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POSSIBILITIES TO INCREASE IRRIGATION EFFICIENCY THROUGH THE OPTIMIZATION OF CROP STRUCTURE

Abstract. *In present conditions, induced by worldwide difficulties regarding energy, raw materials, food and ecological balance, agriculture has a more and more important role in the dynamic of human-machine relation. Agriculture, along with forestry, represents a branch of economy with net energy production and with a significant contribution to environmental protection. Irrigation has a significant contribution for the safety and productivity of crops, although it also could contribute to important deterioration of soil quality if the water is not used efficiently. Model optimization of crop structure, by including specific restrictions represents an efficient way to progress toward the current goals of crop production. In this paper, we aim to present a model that finds an optimal distribution of crops for three types of surfaces (effectively irrigated, arranged for irrigation, and unarranged for irrigation) within specific restrictions.*

Key words: *agriculture, irrigation, Giurgiu county, crop structure, optimization, efficiency.*

JEL Classification: O13

Introduction

Within agricultural holdings, current activity implies to solve problems related to production and work organization, land management, crop rotation, securing and organizing technical means and labor, and production structure establishment.

The paper aims to build a model that allows the optimization of production structure considering, among other restrictions, sustainability and irrigation availability. The proposed model is made by using information from previous literature regarding the relations among analyzed factors, principles and recommendations regarding crop production optimization, and local environmental conditions.

The paper firstly refers to theoretical foundation by exploring sustainability implications on agricultural holding and the conceptual framework of production structure optimization. The second part of the paper details the steps made toward the model's construction, including a brief description of the soil patterns in Giurgiu County, and present a numerical example for an agricultural holding from Giurgiu County.

Sustainable development's implication on the organization of agricultural holdings. Current management problems in Romanian agricultural holdings are influenced by their characteristics, which in turn, reflect the changes that took place in agrarian structures (property structure, organization of holdings and agricultural services, production structure) and, lately, the level of sustainability values integration.

Gafsi et al. (2006) and Rădulescu (2003) considers that the integration of sustainability in the organization of agricultural holding will show up in how problems related to size, production structure, agricultural marketing and organizational structures are resolved.

The size of agricultural holding. A strategic option for sustainability would be to adjust the size of holdings to a medium one. In Romania that means for a great part of holdings an increase, since most of them have an average size of two hectares. By such measures it becomes possible to apply a science based land management, to improve agricultural works by perfecting the capital's material components (mechanization, use of chemical inputs and superior varieties and hybrids).

Production structure. In order to achieve sustainability goals the production structure has to be elastic enough to allow adjustments according to the needs of national economy, exports, and food processing industry. Products with "ecological" qualities in larger and homogenous amounts could be a good target from this point of view.

Agricultural marketing and organizational structures. The establishment of new organizational and marketing structures will allow improvements in valuation of production, provision of inputs and information availability. Thus, farmers will save expenses and time for current holding activities.

Studies concerned with production structures make some recommendations regarding the elements to be considered and the formulas proved to be performing in certain areas. According to the results of Rădulescu (2003), Shah (2006) and Quadir and Oster (2004) the elaboration of production structure and program in a sustainable agricultural holding should take in account the following: the surface of land and the size of livestock; market demand; natural conditions and soil quality; mean yields in the last three years; production capacities; technologies; production costs in the last three years.

Results of agronomic research performed by the National Agricultural Research and Development Institute Fundulea (NARDIF) are useful in construing the crop structure. Thus, NARDIF (2001) recommends for the specific conditions of the Romanian Plain the following structure: 25-50% perennial fodder crops; 12.5-25.0% wheat; 12.5-25.0% corn; 6.0-12.5% beans; and 6.0-12.5% sunflower.

Principles and recommendations for production structure optimization. In order to optimize the structure of production there is necessary to apply rigorously the crops' rotation. Voicu (2000) distinguishes a set of principles and recommendations that would be also useful in establishing an optimal structure of crops. These are represented by the following:

- dividing cultivated land in plots that have relatively uniform relief, physical and chemical properties, and which include a small natural reserve;
- preventing species and varieties that are not appropriated in that region or that are pest-sensitive to be cultivated;
- cultivating crops that have demand on agricultural markets and/or that are beneficial for soil;
- establishing a balanced ratio among crops that are favorable and unfavorable for soil conservation;
- use of perennial fodder crops as heads of crop rotation;
- increased use of annual and perennial *Leguminous* crops;
- alternating crops with deep and superficial roots;
- systematical cultivation of green fertilizer crops.

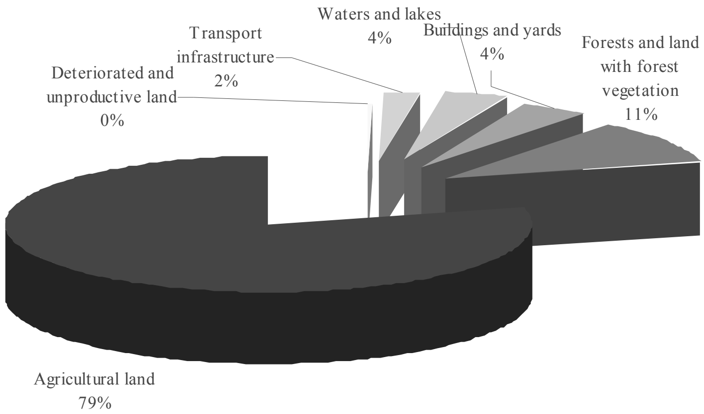
Optimization of production structure is strongly related with the size and limits of farms. According to Bold and Avram (1995), in order to respect sustainability, these features should be established by respecting conditions such as:

- allowing the possibility to perfect organizational structures by respecting farm's profile and environmental needs;
- compact plots with direct functional links with production centers, settlements, and processing centers;
- respecting the limits of natural ecosystems (forests, rivers etc.), infrastructure (dams, channels) or conventionally established ones;
- optimal use of production resources with the possibility to differentiate them for the plots with ecological restrains.

A proper land organization, comprising compact plots and regular geometric shapes, will allow a reduction of fuel consumption, significant improvements of cultural techniques contributing toward sustainability.

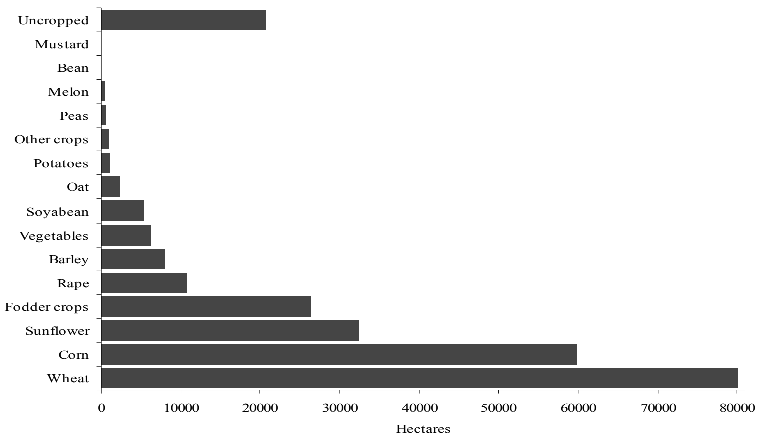
Soil features in Giurgiu County. Soil features are usually described by referring to certain aspects such as land structure according to the category and type of use and pressures that affect soil quality (use of pesticides, fertilizers, and irrigation).

Land structure. In Giurgiu County agricultural use of land is dominant (Fig.1) being of 78.7%. Arable land is the main type of agricultural use, since it accounts for more than 260 thousands hectares, representing 73.9% of the surface with agricultural use.



Source: Direction for Agriculture and Rural Development

Figure 1. Land repartition in categories of use



Source: Direction for Agriculture and Rural Development Giurgiu

Figure 2. Cropped arable land in 2007

The main crops in Giurgiu County are cereals, technical crops, and vegetables. Fig.2 presents the state of crop structure in 2007 which reflects that wheat, corn and sunflower occupied together more than half (66%) of the arable land. It is important to note that a significant area (20 738 ha) remained outside cropping in this year.

Pressures on soil quality. The use of fertilizers and pesticides has a favorable impact on the economic and financial performance of agricultural holdings. Nevertheless, the triple bottom-line reporting of sustainability enlightens also important weaknesses arising from the ecological effects of using such chemical industry products on large scale and for prolonged period of times. At some extent, the situation is similar for irrigation too. Further we give some data concerning the size of such pressures measured with the applied annual quantities.

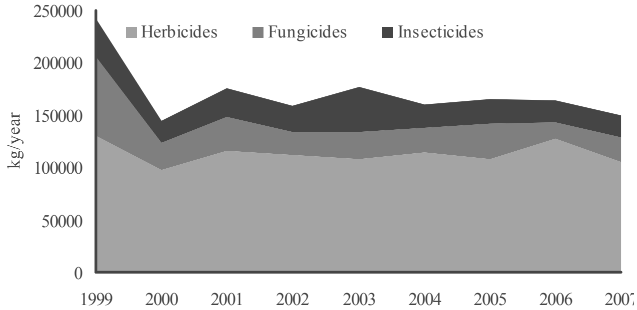
The total amount of *fertilizers* accounted for more than 13 thousands tone active substance. This is made up from a specific use of 47.7 kg/ha for the agricultural land, being higher for arable land (50.8 kg/ha). The use of fertilizers varied from one year to another the highest amount being recorded in 2006 (Fig.3).

Source: Direction for Agriculture and Rural Development Giurgiu

Figure 3. Evolution of fertilizers use

There are also used some organic fertilizers (manure and composted organic waste) in population's households and this type of contribution accounted for 9.6 tones per hectare in 2007. This type of fertilizers has a favorable contribution to soil ecological balance. Therefore, the greater their amount, the greater is the contribution toward sustainability.

Pesticides are used in the fight against pests of various types – fungi (fungicides), insects and other arthropods (insecticides), and weeds (herbicides). In Giurgiu County herbicides are the most used one, considering both the amount applied and the surface covered. Looking back this pressure could be considered as decreasing (Fig.4).



Source: Direction for Agriculture and Rural Development Giurgiu

Figure 4. Evolution of pesticides use

Irrigations attempt to correct the unequal temporal and spatial repartition of rainfall which is the main factor affecting water availability. In other words, irrigations are efficient solutions for enhancing yields and securing their constancy from one year to another. A secondary effect of irrigation, with harmful potential on soil quality, results because of the partial use of irrigation water.

The unused water could dissolve soil minerals increasing their concentration beyond the toxicity threshold or could accumulate and favors the development of marshes. Such undesirable effects could be avoided by a complementary drainage system which removes the excess water.

Table 1. Irrigation use in Giurgiu County for 2007

Irrigated crops	Irrigations (number)	Volume of water (m^3)	Irrigated area (ha)
Wheat	1	500	2 445
Corn	2	600	1 482
Soybean	3	600	2 453
Vegetables	5	300	748
Other crops	2	500	635

Source: Direction for Agriculture and Rural Development Giurgiu

In Giurgiu County the area arranged for irrigation is a small one. Thus in 2007, 51 005 hectares were irrigated with 2 500 cubic meters of water applied in several times depending on the crop, as it results from table 1.

Factors that influence irrigation's efficiency. The application of statistical and mathematical methods for the evaluation of irrigations efficiency could reveal some reserves at different levels (holding, region, and branch) from the point of view of intensive and extensive use of agricultural land.

Reaching the irrigations final aim – superior yields – has to consider a set of restrictions, such as: maximizing productions, minimizing water consumption, improving production quality, increasing soil fertility, minimizing energy consumption, improving production efficiency, minimizing the investment recovery period. Other restrictions to be considered are: soil's moisture, salinity, and production capacity annual rainfall regime, existing agricultural machineries, crop production plan, crops structure, labor structure, crop rotation, available irrigation infrastructure.

Crop structure has an important effect on the efficiency of irrigation. Applying irrigation contributes to enhance land's productive potential with 28-67% depending on crop. These effects are higher for potatoes, corn, and sunflower and lower for cereal crops (Quadir and Oster, 2004). The efficiency of irrigation also depends on other factors such as crop rotation, use of fertilizers, agricultural techniques. The combination of effects resulted from irrigation and other water management and agricultural practices could have an important contribution toward sustainability by preserving and even enhancing soil's fertility (Rădulescu, 2003). Crops structure influence on irrigation efficiency is amplified in case of holdings situated in areas with high occurrence of natural hazards, having unbalanced structure of human and energy resources (Stroe and Dobre, 1990).

According to Playan and Mateos (2006) irrigation optimization leads to a number of outputs such as increased water productivity, improved water conservation, reduced basin-wide resources, improved environment and lively rural areas, which, on their turn, could enhance environmental sustainability. Fig. 6 presents the roadmap proposed by the authors through two categories of actions: structure and management.

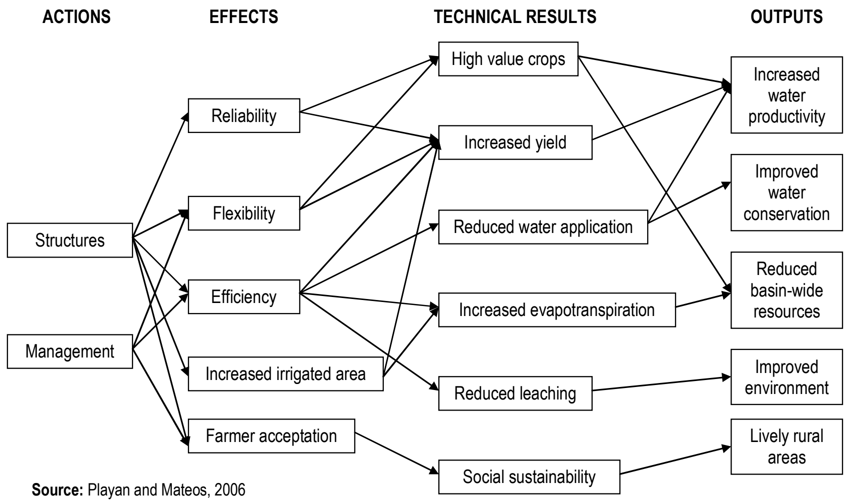


Figure 5. Flux diagram of actions, effects, technical results, and outputs related to irrigation modernization and optimization

Optimization of irrigated crops' structure could contribute to the above mentioned environmental gains through five paths: reliability, flexibility, efficiency, increased irrigated area, and farmer acceptance. Meanwhile, for management actions with the same purpose there are available only three paths.

Crop structure optimization model for improved efficiency of irrigation. Considering the above mentioned relations and particular conditions of Giurgiu County we construed a model that allows the optimization of crop structure in order to improve the efficiency of irrigation. The model envisages finding a distribution of crops that corresponds to maximized productions within the restrictions represented by energy resources, labor, volume of fertilizers, volume of irrigation water, and a certain level of financial indicators (production cost and profit).

x_i – surface cultivated with i crop within the effectively irrigated surface
y_i – surface cultivated with i crop within the surface arranged for irrigation
z_i – surface cultivated with i crop within the surface unarranged for irrigation

p – proportion of surface occupied by irrigation infrastructure (channels) in the total of surface arranged for irrigation
ST – total surface
e_i, e_i', e_i'' – the necessary energy resource base for each of the three types of surfaces
Bn – the total available energy of the holding
fm_i, fm_i', fm_i'' – the necessary of man-day per hectare for each of the three types of surfaces
FTM – total annual available fund of man-day
a_i, a_i', a_i'' – the necessary fertilizers amount per hectare for each of the three types of surfaces
SING – total annual available amount of fertilizers
c_i, c_i', c_i'' – production costs per hectare for the cultivated i crop for each of the three types of surfaces
Cp – total estimated cost
b_i, b_i', b_i'' – profit per hectare for the i crop cultivated land for each of the three types of surfaces
*Bp*1 – total presumptive profit increase
SAIRIG – surface arranged for irrigation
α_i, β_i – maximal, respectively, minimal surface that could be cultivated with i crop in that year
q_i, q_i', q_i'' – value volume of estimated average production per hectare for the i crop for each of the three types of surfaces
γ_i – specific water consumption for irrigation for the i crop
i = 1, …, n – list of crops considered
Qwater – water available for irrigation

Considering these notations, the projects restrictions could be written as it follows:
1) Restriction of integral use of agricultural land

$$\sum_{i=1}^{M}(1-p)\cdot(x_i+y_i+z_i)=ST \quad (1)$$

2) Restriction of not outrunning the availability of energy resources

$$\sum_{i=1}^{n}(e_i\cdot x_i+e_i'\cdot y_i+e_i''\cdot z_i)\le Bn \quad (2)$$

3) Restriction of not outrunning the availability of man-day fund

$$\sum_{i=1}^{n}(fm_i\cdot x_i+fm_i'\cdot y_i+fm_i''\cdot z_i)\le FTM \quad (3)$$

4) Restriction of not outrunning the availability of fertilizers amounts

$$\sum_{i=1}^{n}(a_i\cdot x_i+a_i'\cdot y_i+a_i''\cdot z_i)\le SING \quad (4)$$

5) Restriction of not outrunning the costs

$$\sum_{i=1}^{n}(c_i \cdot x_i + c_i' \cdot y_i + c_i'' \cdot z_i) \le Cp \qquad (5)$$

6) Restriction of water consumption

$$\sum_{i=1}^{n} r_i \cdot x_i \le Qwater \qquad (6)$$

7) Restriction of profit increase due to irrigation

$$\sum_{i=1}^{n}\{[b_i - b_i'' \cdot (1-p)] \cdot x_i + [b_i' - b_i'' \cdot (1-p)]\} \cdot y_i \ge \Delta Bp1 \qquad (7)$$

8) Restriction of not outrunning the surface of arranged for irrigation

$$\sum_{i=1}^{n}(x_i + y_i) = SAIRIG \qquad (8)$$

9) Restriction of surfaces structure

$$\beta_i \le x_i + y_i + z_i \le \alpha_i \qquad i = 1,...,n \qquad (9)$$

The objective function – maximizing production (yield)

$$\sum_{i=1}^{n}(q_i \cdot x_i + q_i'' \cdot y_i + q_i'' \cdot z_i) \qquad (10)$$

The proposed model could be improved by considering other restrictions related to fodder production, crop rotation, soil quality etc. In irrigation optimization the final aim is not only to maximize production, but to allow the use of those surfaces for a long period of time by increasing the quality and fertility of soils. Such models gain in usefulness if we consider the need to increase production along with care for environmental values, as key conditions for sustainability.

Numerical example. Empirical data for computation was provided by S.C. Diada S.R.L. from Giurgiu county. The following working hypotheses were considered:

- The total area of the holding is 1 150 hectares, of which maximum 150 hectares are effectively irrigated, 750 hectares arranged for irrigation, and 250 hectares are unarranged for irrigation.
- Envisaged crops: wheat, barley, rapeseed, corn, and soybean.
- According to the plan the minimum area to be covered by each crop are as follows: 400 hectares wheat; 300 hectares barley; 100 hectares rapeseed; 50 hectares corn; 100 hectares soybean.
- For each crop cultivated in the three different systems it were considered two restrictions: one regarding the nitrogen need in active substance, and one regarding the minimum request for cereal yield.
- The objective function is to obtain maximum profit.

- p value is 1.5%.

Notations:

- x_1, …, x_5: surfaces cultivated with each of the five crops within the effectively irrigated surface;
- x_6, …, x_{10}: surfaces cultivated with each of the five crops within the surface arranged for irrigation;
- x_{11}, …, x_{15}: surfaces cultivated with each of the five crops within the surface unarranged for irrigation.

Data of specific consumption of each cultivated hectare are presented in table 2.

Table 2. Specific consumptions

Cultivated surfaces	Nitrogen need in active substance (kg/ha)	Water need (m3/ha)	Mean production (t/ha)	Mean profit (lei/ha)
x_1	70	800	4.00	400
x_2	60	800	4.50	400
x_3	70	600	2.50	600
x_4	100	1 000	6.50	800
x_5	40	1 000	2.50	800
x_6	70	-	3.00	200
x_7	60	-	3.50	200
x_8	70	-	2.00	350
x_9	100	-	4.50	400
x_{10}	40	-	1.25	400
x_{11}	70	-	3.00	200
x_{12}	60	-	3.50	200
x_{13}	70	-	2.00	350
x_{14}	100	-	4.50	400
x_{15}	40	-	1.25	400

In these conditions, the problems model is:

$$\max f = 400x_1+400x_2+600x_3+800x_4+800x_5+200x_6+200x_7+350x_8+400x_9+400x_{10}+200x_{11}+200x_{12}+350x_{13}+400x_{14}+400x_{15} \quad (11)$$

$$x_2 + x_7 + x_{12} \geq 300 \quad (12)$$

$$x_3 + x_8 + x_{13} \geq 100 \quad (13)$$

$$x_4 + x_9 + x_{14} \geq 50 \quad (14)$$

$$x_5 + x_{10} + x_{15} \leq 150 \quad (15)$$

$$x_1 + x_2 + x_3 + x_4 + x_5 \leq 150 \quad (16)$$

$$x_6 + x_7 + x_8 + x_9 + x_{10} \leq 750 \quad (17)$$

$$x_{11} + x_{12} + x_{13} + x_{14} + x_{15} \leq 250 \quad (18)$$

$$x_1 + x_6 + x_{11} \geq 400 \quad (19)$$

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} \leq 900 \quad (20)$$

$$4x_1 + 4{,}5x_2 + 2{,}5x_3 + 6{,}5x_4 + 2{,}5x_5 + 3x_6 + 3{,}5x_7 + 2x_8 + \\ + 4{,}5x_9 + 1{,}25x_{10} + 3x_{11} + 3{,}5x_{12} + 2x_{13} + 4{,}5x_{14} + 1{,}25x_{15} \geq 3000 \quad (21)$$

$$68{,}95x_1 + 59{,}1x_2 + 68{,}95x_3 + 98{,}5x_4 + 39{,}4x_5 + 68{,}95x_6 + 59{,}1x_7 + 68{,}95x_8 + \\ + 98{,}5x_9 + 39{,}4x_{10} + 70x_{11} + 60x_{12} + 70x_{13} + 100x_{14} + 40x_{15} \geq 77000 \quad (22)$$

$$x_1,\ldots,x_{15} \geq 0 \quad (23)$$

The model's solution is: $x_4 = 150$; $x_6 = 400$ ha; $x_7 = 200$; $x_8 = 134$; $x_9 = 16$; $x_{12} = 166$; $x_{15} = 150$. That means 400 hectares cultivated with wheat within the surface arranged for irrigation; 300 hectares cultivated with barley, of which 200 hectares within the surface arranged for irrigation and 100 hectares within the surface unarranged for irrigation; 134 hectares cultivated with rapeseed within the surface arranged for irrigation; 166 hectares cultivated with corn of which 100 hectares within the effectively irrigated surface; and 150 hectares cultivated with soybean with the surface unarranged for irrigation. The maximum profit to be obtained is 373 316.413 lei.

If the effectively irrigated surface is enhanced with one hectare the holding's profit would raise with 400 lei. If the maximum surface cropped with soybean would increase with one hectare the holding's profit would increase with 100 lei if there are applied measures to respect all restrictions. This means a water need of 150 000 m^3.

Conclusions

There are a number of favorable circumstances that could transform sustainable agriculture in a widespread practice among Romanian producers. These include the new approach of current European and national rural development policies, the relatively low exposure to chemical pollution for a large part of the agricultural land, and increased demand for high quality and healthy food. Meanwhile, there are important barriers to be overcome such as agricultural property atomization, lack of resources needed for change and certification, and difficulties in accessing governmental support.

Irrigation has a significant contribution for the safety and productivity of crops, although it also could contribute to important deterioration of soil quality if the water is not used efficiently. Further, optimization of crop structure could contribute toward sustainability by increased water productivity, improved water conservation, reduced basin wide resources, improved environment, and a lively rural area.

The proposed model finds an optimal distribution of crops for three types of surfaces (effectively irrigated, arranged for irrigation, and unarranged for irrigation) within restrictions regarding fertilizers consumption, and the minimum level of cereal production by using profit maximization as objective function.

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