Assessment of Sustainable Production in rural areas

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Summary

This paper presents a model for sustainable planning and optimization of agricultural production. The model is a mathematical programming model, based on multicriteria techniques, and is 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, labour, available capital, common agricultural policy etc. The proposed model was applied to the region of Thessaly, in central Greece. In all prefectures, the optimum production plan achieves greater gross return, les fertilizers use, and less irrigated water use than the existent production plan.

Keywords: sustainable planning, multicriteria analysis, optimization of agricultural production

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1. INTRODUCTION

Common Agricultural Policy continues to play a major role in affecting agriculture, agricultural production, and the farming population. The focus on non-protected national markets and the enlargement of the European Union are creating a new reality for agriculture and rural areas in general. The overall economic contribution of farm-households in rural areas depends on the weight of agriculture in each area. The policies of the European Union (EU) highlight the multi-functional role of the rural areas, which extends beyond the role of agriculture to include other activities. Additionally, the issue of maintaining economically vital rural communities, particularly in disadvantaged regions where alternative income opportunities are limited, is a traditional argument connected to CAP. However, in the last decades, a full range of new issues has emerged (Manos et al., 2010a, 2010b, 2011; Viaggi et al., 2013). Different policies in agriculture affect people living in rural areas and have impacts on agricultural income and rural employment, maintaining also the social fabric of rural areas.

Modelling the dynamics of agricultural systems, economists recognized that farms and farm regions vary and that this variation is important, but rather than attribute this variation to different factors, they concentrated on defining farm types by structural variables such as farm size and enterprise mix. The economic element of these farms has been assumed to be constant, and all farm decision-making units have been assumed to act as rational financial maximizers (Armir et. al., 1991; Ghadim et. al., 1991). In many ways, this is almost inevitable given that most agricultural modellers use linear programming techniques to model the economic dimension of agricultural systems. However, common sense suggests that not all farmers within any given farm type are similar, and it is becoming increasingly apparent that few individuals maximize financial gain.

Given this situation, one alternative approach would be to develop a model, which assumes some degree of commonality in the behaviour of individuals, but also recognizes that the characteristics of the individuals will influence the specifics of any generalized response (Edward-Jones & McGregor, 1994). Such a model could be based on a typology of farms, in a similar manner to that developed for the structural variables of farming systems, and would function via decision-making model, which would be transferable between situations, and would permit variation in the social and cultural situation to have some influence on the final output (Gladwin, 1983).

This paper presents a tool for the analysis and the simulation of production plans. The objective 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. Specifically, a

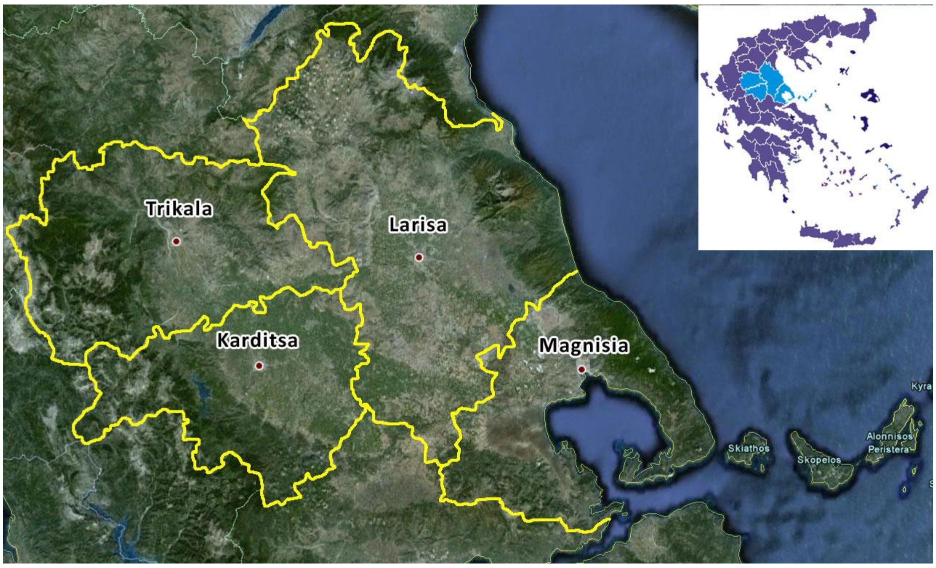
MCDM model is used, in order to achieve better policy-making procedures and the simulation of the most realistic decision process. The utility MCDM approach in comparison with other approaches such as linear programming, cost benefit analysis, etc. can achieve optimum farm resource allocations (land, 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.

The data needed resulted from a research project entitled "Sustainable management of soil-water sources of Thessaly aiming at the optimum agricultural production (SMaRT)". We have applied the methodology in the region of Thessaly, and more specifically in the four Prefectures of it, Larisa Magnisia, Karditsa and Trikala.

2. DESCRIPTION OF STUDY AREA

The area of study is the region of Thessaly, and more specifically the four Prefectures Karditsa, Larisa, Magnisia and Trikala. Thessaly occupies the central part of mainland Greece and consists of a low-lying plain surrounded by high mountain ranges. It comprises the prefectures of Larisa, Magnisia, Trikala and Karditsa, together with the Northern Sporades group of islands, the largest of which are Skiathos, Skopelos and Alonisos. The main urban centres are Larisa, Volos, Trikala and Karditsa which are the capitals of the four prefectures. 36% of the area of Thessaly is lowland, 17% is semi-mountainous and 47% is mountainous. 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. Furthermore, the labour force is underemployed, agricultural machinery underused and land is expensive to buy or lease. As a result, costs in the region are relatively high. The utilized agricultural area (UAA) in Thessaly covers an area of 432,059 ha. Arable crops are the main cultivation for the majority of the agricultural holdings. In arable crops are included cereals, cotton, maize, alfalfa, sugar beets and vineyards.

Figure 1: Map of the Region.



3. OPTIMIZATION OF THE PRODUCTION PLAN

The chosen model is a multicriteria mathematical programming (MCDM) model. In order to analyse how Common Agriculture Policy may influence agricultural production decisions we extend Sumpsi et al. (1993, 1997) and Amador et al. (1998) 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. This methodology has been successfully implemented on real agricultural systems by various researchers (Balali et al., 2011; Bartolini et al., 2007a, 2007b, 2007; Berbel and Rodriguez, 1998; Bournaris et al., 2011; Bournaris and Papathanasiou, 2012; Bournaris and Manos, 2012; Gomez-Limon and Berbel, 2000; Gomez-Limon and Riesgo, 2004; Gomez-Limon and Sanchez-Fernandez, 2010; Manos et al., 2006, 2007, 2008, 2010a, 2010b, 2011, 2013).

The MCDM model is used in order to achieve better policy-making procedures and the simulation of the most realistic decision process. The MCDM model was chosen because of the variety of criteria taken into account by farmers when they plan their crop plans. It also assembles the multifuntionality of agriculture involving variables related with economic, social and environmental aspects. 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 employ this methodology to estimate a utility function in order to simulate farmers' decision-making processes. Briefly, the methodology can be summarised as follows:

1. establish a set of objectives that are important for farmers,
2. determine the pay-off matrix of the above set of objectives,
3. using this matrix estimate a set of weights that optimally reflect farmers' preferences.

Data requirements and model specification: The research carried out was based on the data gathered in the framework of the research project entitled "Sustainable management of soil-water sources of Thessaly aiming at the optimum agricultural production (SMaRT)", funded by EEA grants. The purpose of the project was to provide information and methodologies for sustainable agriculture in the region of Thessaly, with the overall objective of contributing to sustainable development through the improvement of agricultural production, mitigation of desertification risk, irrigation water saving and encouragement of alternative crops. 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.

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

Objectives: This model will optimize at the same time three different criteria, the gross margin maximization, the fertilizers minimization, and the labour minimization. Farmers wish to maximise profits, but calculation of profit requires the computation of some relatively difficult factors such as depreciation. Therefore, for convenience it is assumed that gross margin (GM) is a good estimator of profit, and maximisation of profit is equivalent in the short run to maximisation of gross margin. The objective function included in the model is defined as follows:

$$MaxGM = \Sigma GM_i \times X_i \quad (1)$$

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

Fertilizer minimization is a public objective. For this reason it is not considered in the decision process by farmers. The most obvious indicators are those related to the consumption of water and use of pesticides that are directly related to the pollution of water resources and appear more directly quantifiable at farm level. They are, nevertheless, not obviously subject to aggregation at higher level and their effects on the environment can be evaluated only after some elaboration of prediction models based on diffusion functions. Fertilizer minimization is the main form for calculating the surpluses of nitrogen potentially dangerous for the environment. It would also be the main indicator of the impact of farming on the environment as groundwater quality is concerned. In this way, all nitrogen reaching the cultivated soil is included as input. Similar indicators can be designed for other nutrients, such as phosphorus and potassium. For this reason, fertilizer is computed as the sum of fertilizers used for all crops (TF), and its objective function will be:

$$Min\,TF = \Sigma F_i \times X_i \quad (2)$$

The minimization of labour implies not only a reduction of input cost, but also an increase of leisure time and reduction of administration and management processes. The farmers usually show an aversion to hiring labour. An explanation of this behaviour is that this parameter is connected with the complexity of crops because the hired labour adds a degree of complexity to family farming. For this reason, labour is calculated as the sum of labour for all farm activities (TL), therefore the objective function will be:

$$MinTL = \Sigma TL_i \times X_i \quad (3)$$

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

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

Attributes: We finally estimate as attributes fertilizer and irrigated water use, 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.

3.1. Results

We applied to our model the weighted goal programming technique. The three objectives were:

1. Maximisation of Total Gross Margin (GM)
2. Minimisation of Fertilizer use (TF)
3. Minimisation of Total Labour (TL)

Table 1. Pay of Matrix in Karditsa.

Values	Optimum			Real
	GM	TF	TL	(observed values)
GM	52,652	48,207	47,484	51,867
TF	37,412	35,801	36,603	39,038
TL	14,656	13,599	13,581	14,996

Table 2. Pay of Matrix in Larisa.

Values	Optimum			Real (observed values)
	GM	TF	TL	
GM	76,696	61,353	49,491	75,861
TF	30,808	29,948	29,951	32,565
TL	12,615	11,362	11,176	13,410

Table 3. Pay of Matrix in Magnisia.

Values	Optimum			Real (observed values)
	GM	TF	TL	
GM	324,706	292,555	255,286	319,597
TF	37,115	36,869	36,879	37,123
TL	22,151	19,505	18,920	22,154

Table 4. Pay of Matrix in Trikala.

Values	Optimum			Real (observed values)
	GM	TF	TL	
GM	77,962	69,805	69,443	76,685
TF	33,596	32,348	32,760	35,628
TL	15,875	15,029	15,021	16,511

The pay-off matrices for the four Prefectures of Thessaly are presented in the tables above (tables 1-4). The last column shows real data (observed) for each study area analysed. These values show for each Prefecture the actual crop distribution (considering a theoretical 100 ha farm) and the relation among different crops and the objectives considered [gross margin (GM), fertilizers (TF) and labour (TL)]. We can see how far the real situation (2010) is from any single optimum (column). This may induce us to try a combination of objectives as a better simulation of farmers' behaviour. Besides, this is the basis for the multicriteria theory and for the methodology described. With the values of tables 1, 2, 3 and 4, we obtain for each Prefecture the set of weights that best reflects farmers' preferences. These are:

Table 5. Weights that best reflects farmers’ preferences

	Karditsa	Larisa	Magnisia	Trikala
W1 = (maximize GM)	0.9998	0.9693	0.9264	0.8501
W2 = (minimize TF)	0.00	0.00	0.00	0.00
W3 = (minimize TL)	0.0002	0.0307	0.0736	0.1499

These weights show a type of farmers’ behaviour that combines profit maximization and total labour minimization. The minimization of total labour is an important criterion, since it has weight 14.99% in Trikala, 7.36% in Magnisia and 3.07% in Larisa agricultural area. This is combined with the criterion of profit maximization that has a large weight (85.01% in Trikala, 92.64% in Magnisia, 96.93% in Larisa and 99.98% in Karditsa). On the contrary, fertilizers minimization is not considered as a relevant criterion in these particular agricultural systems. The estimation of these weights was based on the current situation (2010). In this sense it is important to note that the set of weights can be considered as a structural factor. As these weights correspond to the psychological attitudes of the producers it is reasonable to assume that they will be kept at the same level in the short and the medium run, and this is actually an important pre-assumption in our simulation. We will use the weightings given above in order to represent the farmers' utility function. For each Prefecture, the utility function will be as follows:

- Karditsa: U = 99.98%GM – 0.02TL (4)
- Larisa: U = 96.93%GM – 3.07TL (5)
- Magnisia: U = 92.64%GM – 7.36TL (6)
- Trikala: U = 85.01%GM – 14.99TL (7)

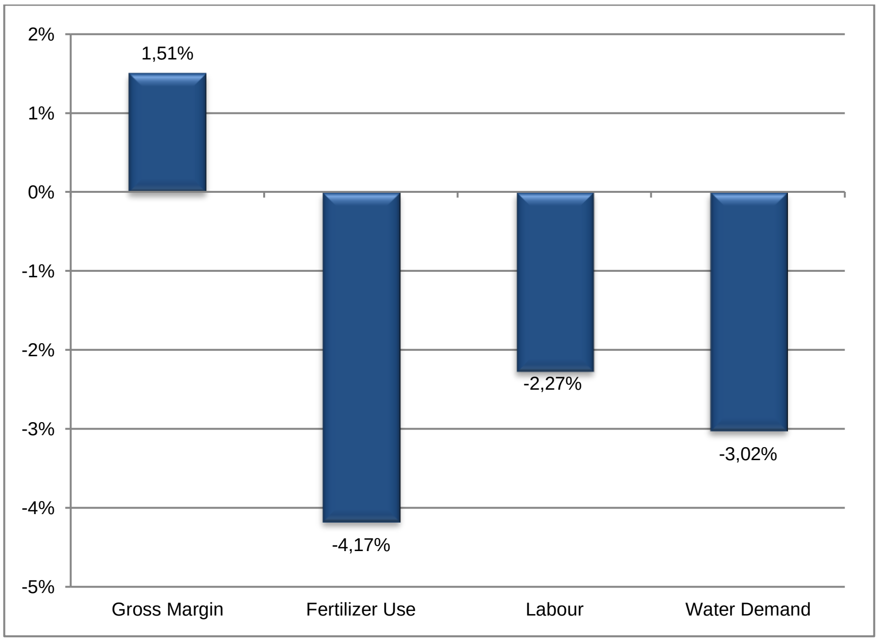
It is essential to compare the real (observed) situation with the situation predicted with the help of the estimated utility function (Eq. 4, 5, 6 and 7). The next four tables show that the adopted methodology produces a better approximation to observed values.

The results of the MCDM model for Karditsa suggest the abandonment of soft wheat, oat and sugar beets cultivations (table 6). There is a decrease of 36.1% in the cultivated area of maize, and 9.07% in the cultivated area of hard wheat. In addition, there is an increase of 50% in the cultivated area of vines, 27.66% in the area of tomatoes, 20% in the area of barley, 18.75% of vetch, 0.51% of cotton and an increase 9.83% 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 13.3% of the total cultivated area of Karditsa. From the comparison of the existent and optimal production plans, we observe that gross margin is increased by 1.51% (figure 2). In addition, we observe a reduction of fertilizers' use by 4.17%. Regarding labour use, we observe a reduction of 2.27%, due to increased set aside and finally water demand decreased 3.02%.

Table 6. Comparison between observed values and MCDM model in Karditsa.

	Existent Plan	MCDM model	
		model values	% deviation
Gross Margin (€)	48,987,305	49,728,414	+ 1.51%
Fertilizer Use (Kg)	36,870,717	35,334,832	- 4.17%
Total Labour (hours)	14,163,554	13,841,931	- 2.27%
Water Demand (m3)	455,526,255	441,753,606	- 3.02%
Soft Wheat	2.29%	0.00%	- 100%
Hard Wheat	32.74%	29.77%	- 9.07%
Barley	1.10%	1.32%	+ 20.00%
Oat	0.51%	0.00%	- 100%
Maize	5.79%	3.70%	- 36.10%
Sugar beets	0.26%	0.00%	- 100%
Cotton	42.98%	43.20%	+ 0.51%
Alfalfa	5.19%	5.70%	+ 9.83%
Vetch	0.64%	0.76%	+ 18.75%
Tomatoes	0.47%	0.60%	+ 27.66%
Vines	1.10%	1.65%	+ 50.00%
Set Aside	6.94%	13.30%	+ 91.64%
TOTAL	100%	100%	

Figure 2. Optimum Production Plan in Karditsa.

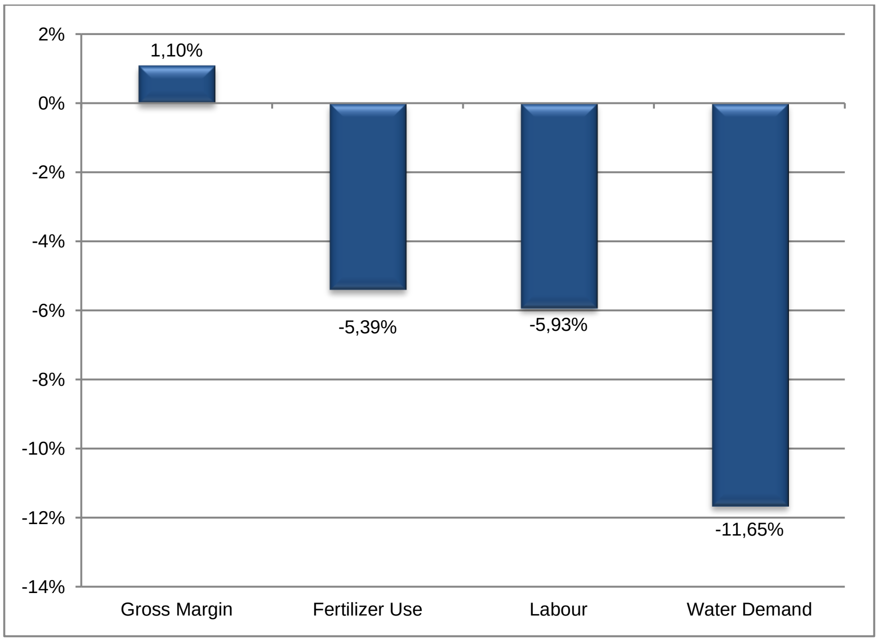


The results of the MCDM model for Larisa suggest the abandonment of rye, and sugar beets cultivations (table 7). There is a decrease of 40% in the cultivated area of soft wheat, and 86% in the cultivated area of maize. In addition, there is an increase of 17% in the cultivated area of tomatoes, 9.88% 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 is increased by 1.10% (figure 3). In addition, we observe a reduction of fertilizers' use by 5.39%. Regarding labour use, we observe a reduction of 5.93%, due to increased set aside and finally water demand decreased 11.65%.

Table 7. 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 (m3)	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%
Sugar beets	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%	

Figure 3. Optimum Production Plan in Larisa.

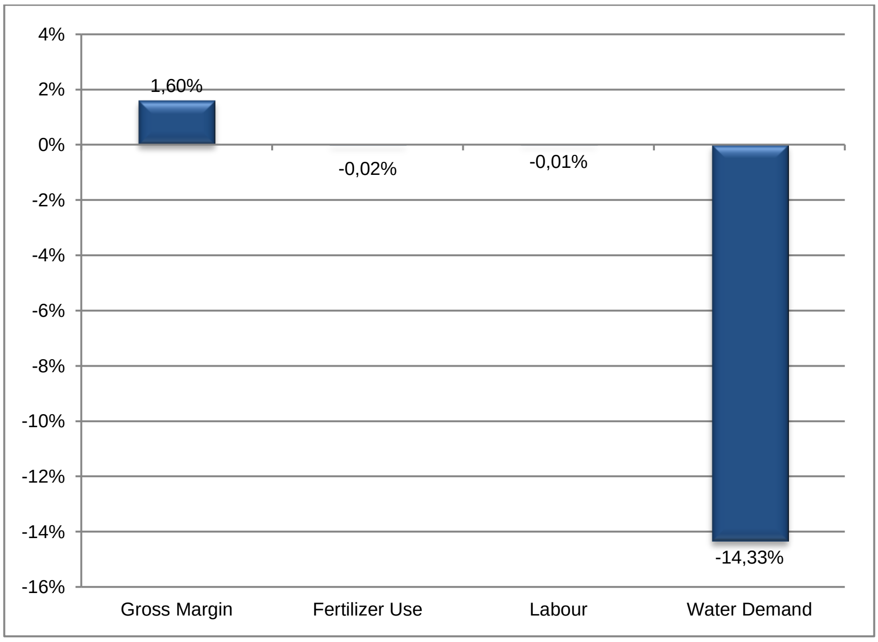


Additionally, the results of the model for Magnisia agricultural area, suggest the abandonment of sugar beets cultivation (table 8). We observe that there is a decrease of 73.6% in the cultivated area of maize, and 8.57 in the cultivated area of cotton. In addition, there is an increase of 349% in the cultivated area of soft wheat, 47% in the area of vines, 42% in the area of oat, 17% of tomatoes, 9.4% of vetch, 5% of hard wheat, 4.88 of barley, 6.23% of alfalfa, 1.97% of olives and an increase 1.84% in the cultivated area of apples. The participation of set aside in the optimal production plan decreases, as compared with the existent production plan, by 3.94% of the total cultivated area of Magnisia. From the comparison of the existent and optimal production plans we observe that gross margin is increased by 1.60% (figure 4). In addition, we observe a reduction of fertilizers' use by 0.02%. Regarding water demand, we observe a reduction of 14.33% and finally labour use decreased 0.01%. These results are expected because of the high participation of the trees in the crop plan which are intensive in labour use.

Table 8. Comparison between observed values and MCDM model in Magnisia.

	Existent Plan	MCDM model	
		model values	% deviation
Gross Margin (€)	231,188,315	234,877,176	+ 1.60%
Fertilizer Use (Kg)	26,854,148	26,848,280	- 0.02%
Total Labour (hours)	16,025,611	16,023,371	- 0.01%
Water Demand (m3)	110,471,869	94,636,780	- 14.33%
Soft Wheat	0.55%	2.47%	+ 349%
Hard Wheat	31.01%	32.56%	+ 5.00%
Barley	6.56%	6.88%	+ 4.88%
Oat	0.42%	0.60%	+ 42.86%
Maize	2.20%	0.58%	- 73.64%
Sugar beets	0.39%	0.00%	- 100%
Cotton	8.52%	7.79%	- 8.57%
Alfalfa	2.89%	3.07%	+ 6.23%
Vetch	1.48%	1.62%	+ 9.46%
Apples	3.26%	3.32%	+ 1.84%
Tomatoes	0.85%	1.00%	+ 17.65%
Vines	0.68%	1.00%	+ 47.06%
Olives	34.47%	35.15%	+ 1.97%
Set Aside	6.72%	3.94%	- 41.37%
TOTAL	100%	100%	

Figure 4. Optimum Production Plan in Magnisia.

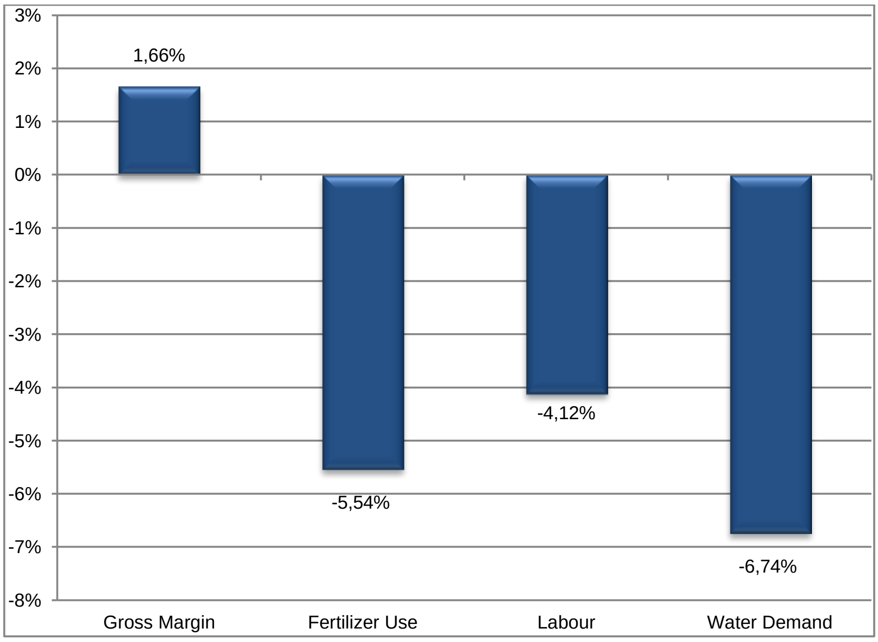


Finally, the results of the MCDM model for Trikala agricultural area, suggest the abandonment of vetch cultivation (table 9). There is a decrease of 45.55% in the cultivated area of soft wheat, and 33.27% in the cultivated area of maize. In addition, there is an increase of 36.49% in the cultivated area 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 is increased by 1.66% (figure 5). 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%.

Table 9. 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 (m3)	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%	

Figure 5. Optimum Production Plan in Trikala.



4. 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.).

The MCDM model was applied in each one of the four Prefectures of the region of Thessaly in the central Greece. The MCDM model gives for each prefecture a set of weights that best reflects farmers' preferences in accordance with the three criteria. The obtained farmers' utility function in all prefectures show a type of farmers' behaviour that combines profit maximization and labour minimization.

Comparing the existent production plan with the predicted one we can conclude that the methodology we have adopted gives a better approximation to observed values at the present. The MCDM model proposes optimum production plans that achieve greater total gross margin from 1.10% to 1.66% than the existent plans. On the issue of the minimization of total labour, the MCDM model achieves an important reduction in almost all Prefectures of Thessaly. Labour use remains in the same level in Magnisia without significant differences because of the intensive labour demand of the trees cultivation (olives and apples). Finally, from the comparison of the existent and optimum production plans, the proposed production plans achieve a reduction of water demand from 3.02% up to 14.33% and a decrease in fertilizer use (up to 5.54%).

The proposed MCDM model has further possibilities to evaluate different scenarios of current and future European policies in agriculture, and achieve different alternative production plans and different agricultural land uses. At the same time to estimate the economic, social and environmental impacts of these policies. Presupposition in order to be operational, these scenarios must be chosen on the basis of the main EU policies affecting agricultural policy, farm structure and farmers' behaviour in rural areas.

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