, but they can be used as fodder, if the farm has a zootechnical department, or sold as fodder to other farms. The leaping sola is not an actual part of the cropping-system, its name giving the impression of the fact that the soil is kind of resting from the actual production. For a better output, we will use a string-type array which contains the name of the crops. The variable Nr_pop will store the total number of chromosomes in the population. The chromosomes will be stored in a bi-dimensional array denoted by pop[Nr_pop][m], with the next symbolization:

- pop[i] = a chromosome / a solution which represents a rotation possibility, i = 1, Nr_pop.
- pop[i][j] = k, k=1,n (a gene / a culture from within a rotation, i=1, Nr_pop; j=1,m)

The genes of the chromosome will contain numbers from 1 to n and not binaries. The initial population is obtained by random generation. In our case, the fitness function calculates the profit of every chromosome. It has the next form:

Being a genetic algorithm, we will need a fitness function.

$$f(pop[i]) = \sum_{j=1}^{m} price\big[pop[i][j]\big] \times prod\big[pop[i][j]\big] - cost\big[pop[i][j]\big]$$

This function has to be maximized in order to obtain the highest profit. For storing profit values, we use a double-type array profit[Nr_pop] which contains the profit for each chromosome. As for the operators, we will use the mutation within a chromosome and selection by sort. In addition, we must respect another condition: The order of the cultures in a rotation. Some cultures are not planted after certain crops (for example, wheat is not recommended after another cereal, such as barley). In this matter, cultures are read from an input file in the same way as adjacency lists from oriented graphs and then stored in an array of arrays, denoted by a[n][a[n][0]]. For example, from the file are read the next numbers:

1 2; 1 4; 1 5; 1 9; 2 4; 2 5; 2 9

On a row, the first number represents the main culture and the second one the possible precursory culture. Using this structure we built the rotation by randomly generating a precursory culture based on the main one. The number of precursors for every culture is stored in a[i][0], where i is the chromosome. Thus:

- 1 has as precursors 2 4 5 9, a[1][0]=4
- 2 has as precursors 4 5 9, a[2][0]=3.

The list continues with the next crops.

The generation of the initial population, at a chromosome level, is made backwards, from the end of the chromosome to its beginning, as shown in Fig. 1.

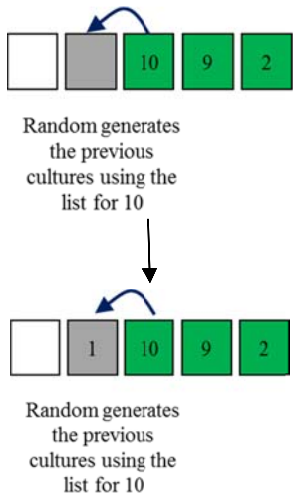

Fig. 1 The generation of a chromosome

Practically, the algorithm can be sketched as:

```
read n,m,k,HA,cost,price,prod
create array a
generate initial population
for i = 1,No_generations do
    crossover
    sort
    mutation
    sort
endfor
for i = 1,k do
    for j = 1,m do
        write popi,j
endfor
```

The crossover part consists in choosing two chromosomes using a random method and interchange parts of them depending on a crossover point, also chosen randomly. The crossover respects the order of the cultures within the crop rotation.

The mutation part consists in randomly choosing a chromosome (N) and two positions in it (M and P), then shifting the values at the chosen positions, with the verification of the order condition. The mutation function is schematically presented in the next rows (NoMutations is initialized before, being the number of mutation the algorithm makes):

```
for i=1,NoMutations do
    N←rand()%Nr_Pop-201
    do
        sw←1
        M←1+rand()%m
        P←1+rand()%m
        s←1
        while sw=1 or s ≤ a[pop[N][P]][0] do
            if pop[N][M-1] = a [pop[N][P]][s] then
                sw←0
            s←s+1
        endwhile
        s←1
```

```
        while sw=1 or s ≤ a[pop[N][M]][0] do
            if pop[N][P-1] = a [pop[N][M]][s] then
                sw←0
            s←s+1
        endwhile
    while sw=0
aux←pop[N][M]
pop[N][M]←pop[N][P]
pop[N][P]←aux
profit[N]←f(N)
```

Sorting can be made using any type of sorting method (bubble sort, merge sort, quick sort etc.). This sort is made for showing the most profitable cropping-system possibility. At every step, the profit of every individual is calculated using the fitness function. The values are sort by profit array.

At the end, the first k values are output, because they have the highest profit.

V. Results after the Implementation

In the next rows, we will present some of the results output after the implementation of the algorithm. For this, we consider 10 cultures (n=10) as a base: wheat, corn, barley, sunflower, colza, peas, soy, two-row-barley, beans and sugar-beet. We consider a farm of 60 ha (HA=60) located in Romanian Plain and we want a five-year rotation (m=5). The values for costs, prices and production for 2014 are shown in Table I. We want to output the first 14 solutions (k=14). The crops used for the leaping sola are alfalfa, clover, lupin and tick-bean (leap=4). For these cultures, we will show in Table I only the cost, the capitalization being indirect.

TABLE I
Costs, Productions and Prices for Cultures in Use

Crop	Cost / ha [lei/ha]	Production /ha [kg/ha]	Price [lei/kg]
Wheat	2674.0	3500.0	0.6
Corn	2563.1	4000.0	0.6
Barley	2812.3	4000.0	0.65
Sunflower	2399.9	1800.0	1.1
Colza	2554.4	3000.0	1.3
Peas	3773.5	1600.0	2.0
Soy	2675.4	1800.0	2.3
Two-row barley	2753.0	4000.0	0.65
Beans	3785.1	1600.0	10.0
Sugar beet	4000.0	55000.0	0.15
Alfalfa	1300.0	-	-
Clover	1759.5	-	-
Lupin	1486.8	-	-
Tick-bean	1358.7	-	-

What would happen if we planted the same culture on the whole area? Table II presents the values in this case.

We can see that in their majority the cultures are not as profitable as a cropping-system possibility. In practice, the cropping system is highly used, because of the effect on the soil and environment.

Table III presents the results after the implementation of the algorithm.

TABLE II
Profit in Non-Rotation Cases

Crop	Profit	Costs	Income
Wheat	1,560	160,440	126,000
Corn	26,214	153,786	144,000
Barley	23,262	168,738	156,000
Sunflower	10,806	143,994	118,800
Colza	116,736	153,264	234,000
Peas	1,590	226,410	192,000
Soy	123,876	160,524	248,400
Two-row barley	26,820	165,180	156,000
Beans	768,894	227,106	960,000
Sugar beet	291,000	240,000	495,000

TABLE III
Results for the Algorithm

No.	Cropping-system possibility	Profit	Costs	Income
1	Colza Soy Sugar-beet Beans Alfalfa	193,396.80	172,483.20	365,880.00
2	Colza Soy Sugar-beet Beans Alfalfa	188,587.20	177,292.80	365,880.00
3	Beans Sugar-beet Corn Soy Alfalfa	175,996.80	171,883.20	347,880.00
4	Soy Sugar-beet Two-row-barley Beans Alfalfa	175,413.60	174,866.40	350,280.00
5	Soy Sugar-beet Beans Barley Alfalfa	175,406.40	174,873.60	350,280.00
6	Soy Sugar-beet Beans Barley Alfalfa	175,406.40	174,873.60	350,280.00
7	Corn Beans Sugar-beet Soy Alfalfa	175,292.40	172,587.60	347,880.00
8	Colza Barley Sugar-beet Beans Alfalfa	173,978.40	173,421.60	347,400.00
9	Sugar-beet Beans Barley Colza Alfalfa	173,978.40	173,421.60	347,400.00
10	Colza Barley Sugar-beet Beans Alfalfa	173,978.40	173,421.60	347,400.00
11	Sugar-beet Beans Barley Colza Alfalfa	173,978.40	173,421.60	347,400.00
12	Soy Sugar-beet Corn Beans Alfalfa	173,755.20	174,124.80	347,880.00
13	Sugar-beet Beans Barley Colza Alfalfa	173,274.00	174,126.00	347,400.00
14	Barley Soy Sugar-beet Beans Alfalfa	173,164.80	177,115.20	350,280.00

Next, we will present some data regarding the performance of the algorithm.

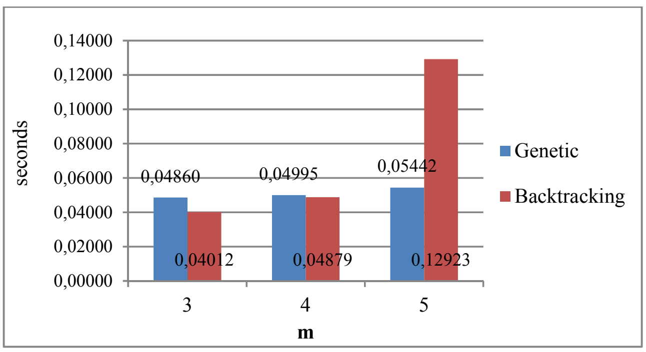

Fig. 2 Runtime for the algorithm

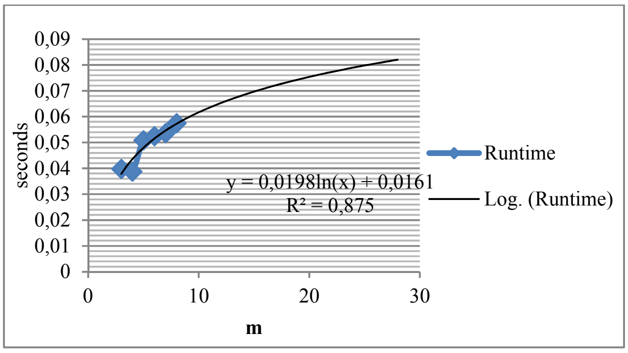

Fig. 3 Runtime for the algorithm for different values of m and predictions for m rising

The time passed between the start and the end of the algorithm implementation for this input data was 0.062356065 seconds. The value obtained for the runtime for n=21 and m=6, for the same number of generations, was 0.048070223 seconds, showing that the runtime does not depend on changes of n or m. In other implementations using different algorithms, the output data was slightly different in matter of number of solutions and even optimized possibilities. Fig. 2 presents the values for different values of m. The value of the number of generations is 200 and the number of cultures (n) is 9. Compared to backtracking method shown in red lines, the runtime remains almost constant, while the backtracking algorithm one is growing.

VI. Conclusion

The results shown in this paper are useful in various holdings which require the rotation of cultures. A future work based on the present one would be finding other methods which would bring improvements to the actual method. The development can be made as well as for the choice of the algorithm. In this sense, a useful study can be made for memetic algorithms or on the effects of using GA in agriculture and what improvements can be brought to GAs from the agriculture. Another direction of developing this subject is to find other methods used in agriculture for improving productions with as low as possible costs and avoiding damage over the environment.

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