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An Algorithm Based on the Backtracking Method for Cropping-Systems and the Rotation of Cultures

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Abstract

Cropping-system is an old agricultural method which has benefits over both the soil and the crop. Generating a cropping-system is a slightly difficult task, which can put the unexperienced and even trained farmers in difficulty. The rules that must be respected are numerous and are particular to every plant and the content in nutritive substances of the soil. Therefore, the technology can help the farmer to make a decision within the management system of the farm. The backtracking method is helpful in this situation for generating all the possibilities of a cropping-system, respecting the rules presented in this type of system. In this paper we present a method of generating them and calculating the most profitable cropping-system possibility, based on a backtracking algorithm and also a Java GUI for an easier overview on the issue and on the results.

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Keywords: cropping-system; backtracking; culture; Java; budget.

1. General information

The agriculture is a domain present every day in our life, being essential for the survival of human beings because it assure the daily food. Although it appears to be simple on a first sight, the agriculture is complex and a series of

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technologies, works and rules are necessary for obtaining food, as well as raw materials for some industries and activity domains present in our society.

The essence of agriculture is the communion between nature and humans, the gentle usage of its resources and the respect for the environment. We have to listen to its voice and to have a mild behavior in order to obtain the best food, so necessary for the mankind. One of the methods we can use to use rationally is the cropping-system and, implicitly, the rotation of cultures. Combined with the correct usage of other resources, (e.g. water [4], [5]), it can grow the production. In this section we will present the advantages of the cropping-system method for agriculture.

What does cropping-system means and what it supposes? As the name says, the cropping-system consist in the partition of the agricultural surface and the cultivation of a different plant in each parcel, in the next year the cultures rotating in the next parcel. For example, we have four cultures: wheat, barley, corn and sunflower. We want to obtain higher high-quality productions. Who can help us? We call for it at the soil – where we plant the seeds and which is the food reservoir for the plant. In order for it to be up to the mark, it has to be neat, it should be stocked with essential nutritive elements, essential mineral substances and water, so necessary for plant growth. We need to use the culture rotation to assure that the soil is always prepared for supporting plants. Cropping-system has several important rules that have to be kept in order to obtain the desired effects and not to endanger the soil resource, microclimate and to waste money. We need specialty information, we have to search for specialists in the domain and use the method we will describe further in this article for information and even planning.

The usage of informatics for solving problems in various domains is more and more visible. For example, the issue discussed in this paper uses notions regarding combinatorics, graph theory (the "fitting matrix" being similar to an adjacency matrix), presented in [3], as well as recurrence theory [2], which are the base for backtracking method.

With all its advantages, cropping-system is not used at its highest potential in Romania. The paper proposes and advocates for the usage of cropping-system as a non-invasive method for increasing production and protecting the environment. It gives the general information and some effective arguments supported by examples for the usage of this method as environmental and thrifty.

In the second section we will detail the most important notions about cropping-systems and the rotation of cultures. The next part will contain references about work made in this direction and the way this problem was handled in other papers and section 4 will describe in detail the method used to generate the cropping-system possibilities. Section 5 is divided in two subsections and contains the description of Java GUI made for the method and a brief example of generating cropping-system possibilities, as well as some data regarding the algorithm performance. Section 6 contains the conclusions and some final ideas.

The choice of a backtracking algorithm was made for the particular ordered output of the solutions, all the possibilities being generated, as well as for starting a comparison between this method and other types of methods. Also, the number of solutions depends and is set by the algorithm, not by the user. Using backtracking method helps at showing accurately the most profitable solution, because all the solutions are generated and output. The output solutions are always the same, because they not depend on the time of generation. So, we can say that the multitude of solutions is a strength point of the algorithm, despite its disadvantages.

2. Cropping-system method. General notions and restrictions regarding this method

The cropping-system represents the rational location of different cultures in time and space in an agricultural holding. It is the modality of obtaining agricultural high-quality products and high productions. The cropping-system must be made depending on predominant factors in the area where it is used: natural conditions (climate, pedological conditions), relief, holding specialization, holding size, production costs [1].

We must familiarize with the notions regarding cropping-system:

- The parcel (or sola) is the surface obtained after dividing the total surface
- The main culture is the culture presented in the current year on a sola
- The precursory culture is the culture cultivated in the previous year on a sola
- The next culture is the culture that follows on the sola in the next year
- The ante-precursory culture is the culture cultivated two years before on a sola

Various types of cropping-systems are known:

- Field rotation covers the main cultures (cereals, technical plants, legumes), which is differentiated depending on the number of parcels on which is made: short (3-5 parcels), middle (6-8 parcels) and long (above 8 parcels) and which make the object of this article
- Fodder rotation satisfies the farm needs related to feeding animals, assuring high-quality fodder to them. It can be practiced on field occupied with pastures and meadows and also on the arable lands surrounding farms. This type of cropping-system assures the soil fertilization in the same time by cultivating perennial plants.
- Special cropping-system which is organized for some types of cultures.
- Mixt cropping-system combines the components of two or more types of cropping-systems.

The culture rotation is a technological link that cannot lack from a culture itinerary. The culture rotation presents numerous advantages. We present just two of them here: removes the pests and diseases that can affect cultures; using legumes is necessary for fertilizing soil with nitrogen coming from the symbiotic activity of these plants.

The principles which are the base of cropping-system have in view the objectives undertaken in a holding, but also factors as [1]: pedo-climate conditions, the diversity of used varieties and hybrids, the risks of transmitting diseases and pests, the effect of the precursory plant over the soil fertility.

Cropping-systems may have effects on the chemical, physical and biological proprieties of the soil.

The research showed that cropping-system has a particular role, especially for prevention of soil erosion, hydric erosion being the main factor of agricultural areas degradation. The cropping-system can also influence chemical soil proprieties. Cultivated plants have different requests regarding nutritive elements consumption necessary to their development.

In modern agriculture, the economic sector is still important, but this does not mean that the social and ecological factor have to be left aside. The cropping-system has direct effects on them, because its disuse or an unbalanced rotation will lead to a negative influence over the agricultural production.

We can list and emphasize here some general rules that must be respected when using a cropping-system:

- Straw cereals must not occupy more than 50% of the total surface in the cropping-system.
- Row cultures must not occupy more than 1/3 of the total surface in the cropping-system.
- There are cultures that do not come back on the same sola in a certain interval (for example, sunflower comes back on the same sola after 6 years).
- The precursory culture must let the soil free before starting the main culture technology.
- The precursory and the main culture, as well as the next culture must not have the same pests and diseases.

3. Overview on the issue

Cropping-system issue is widely researched, due to its advantages. The scientists made studies on both economic and environmental problems. Also, a wide variety of studies regarding crops and their behavior are taken into account for research. But the cropping-system requires a good knowledge about cultures. In this matter, a complete study about crop simulation and management is presented in paper [12]. Furthermore, using indices and satellite-based data can show the performance of rotation of cultures, as shown in paper [13]. The usage of other methods and economic issues are detailed in papers [14] and [15]. The study of cropping system and its environmental implications is made in paper [16].

4. Modality of generating cultures in cropping-system – description of the algorithm

The cultures will be coded by consecutive numbers: 1, 2, 3, … . In this way, we use the next data structures:

- k – the total number of cultures
- Total_cultures[i] – memorize the totality of cultures, i=1,k
- Budget[i] – the budget spent for the i culture, i=1,k

From all these cultures, the user will have the occasion to choose the cultures wanted to be cultivated. The initial number of crops in the program is 9.

In order to generate all the cropping-system possibilities within the holding, we use a method based on backtracking algorithm. The method uses as input data for finding cropping-system possibilities the number of cultures which can be cultivated in the area (n), the number of parcels in which the total surface is divided (which also means the number of years in the cropping-system – its duration – or the number of cultures to be cultivated, in our case is marked with m) and the “fitting” matrix, which shows what precursory cultures can be cultivated before the main culture, which can be updated continuously with various cultures, as it can be seen in Table 1.

Table 1. Example of rows and columns in the “fitting” two-dimensional array

	Wheat	Corn	Barley	Sunflower	Colza	Peas	Soy
Wheat	0	0	0	1	1	1	1
Corn	1	0	1	0	0	1	1
Barley	0	0	0	1	1	1	0
Sunflower	1	1	1	0	0	1	0
Colza	1	0	1	0	0	1	0
Peas	1	0	1	1	0	0	0
Soy	1	1	1	1	1	0	1

To find the budget for the cropping-system, we add as input data the budget for each culture, taken from the technological sheet of every culture. If we want to find the most profitable cropping-system possibility, the input data will include, besides the one above, the crop price if it is traded as raw material, or the costs for making a product and its price, if the raw material is processed and the intermediary or finite product is sold (for example, the wheat culture, if it is sold as raw material, the price of a ton of wheat is considered, and if the wheat is transformed into flour which is sold, the flour price is considered etc.). We will denote them, one at a time:

- n – the number of possible cultures
- Cultures[n] – chosen cultures that can be cultivated
- m – the number of cultures that are wanted to be cultivated / the number of soles / the duration of the cropping-system
- Possible_cultures [m] – the cultures that are wanted to be cultivated
- Fitting[n][n] – the “fitting” matrix (two-dimensional array)
- Budget[n] – the budget spent for each culture
- Price[n] – the price for the crop that is sold / Product_price[n], Product_costs[n] – selling price for the product obtained from the crop as raw material

The backtracking method used in this case is similar to the one used in the well-known map coloring problem, [2] and [3], with the difference that solving array will not memorize values between 1 and 4, but between 1 and n, n being the number of possible cultures. Also, it is not generated a single solution, but the algorithm provides several solutions, being very similar to generating combinations. Practically, the conditions which cumulate in this case are:

- Fitting[i][j] = 1, where i is the current culture and j is the plant verified to be precursory for plant i, including the particular case for the last culture in the row with the first
- Possible_cultures[k] ≠ Possible_cultures[i], i=1,k, which means that the possibilities in a solution are different

At the beginning, each number is associated with a culture. After the generation, cultures are output depending on the numbers attributed with them. We will take an example:

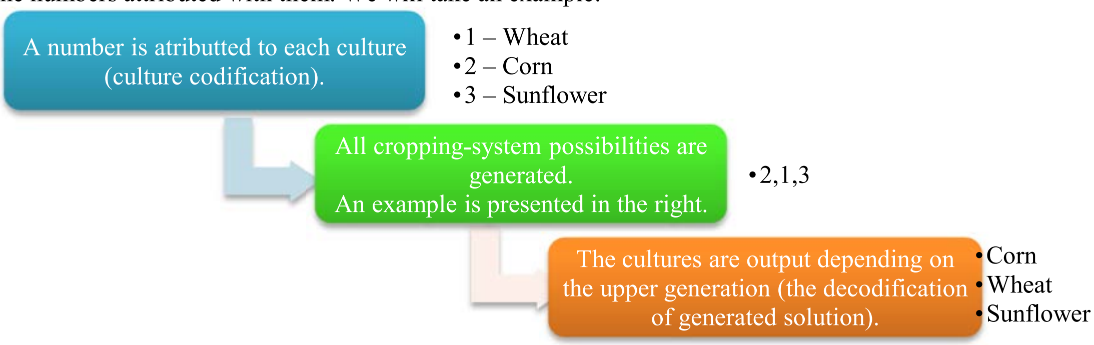

Fig. 1. The process of generating cropping-system possibilities

The generated solutions will be stored in the string x with components x_1, x_2, x_3, … , x_m, where x_i can take as values any numbers from the set {1, 2, …, n}, i=1,m.

The algorithm that uses backtracking method will verify for each generated component x_k if satisfies the condition:

- Potrivire[k][i]=1, where k is the current culture and i is the plant verified to be precursory for plant k.

Once a solution is generated in the string x, this can be output or stored in a two-dimensional array, each line being a possibility of rotating the cultures.

5. Results

5.1. A Java implementation for the algorithm

To emphasize the utility of this method, we projected an interface using Java programming language. The steps described above are emphasized separately within the interface by their inclusion in different areas of the applications. The interface can be seen in Figure 2.

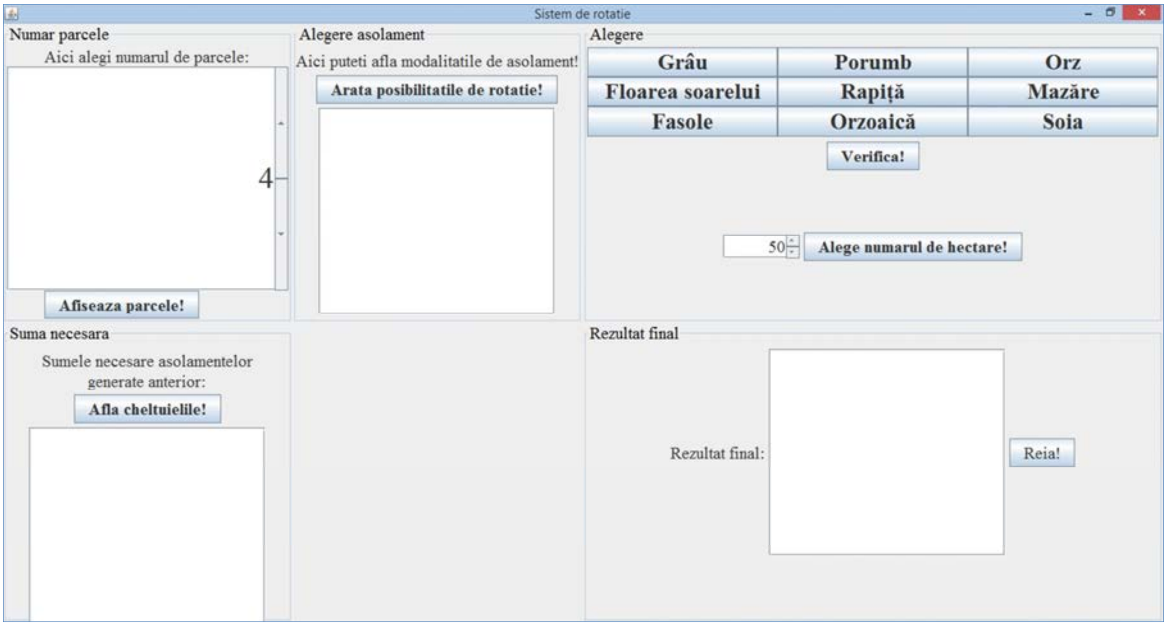

Fig. 2. Java GUI for the algorithm

The user chooses which cultures can be cultivated. Then the duration of the rotation is established (the number of parcels in which the entire surface will be divided or m). After that, the cropping-system possibilities are generated using one of the two methods mentioned above. Based on this list, the budget for every possibility is generated and output in the next area of the interface. For finding the most profitable cropping-system possibility we will follow one of the two directions: for the first direction, when the production is sold directly, the total income per possibility and the profit afferent to each one is calculated. For the second direction, in case of selling products obtained from the crops in the cropping-system, the user introduces the price for every product and the expenses for its production, finding further the afferent profit obtained after the sold of products.

5.2. Example

We will show in the next rows an example of generating cropping-system possibilities. We consider at this time that our “fitting” two-dimensional array contains 7 cultures: wheat, corn, barley, colza, sunflower, peas and soy. We take as example an agricultural holding situated in the south of Olt County, near Danube meadow, which has a surface of 60 ha, each culture cultivated on a surface of 20 ha. The prices and the average production for the seven cultures are presented in Table 2.

Table 2. Price and average production for cultures taken as example [10]

Culture	Price on market in 2014 [lei/kg]	Average production in 2014 [kg/ha]	Costs / ha [lei/ha]
Wheat	0.6	3500	2674.0
Corn	0.6	4000	2563.1
Barley	0.65	4000	2812.3
Sunflower	1.1	1600	2399.9
Colza	1.3	1800	2554.4
Peas	2	3000	3773.5
Soy	2.3	1500	2675.4

The farmer wants a three-course rotation. In this location, the climate is characterized by the next values:

- The annual average temperature is 11˚C, in the winter is -3˚C and in the summer reaches 23˚C.
- The annual average precipitations reach 500mm, in the winter being 150-200mm and in the summer 250-300mm.
- The soil type is chernozem, a soil with a high fertility.

From these cultures we must choose three cultures and we choose this set of seven crops as base for our backtracking algorithm. The total number of cropping-system possibilities which the farmer can plant in the first year is 39, taking into account their order. The possibilities and the numbers for year 2014 for each possibility resulted from the algorithm are presented in Table 3. The euro is set at the value of 4.4 lei and the value of subsidies is 156.89 euro.

Table 3. Results after implementing the algorithm for the upper example, using the values from Table 2

No.	Possibility	Costs (lei)	Income (lei)	Profit after selling the crop (lei)	Profit with subsidies (lei)
1	*2*	*3*	*4*	*5*	*6*
1.	Wheat - Corn - Sunflower	152,740	125,200	-27,540	26,849.70
2.	Wheat - Corn - Soy	158,250	159,000	750	1,440.32
3.	Wheat - Sunflower - Peas	176,948	197,200	20,252	20,942.30
4.	Wheat - Sunflower - Soy	154,986	146,200	-8,786	-8,095.68
5.	Wheat - Colza - Soy	158,076	157,800	-276	414.32
6.	Wheat - Peas - Sunflower	176,948	197,200	20,252	20,942.30
7.	Wheat - Peas - Colza	180,038	208,800	28,762	29,452.30
8.	Corn - Sunflower - Wheat	152,740	125,200	-27,540	-26,849.70
9.	Corn - Sunflower - Barley	155,506	135200	-20,306	-19,615.70
10.	Corn - Sunflower - Peas	174,730	203,200	28,470	29,160.30
11.	Corn - Sunflower - Soy	152,768	152,200	-568	122.32
12.	Corn - Soy - Wheat	158,250	159,000	750	1,440.32
13.	Barley - Corn - Sunflower	155,506	135,200	-20,306	-19,615.70
14.	Barley - Sunflower - Peas	179,714	207,200	27,486	28,176.30
15.	Barley - Peas - Sunflower	179,714	207,200	27,486	28,176.30
16.	Barley - Peas - Colza	182,804	218,800	35,996	36,686.30

17.	Sunflower - Wheat - Corn	152,740	125,200	-27,540	-26,849.70
18.	Sunflower - Wheat - Peas	176,948	197,200	20,252	20,942.30
19.	Sunflower - Barley - Corn	155,506	135,200	-20,306	-19,615.70
20.	Sunflower - Barley - Peas	179,714	207,200	27,486	28,176.30
21.	Sunflower - Peas - Wheat	176,948	197,200	20,252	20,942.30
22.	Sunflower - Peas - Corn	174,730	203,200	28,470	29,160.30
23.	Sunflower - Peas - Barley	179,714	207,200	27,486	28,176.30
24.	Sunflower - Soy - Wheat	154,986	146,200	-8,786	-8,095.68
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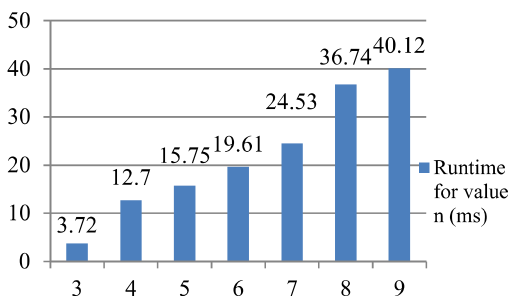
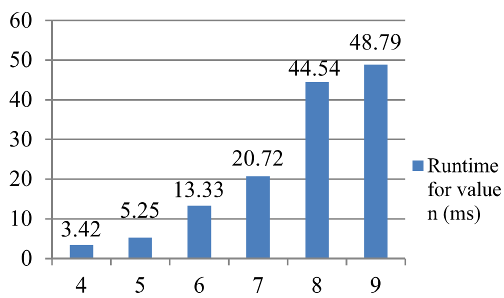
29.	Peas - Wheat - Sunflower	176,948	197,200	20,252	20,942.30
30.	Peas - Corn - Sunflower	174,730	203,200	28,470	29,160.30
31.	Peas - Barley - Sunflower	179,714	207,200	27,486	28,176.30
32.	Peas - Sunflower - Wheat	176,948	197,200	20,252	20,942.30
33.	Peas - Sunflower - Barley	179,714	207,200	27,486	28,176.30
34.	Peas - Colza - Wheat	180,038	208,800	28,762	29,452.30
35.	Peas - Colza - Barley	182,804	218,800	35,996	36,686.30
36.	Soy - Wheat - Corn	158,250	159,000	750	1,440.32
37.	Soy - Wheat - Sunflower	154,986	146,200	-8,786	-8,095.68
38.	Soy - Wheat - Colza	158,076	157,800	-276	414.32
39.	Soy - Corn - Sunflower	152,768	152,200	-568	122.32

We will observe that the most profitable possibility in 2014 was *Barley – Peas – Colza* in its "cyclical" form. You can observe that we have taken into account the order, which means that each cropping-system possibility is present with its translation to the next right position.

Now, we will study the algorithm behavior for various values of the years in the rotation. The runtime value for the Java implementations are presented for different values given to n (the cardinal number of the set that contains the cultures, explained in Section III) is presented in Fig. 3 and Fig. 4.

The value for n=9 and m=9 is 329.19 ms (mili-seconds). It can be observed from the graphic that the value is increasing once n and m increase, which is quite a major restriction for this algorithm.





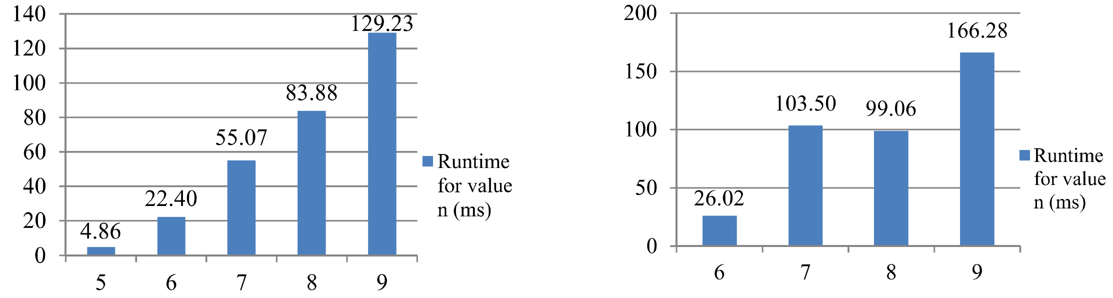


Fig. 3. Java implementation runtime for different values of n and m

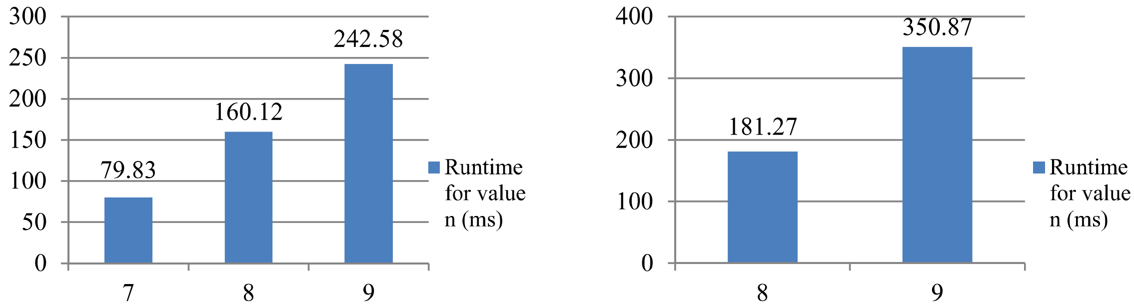


Fig. 4. Java implementation runtime for different values of n and m

6. Conclusions

Obtaining profit in agriculture is a challenge today and, therefore, in the context of environment protection and rational usage of resources, various solutions must be found. The cropping-system is one of them and the interference of technology in agriculture brings the opportunity of obtaining crops gains without using any solution that can be harmful to the environment.

But the agricultural domain works with parameters not as precise as in other domains and this is the difficult part in technologizing agriculture and make the job of the farmer easier. There are and will still be particularities in agriculture that depend only on the natural conditions and the farmer.

The generation of cropping-system possibilities may also be made using algorithms based on different types of methods (such as random generation), which can improve the limitations and restrictions of a backtracking algorithm. The implementation of these algorithms is a direction of research in our future work.

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