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Sustainable Optimization of Agricultural Production

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Abstract

This paper presents a model for sustainable optimization of agricultural production. The model is a mathematical programming model, based on multicriteria techniques, and can be used as a tool for the analysis and simulation of agricultural production plans, as well as for the study of impacts of the various policies in agriculture. The model can achieve the optimum production plan of an agricultural region combining in one utility function different conflicting criteria as the maximization of gross margin and the minimization of fertilizers used, under a set of constraints for land, labor, available capital, common agricultural policy etc. The proposed model was applied to two prefectures of the region of Thessaly, in central Greece. In both prefectures, the optimum production plan achieves greater gross return, less fertilizers use, and less irrigated water use than the existent production plan.

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Keywords: sustainable optimization; multicriteria analysis; agricultural production

1. Introduction

The objective of this paper is to achieve an optimum agricultural production plan, combining different criteria to a utility function under a set of constraints concerning different categories of land, labour, available capital, CAP etc. For this purpose, we extended Sumpsi et al. [1] and Amador et al. [2] methodologies for the analysis and simulation of agricultural systems based upon multicriteria techniques. These authors propose weighted goal programming as a methodology for the analysis of decision making. Specifically, an MCDM model is used in order to achieve better policy-making procedures and the simulation of the most realistic

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decision process. The utility MCDM approach in comparison with other approaches such as linear programming, cost benefit analysis, etc. can achieve optimum farm resource allocations (land, labour, capital, water, etc.) that imply the simultaneous optimization of several conflicting criteria, such as the maximization of gross margin, the minimization of fertilizers, the minimization of labour used, etc.

We have applied the methodology in the region of Thessaly, and more specifically in two Prefectures of it, namely Larisa and Trikala. The data needed resulted from a European research project funded by European Commission.

2. Methodology and model definition

The chosen model is an Optimization Multicriteria Mathematical Programming model based on Weighting Goal Programming [1] and Amador et al. [2]. The methodology model is also based on GIS maps (sensitivity vulnerability maps) and facilitates and optimizes the decision-making process relating to the problems of land use/water management/environmental protection. The model achieves the optimum production plan in the area combining different criteria to a utility function under a set of constraints concerning different categories of land, labor, available capital, etc. The model is further used to simulate different scenarios and policies due to changes on different environmental parameters. In this way we get alternative production plans and agricultural land uses as well as the economic, social and environmental impact of different policies.

The methodology of weighting goal programming has been successfully implemented on real agricultural systems [3, 4, 5, 6, 7, 8]. We employ this methodology to estimate a surrogate utility function in order to simulate farmers' decision-making processes, broadening in this way the traditional profit-maximizing assumption.

2.1. Variables

Each farmer has a set of variables Xi (crops) consisting the decision variables of the model.

2.2. Objectives

This model will optimize at the same time three different criteria, the gross margin maximization, the fertilizers minimization, and the labour minimization.

Gross margin maximisation

The objective function included in the model is defined as follows:

$$MaxGM = \Sigma GMi \ x \ Xi$$

where GM is the total gross margin, is crop i and GMi is the gross margin of crop i.

Fertiliser minimisation

The fertilizer is computed as the sum of fertilizers used for all crops (TF), and its objective function will be as follows:

$$\Sigma \ TFi \ \ x \ Xi \ \ = TF$$

Minimization of labor

The labor is calculated as the sum of labor for all farm activities (TL), therefore the objective function will be:

$$\Sigma TLi \ \ Xi \ \ = TL$$

2.3. Constraints

The optimization of the model is attained under a set of constraints that refer to:

- Total cultivation area
- CAP constraints (production rights, quotas and set aside)
- Market and other constraints
- Rotational and agronomic considerations
- Irrigation Constraints

2.4. Attributes

We finally estimate the following two attributes

- *Fertiliser use*
- *Irrigated water use*

that are regarded by the producers as costs and not as decision variables. They are also very relevant in the sustainable planning of agricultural production as they represent the environmental impact.

3. Area of study and data

We have applied the proposed model in the region of Thessaly in Greece, and more specifically in the two Prefectures Larisa and Trikala. Thessaly occupies the central part of mainland Greece and consists of a low-lying plain surrounded by high mountain ranges. The Thessaly plain is the most extensive in Greece, with considerable farming activity, and the main crops include wheat, cotton, maize and sugar beets. The 41% of Thessaly's cultivated land is irrigated, and agricultural holdings are small (more than 20% cover an area of less than 5 ha) and highly fragmented. Arable crops are the main cultivation for the majority of the agricultural holdings. In arable crops cereals, cotton, maize, alfalfa, sugarbeets and vineyards are included.

The research carried out was based on the data gathered in the framework of a European research project funded by European Commission. The technical and economic coefficients of crops in each Prefecture are from the Regional Government of Thessaly and from the Department of Agriculture and Veterinary of each Prefecture. We have also used additional data provided by the Department of Agricultural Economics of Aristotle University of Thessaloniki, and from the National Agricultural Research Foundation.

4. Results

Tables 1 and 2 show the existent and proposed optimum crop plans and their economic results in the two prefectures. The adopted methodology produces better approximations to observed values.

The results for the Larisa area suggest the abandonment of rye, and sugarbeets cultivations. There is a decrease of 40% in the cultivated area of soft wheat, and 86% in the cultivated area of maize. In addition, there is an increase of 17% in the cultivated area of tomatoes, 9.88% in the area of vines, 9.21% of oat, 5% of hard wheat, 4.90% of barley, 4.96% of cotton, 4.35% of vetch, 4.75% of olives, 2.04% of apples and an increase 4.91% in the cultivated area of alfalfa. The participation of set aside in the optimal production plan increases, as compared with the existent production plan, by 7.9% of the total cultivated area of Larisa. From the comparison of the existent and optimal production plans, we observe that gross margin increases by 1.10% (fig. 1). There is a reduction of fertilizers' use by 5.39%. Regarding labour use, we observe a reduction of 5.93%, due to increased set aside.

Table 1. Comparison between observed values and MCDM model in Larisa

	Existent Plan	MCDM model	
		model values	**% deviation**
Gross Margin (€)	**165,607,253**	**167,430,154**	**+ 1.10%**
Fertilizer Use (Kg)	**71,089,746**	**67,254,693**	**- 5.39%**
Total Labour (hours)	**29,273,622**	**27,538,865**	**- 5.93%**
Water Demand (m^3)	**685,135,467**	**605,341,091**	**- 11.65%**
Soft Wheat	6.14%	3.68%	- 40.07%
Hard Wheat	40.21%	42.22%	+ 5.00%
Barley	7.34%	7.7%	+ 4.90%
Oat	0.76%	0.83%	+ 9.21%
Rye	0.32%	0%	- 100%
Maize	5.26%	0.73%	- 86.12%
Sugarbeets	0.79%	0%	- 100%
Cotton	20.98%	22.02%	+ 4.96%
Alfalfa	5.50%	5.77%	+ 4.91%
Vetch	1.15%	1.20%	+4.35%
Apples	0.98%	1.00%	+2.04%
Tomatoes	1.77%	2.08%	+ 17.51%
Vines	1.62%	1.78%	+ 9.88%
Olives	2.95%	3.09%	+ 4.75%
Set Aside	4.23%	7.90%	+ 86.76%
TOTAL	100%	100%	

The results of the MCDM model for Trikala agricultural area, suggest the abandonment of vetch cultivation (table 2). There is a decrease of 45.55% in the cultivated area of soft wheat, and 33.27% in the cultivated area of maize. In addition, there is an increase of 36.49% in the cultivated area of oat, 20% in the area of barley, 19.75% in the area of vines, 8.43% of hard wheat, 9.97% of cotton, 15.64% of alfalfa, and an increase 6.78% in the cultivated area of olives. The participation of set aside in the optimal production plan increases, as compared with the existent production plan, by 13.40% of the total cultivated area of Trikala. From the comparison of the existent and optimal production plans, we observe that gross margin increases by 1.66% (fig. 2). In addition, we observe a reduction of fertilizers' use by 5.54%. Regarding labour use, we observe a reduction of 4.12%, due to increased set aside and finally water demand decreased 6.74%.

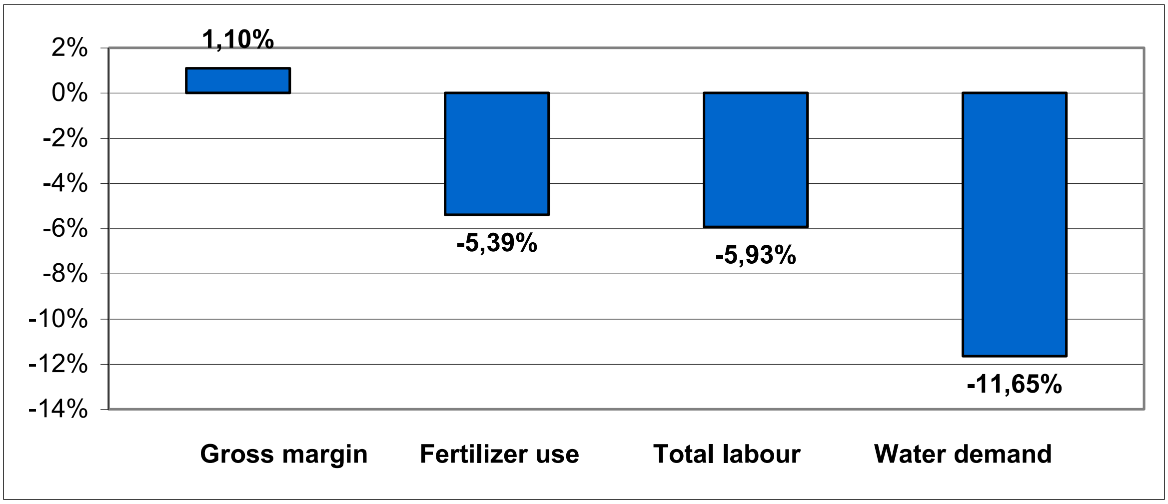

Fig. 1. Optimum Production Plan in Larisa

Table 2. Comparison between observed values and MCDM model in Trikala

	Existent Plan	MCDM model	
		model values	**% deviation**
Gross Margin (€)	**36,019,785**	**36,619,490**	**+ 1.66%**
Fertilizer Use (Kg)	**16,734,628**	**15,807,634**	**- 5.54%**
Total Labour (hours)	**7,755,291**	**7,435,470**	**- 4.12%**
Water Demand (m^3)	**248,167,137**	**231,433,771**	**- 6.74%**
Soft Wheat	7.53%	4.10%	- 45.55%
Hard Wheat	15.77%	17.10%	+ 8.43%
Barley	4.75%	5.70%	+ 20.00%
Oat	0.74%	1.01%	+ 36.49%
Maize	22.51%	15.02%	- 33.27%
Cotton	22.46%	24.70%	+ 9.97%
Alfalfa	11.57%	13.38%	+ 15.64%
Vetch	1.31%	0.00%	- 100%
Vines	1.62%	1.94%	+ 19.75%
Olives	2.95%	3.15%	+ 6.78%
Set Aside	8.79%	13.40%	+ 52.45%
TOTAL	100%	100%	

5. Conclusions

This paper presents an MCDM model for sustainable planning and the optimization of agricultural production. The model is used in order to achieve better policy-making procedures and the simulation of the most realistic decision process. This approach achieves optimum farm resource allocations (land, labour, capital, water, etc.) that imply the simultaneous optimization of the maximization of gross margin, the minimization of fertilizers and the minimization of labour used. The model automatically estimates the use of fertilizers and irrigated water that constitute two important environmental parameters in agricultural production planning.

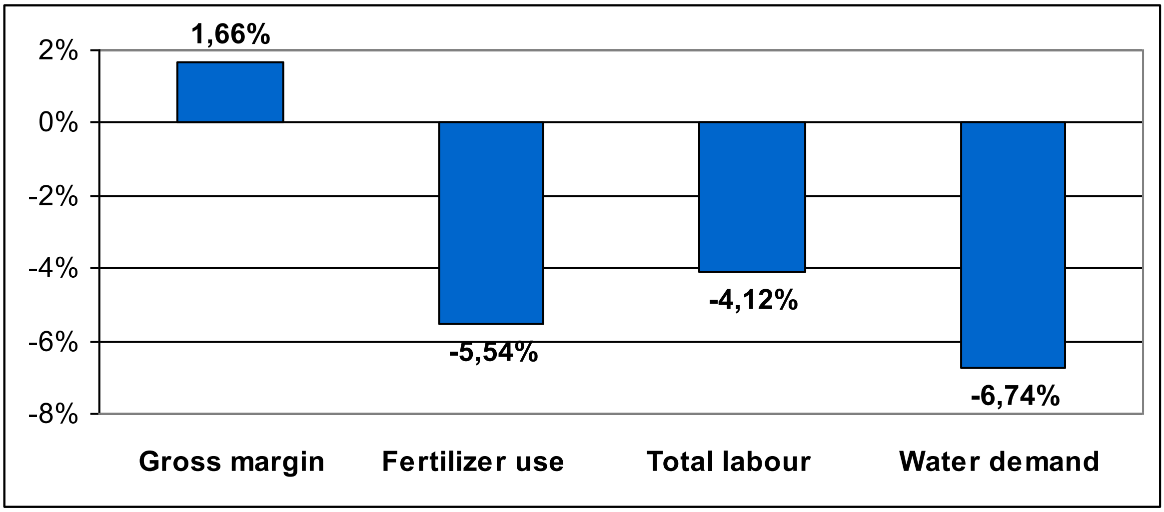

Fig. 2. Optimum Production Plan in Trikala

The MCDM model was applied in two case study areas in Central Greece. For each study area, the MCDM model proposes a production plan having different synthesis of crops than that of the existent plan. In both study areas the proposed plan achieves an increase of total gross margin and a decrease of labor used. In both study areas the proposed plan achieves an important decrease in the use of fertilizers (5.39% and 5.54%) as well as in the use of irrigated water (6.74% and 11.65%).

The proposed model can be further used to evaluate different scenarios of current and future European policies in agriculture (e.g. nitrates directive, water framework, 2020 scenarios etc.) and estimate the the economic, social and environmental impacts of these policies.

References

[1] Sumpsi, M., Amador, F., & Romero, C. On farmers' objectives: a multi-criteria approach. *European Journal of Operational Research* 1997; 96: 64-71.

[2] Amador, F., Sumpsi, M. J., & Romero, C. A non-interactive methodology to assess farmers' utility functions: an application to large farms in Andalusia, Spain. *European Review of Agricultural Economics* 1998; 25: 92-109.

[3] Berbel, J., & Rodriguez, A. An MCDM approach to production analysis: an application to irrigated farms in southern Spain. *European Journal of Operational Research* 1998; 107:108-118.

[4] Gomez-Limon, J., & Riesgo, L. Irrigation water pricing: Differential impacts on irrigated farms. *Agricultural Economics* 2004; 31 (1): 47-66.

[5] Manos, B., Bournaris, T., Kamruzzaman, M., Begum, A., & Papathanasiou, J. The regional impact of irrigation water pricing in Greece under alternative scenarios of European policy: a multicriteria analysis. *Regional Studies* 2006; 40 (9): 1055-1068.

[6] Manos, B., Begum, A., Kamruzzaman, M., Nakou, I., & Papathanasiou, J. Fertilizer Price Policy, the environment and farms behavior. *Journal of Policy Modeling* 2007; 29 (1): 87-97.

[7] Manos, B., Bournaris, T., Papathanasiou, J., & Chatzinikolaou, P. (2008). Evaluation of tobacco cultivation alternatives under the EU common agricultural policy (CAP). *Journal of Policy Modeling* 2008; 31 (2): 225-238.

[8] Manos, B., Papathanasiou, J., Bournaris, T., & Voudouris, K. A multicriteria model for planning agricultural regions within a context of groundwater rational management. *Journal of Environmental Management* 2010; 91: 1593-1600.