A bilevel programming model for farm planning in nitrates sensitive agricultural areas

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Abstract

Farm planning usually uses linear or nonlinear mathematical programming models, which generally achieve one or more goals of the decision maker. The purpose of this study is to develop a model for farm planning, which involves more than one decision maker and uses several conflicting criteria. To this end, the methodology of Bilevel Linear Programming (BLP) for farm planning was applied in order to achieve the optimal production plan. In order to determine the two different levels of BLP we assume that the first goal is the maximization of gross margin for the farmer ("leader") and the second goal is the minimization of fertilizers use which we assume that is represented by the Greek society ("follower"), through the protection of nitrates sensitive areas scheme of the Greek Rural Development Plan 2007-2013. Finally, the results obtained from BLP are compared with the results of the linear programming model.

Keywords: bilevel linear programming, farm planning, agri-environmental schemes, nitrates sensitive areas

Résumé

La planification de la production agricole se fait à travers l'utilisation de modèles de programmation linéaire ou non linéaire, qui en général permettent d'atteindre les objectifs d'un décideur. Le but de cette étude est de développer un modèle de planification agricole, qui implique plusieurs décideurs et critères conflictuels. À cette fin, la méthode de programmation mathématique à deux niveaux est appliquée dans l'organisation des exploitations agricoles afin d'élaborer le plan de production optimale. Afin de déterminer les deux niveaux de programmation linéaire, on utilise des critères contradictoires de maximisation du profit brut pour l'agriculteur, et de minimisation de l'utilisation d'engrais, sur la base du programme pour la protection des zones sensibles aux nitrates dans le Plan de Développement Rural 2007-2013. Ensuite, les résultats obtenus sont comparés avec le modèle simple de la programmation linéaire.

Mots-clés: *programmation mathématique à deux niveaux, organisation des exploitations agricoles, mesures agro-environnementales, zones sensibles aux nitrates.*

1. Introduction

Farm planning usually uses linear or nonlinear mathematical programming models by using one goal (usually maximization of gross margin) or more than one conflicting criteria (goals) (such as maximization of gross margin, minimization of risk, minimization of labour use, minimization of fertilizers use, etc.). In addition, the classical Mathematical Programming refers mainly to problems with one decision maker and for this reason the mathematical model has one objective function or in the case of Multiobjective Mathematical Programming more than one objective functions. All the objective functions are controlled by one decision maker which tries to balance his priorities between them. Mathematical programming models have been widely used in the agricultural sector since Heady (1954) used a linear programming model to determine the land allocation between two crops. When the farmers are oriented and give weight to more than one factor, a Goal Programming model could be developed. Goal programming includes a linear model (LP), in which the objective function represents a weighted level of goals (Romero and Rehman, 1984) and focuses on the weights assigned to decision variables according to their relative importance (Baernett et al., 1982). Sumpsi et al. (1997) and Amador et al. (1998) developed a methodology for the analysis and simulation of agricultural systems based on 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 in Greece (Manos et al., 2006), (Manos et al., 2008), (Manos et al., 2010). On the other hand, in the case of Multilevel Mathematical Programming more than one decision maker is involved in the decision making process, at different hierarchical levels, and the mathematical model must maintain the structure of their respective levels of hierarchy.

The purpose of this study is to develop a model for farm planning in which more than one decision maker is involved and more than one conflicting criteria used. To this end, bilevel linear programming methodology is applied for farm planning and especially in finding the optimal production plan. Initially, the optimal production plan is found with the use of the linear programming model, which maximizes the gross margin. Then, we use the bilevel linear programming with two different levels of decision making. We assume that the first level belongs to the farmer and the second level to the government. The respective levels use the conflicting criteria of gross margin maximization for farmers, and minimization of the fertilizers

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use through the protection of nitrates sensitive areas scheme in the Greek Rural Development Plan 2007-2013 implemented by the Greek government. The implementation of the model is done on an "average farm", which emerged after a survey questionnaire in 24 farms in Thessaloniki, Pella, Imathia, and Kilkis areas involved in the action 2.1. "Protection of nitrates sensitive areas" measure 2.1.4 of the Greek Rural Development Plan (RDP) 2007-2013 "Alexandros Baltatzis".

2. Bilevel Linear Programming

In Multilevel Mathematical Programming more than one decision maker is involved at different hierarchical levels in the decision making process and the mathematical model must maintain the structure of the respective levels of hierarchy. Bilevel programming problems are hierarchical optimization problems in the sense that their constraints are defined in part by a second parametric optimization problem. So in this case the constraints of the problem involve other mathematical models that represent decision-makers who are lower in the hierarchy.

The bilevel linear programming is a Multilevel Mathematical Programming problem, with two levels. The first appearance of the mathematical model of bilevel linear programming in 1973 was a work of J. Bracken and J. McGill (1973), although the first who used the term bilevel, and multilevel programming were W. Candler, R. Norton (1977). However, only in the early 80s due attention was given to these problems. The Stackelberg (1952) game is a problem of mathematical game theory identical to the bilevel programming problem. Taking motivation from Stackelberg many authors studied the bilevel linear programming intensively contributing to the Mathematical Programming scientific community.

In the case of bilevel linear programming, upper level corresponds to the "leader" and the lower to the "follower". For $x \, \varepsilon \, X \, C \, R^n$, $y \, \varepsilon \, Y \, C \, R^m$, $F : X \times Y \rightarrow R^1$ the bilevel linear problem can be written in the following format:

$$min_{x \varepsilon X} \, F(x, y) = c_1 x + d_1 y$$

$$\text{subject to } A_1 x + B_1 y \leq b_1$$

$$min_{y \varepsilon Y} \, f(x, y) = c_2 x + d_2 y$$

$$\text{subject to } A_2 x + B_2 y \leq b_2$$

where c_1, $c_2 \, \varepsilon \, R^n$, d_1, $d_2 \, \varepsilon \, R^m$, b_1, $\varepsilon \, R^p$, b_e, $\varepsilon \, R^q$, $A_1 \, \varepsilon \, R^{p \times n}$, $B_1 \, \varepsilon \, R^{p \times m}$, $A_2 \, \varepsilon \, R^{q \times n}$, $B_2 \, \varepsilon \, R^{q \times m}$, Sets and are additional constraints on the variables e.g. the upper and lower limits.

Model consists of two subproblems: the higher level decision problem (or the leader's problem) and the lower level decision problem (or the follower's problem). The objective function for the higher level problem is F(x, y) and for the lower level is f(x, y). The two problems are connected in a way that the leader's problem sets parameters influencing the follower's problem and the leader's problem, in turn, is affected by the outcome of the follower's problem. The decision sequence is as follows: the leader minimizes his or her objective F(x, y) by selecting an optimal solution of x from the feasibility set X. Given the optimal solution of x, the follower will optimally make his objective f(x, y). In other words, the follower uses only his or her local information to make decisions while the leader make use of the complete information including the follower's possible reaction to the leader's decision in the decision making process.

3. Farm planning model

Farm planning can be done under conditions of uncertainty and we assume that the farmer takes his decisions by situations or policies that may occur at a certain time (Manos, 2009). Dempe in his book "Foundations of Bilevel Programming" (2002) presents a model of bilevel linear programming as the ideal model for problems of environmental conflict, where the "farmer" pollutes the environment during production period and the consumer wants a clean environment in which he acts and consumes the products of the farmer. This context presents applications of bilevel linear programming problems in environmental policy (Dempe, 1996) approaching the problem that we study. For these reasons, we chose a bilevel linear programming model for farm planning.

In farm planning the farmer is usually interested in maximizing the gross margin. On the other hand we feel that society cares for a clean environment in which it operates and acts. These two criteria are conflicting, as the farmer tries to achieve the maximization of gross margin using plant protection products, pesticides and fertilizers and with their excessive use pollutes the environment. In order to achieve the perfect coexistence of these two conflicting goals we chose to use a bilevel linear programming model, where several decision makers at different hierarchical levels are involved in the decision making process. The model which was developed consists of two levels of which the first level concerns the maximization of gross margin for the farmer and the second level concerns the minimization of the fertilizers use of the "average farm", participating in the "Protection of nitrates sensitive areas" scheme of the Greek government which we assume cares for providing clean environment to the society.

We chose these two goals by following the next assumptions. We assume that farmers belong to the first level and they have only one goal to increase their gross margin. Therefore, in order to increase their gross margin they produce crops that will generate the maximum economic benefit, without considering environmental or other consequences of the cultivation of these products. On the other hand, society wants to reduce the environmental burden. The role of defending the wishes of the society is undertaken by the Greek government which is trying to protect the environment with the RDP agri-environmental schemes but also to meet the farmers' goal for the possible loss of income by specifying an amount of subsidies for those involved in the RDP. More specifically, we chose the action 2.1 "Protection of nitrates sensitive areas" of Rural Development Plan "Alexandros Baltatzis". With the implementation of this action several environmental goals are achieved by reducing the amount of fertilizers and water use and by following crop rotation and set aside. Therefore, we assume that this action meets the desires of the society to protect the environment. The program defines to the farmers the price levels of subsidies and the restrictions on land use, nitrate fertilizer and water use and sets two different scenarios which the farmers have to follow. By this bilevel problem we want to achieve the optimal decisions by satisfying both sides without having to overcome some historical limits and guarantees. It is a quite flexible mathematical model because it can be seen in isolation from the perspective of society and from the farmers' side.

3.1. Goals

The bilevel linear programming is similar to the linear programming with the difference that it differentiates the area of constraints, which include a limitation as a linear objective function, creating a nested optimization problem involving two problems at two levels. The bilevel linear programming model which is used for farm planning is a max-min linear problem. The general form in which the max-min bilevel linear programming problem can be written is:

$$max_x \left\{min_y \{cx + dy: Ax + By \leq b, \text{ and } x, y \geq 0 \}\right\}$$

which is a clear case of bilevel linear programming where the goal of the second level is a conflicting goal of the first level:

$$max_x \{cx + dy\}$$

where y solves the:

$$max_x \{-cx - dx\}$$

subject to:

$$Ax + By \leq b$$

$$x, y \geq 0$$

The goals included in the bilevel linear programming model are:

1. Maximization of gross margin can be considered that belongs to the decision making process of the farmer and belongs to the first level ("leader"). The objective function to maximize gross margin which is included in the model is:

$$maxGM = \Sigma\, GM_i \; x \; X_i$$

2. Minimizing the fertilizers use can be considered; it belongs to the choices of society since it is a social goal and belongs to the second level ("follower"). The objective function to minimize the fertilizers use has the following mathematical form:

$$minFER = \Sigma\, FERi \; x \; Xi$$

In the case of max-min bilevel linear programming, the mathematical form of fertilizers use in the objective function of the second level ("follower") is transformed into:

$$maxFER = -(\Sigma\, FERi \; x \; Xi)$$

We believe that the two goals mentioned above are enough to develop a model for farm planning which involved more than one decision maker and used several conflicting criteria.

The model can be written in the following mathematical form:

$$nax_{GM} \{\Sigma\, GMi \; x \; Xi\}$$

where y solves the:

$$max_{FER} \{-\Sigma\, FERi \; x \; Xi\}$$

subject to:

$$Ax + By \leq b$$

$$x, y \geq 0$$

3.2. Constraints and Scenarios

The constraints stemmed from the questionnaire survey of farms, from farmer's data, but also from the conditions for participating in the action 2.1 "Protection of nitrates sensitive areas". Constraints were used for the total cultivated land, for irrigated or non-irrigated land, for variable cost, for total labour, for Common Agricultural Policy (CAP) rules and finally market and other agronomic constraints used. Total cultivated land of all crops (Xi) should be equal to 100. This constraint is used in order to have the results of the model (decision variables Xi) in percentages. Common Agricultural Policy (CAP) constraints are used, as large proportion of agricultural income depends upon CAP subsidies. For this reason, the farmers cannot avoid the CAP regulations that influence most of the crops available for cultivation. Marketing channels and processing facilities put an upper limit on short-term variations of some crops. The upper limit for all the crops has been fixed on the basis of the maximum historical cultivation during the period 2005–2008. Finally, agronomic considerations are taken into account as rotational constraint limits.

Also constraints are used for participating in Action 2.1 "Protection of nitrates sensitive areas".

There are two scenarios, pursuant to which we put constraints on the bilevel linear programming model.

Scenario A: "Combination of permanent set aside and reduction in fertilizers use". Under this scenario the beneficiaries will have to meet the following standards: 1. Set aside. To set permanent set aside area of at least 25% of potentially irrigable land. 2. Fertilizers use. Reducing by 30% the total fertilizers use in relation to the fertilizing action of the respective programs to the remaining 75% of the area.

Scenario B: "Combination of rotation – reduction of fertilizers use and set aside". Under this scenario the beneficiaries would have to meet the following standards: 1. Rotation. Crop rotation of at least 20% of eligible irrigated area to the whole area and put in rotation at least once during the 5 years period. A crop rotation applicable only to rain fed crops. 2. Set aside. Set aside area corresponding to at least 5% of the whole area. 3. Fertilizers use. Reducing by 30% the total fertilizers use in relation to the fertilizing action of the respective farm plan, both at 75% of main crop and 20% of the crop rotation.

All this information has been included both in the simple LP model and in the BLP model.

4. Application of the farm planning model

In order to implement the bilevel linear programming model in farm planning we have used data from a survey in a sample of farms that participate in the agri-environmental schemes R.D.P. 2007-2013 and in particular the action 2.1 "Protection of nitrates sensitive areas". The survey was conducted in May and June 2009 with local visits and personal interviews with heads of the farms. The sample was selected among farms from the prefectures of Thessaloniki – Imathia – Pella and the prefecture of Kilkis. We selected 24 farms participating in the above action. We chose 12 farms from the prefecture of Thessaloniki, 4 from the prefecture of Kilkis, 4 from the prefecture of Pella and 4 from the prefecture of Imathia. The farms selection was done by random sampling. For the collection of technical and economic data of the farms we used a very detailed questionnaire. From the results of this questionnaire an average farm was developed. The variables used for the development of the average farm were the number and variation of crops, farm size, land use, fertilizers use, water use and the participation in the action 2.1 of the Greek RDP. In this "average farm" the Bilelevel farm planning model was implemented.

Table 1 - *Production plan of the "average farm".)*

Crops	ha	%
Soft wheat	14,0	6,5
Durum wheat	28,8	13,3
Barley	5,3	2,5
Vetch	15,1	6,9
Maize	107,0	49,2
Sugarbeet	3,7	1,7
Cotton	1,5	0,7
Alfalfa	34,1	15,7
Cherries	1,0	0,5
Pear	0,6	0,3
Set Aside	6,2	2,8
Total	217,4	100,0

Source: Survey data.

We observe that the current production plan of the "average farm", which emerged from our research, consists of arable crops and trees. Specifically, 6.5% of the total area is cultivated with soft wheat, 13.3% with durum wheat, 2.5% with barley, 6.9% with vetch, 49.2% with maize, 1.7% with sugarbeet, 0.7% with cotton, 15.7% with alfalfa, while the tree-growing area was covered by 0.5% with cherries and by 0.3% with pears. Finally, the "average farm" has set aside 2.8% of the total cultivated area.

4.1. Application of the Linear Programming (LP) Model

As we mentioned before, initially we used the linear programming model for farm planning. Simple linear programming model was applied in order to maximize total gross margin for the "average farm" by using the two scenarios of the action 2.1.

4.1.1. Results of Linear Programming for Scenario A

By applying the linear programming model for Scenario A, we got the optimum production plan. The results show that the farmers abandon the cultivation of cotton and sugar beet, since the optimal production plan does not propose their cultivation . We also observe a decrease by -74.88% in the cultivated area of alfalfa, by -35.24% in the cultivated area of maize, and -6.30% in the cultivated area of pears.

Table 2 - Comparison between current and optimal production plan.

Crops	Current Production Plan	Optimal Production Plan	Difference
Soft Wheat	6,5	9,10	40,94%
Durum Wheat	13,3	19,95	50,39%
Barley	2,5	3,75	52,77%
Vetch	6,9	8,28	19,36%
Maize	49,2	31,86	-35,24%
Sugarbeet	1,7	0,00	-100,00%
Cotton	0,7	0,00	-100,00%
Alfalfa	15,7	3,94	-74,88%
Cherries	0,5	0,75	56,17%
Pear	0,3	0,25	-6,30%
Maize Set Aside		7,97	
Sugarbeet Set Aside		1,71	
Cotton Set Aside		0,69	
Alfalfa Set Aside		11,75	
Total Set Aside	2,8	22,12	677,58%
Total	**100,0**	**100,0**	

In addition, it is proposed to increase by 56.17% the cultivation area of cherry trees, by 52.77% the area of barley, by 50.39% the area of durum wheat, by 40.94% the land of soft wheat and by 19.36% the area of vetches. Finally, it is suggested that 22.12% of the total cultivates area of the "average farm" should be set aside in order to follow the rules of the action 2.1. The comparison between the current production plan and the optimal production plan obtained by linear programming model under the Scenario A of the action 2.1 is presented in the following Table 2.

In order to further analyze the impacts from the implementation of the models, we have computed some attributes such as total gross margin, fertilizers use, labour use and water demand. From the comparison of the current and optimal production plan we observe that gross margin is increased by 1.17%. Also, we observe a reduction in fertilizers use by 30% which is in line with the conditions of participating in the action 2.1 "Protection of nitrates sensitive areas'. Regarding the labour use we observe a reduction of 39.69%, due to increased set aside and finally water demand decrease by 46,18%.

Table 3 - Comparison between current and optimal production plan.

Gross margin	**1,17%**
Fertilizers use	**-30,00%**
Labour use	**-39,69%**
Water demand	**-46,18%**

4.1.2. Results of Linear Programming for Scenario B

The results show that the farmer has to make a reduction of 46.34% in cultivated area of sugarbeet, 21.46% in maize, 6.30% in pears and 5.27% in cotton cultivation. There is an increase by 56.17% in cherries, 52.77% in barley, 50.39% in durum wheat, 40.94% in soft wheat and an increase by 19.36% in vetch. The participation of set aside in optimal production plan was reduced -3.03% by compared with the current production plan. The comparison between the current production plan and the optimal production plan resulted from Scenario B as reported in Table 4.

From the comparison of the current and optimal production plan we observe that gross margin is increased by 10.87%. Also, we observe a reduction in fertilizers use by 30% which is in line with the conditions of participating in action 2.1 "Protection of nitrates sensitive areas'. Regarding the labour use we observe a reduction of 13.25%, due to increased set aside and finally water demand decrease by 16,77%.

Table 4 - *Comparison between current and optimal production plan.*

Crops	Current production plan	Optimal production plan	Difference
Soft Wheat	6,5	9,10	40,94%
Durum Wheat	13,3	19,95	50,39%
Barley	2,5	3,75	52,77%
Vetch	6,9	8,28	19,36%
Maize	49,2	38,65	-21,46%
Sugarbeet	1,7	0,92	-46,34%
Cotton	0,7	0,66	-5,27%
Alfalfa	15,7	14,94	-4,75%
Cherries	0,5	0,75	56,17%
Pear	0,3	0,25	-6,30%
Maize Set Aside		1,93	
Sugarbeet Set Aside		0,05	
Cotton Set Aside		0,03	
Alfalfa Set Aside		0,75	
Total Set Aside	2,8	2,76	-3,03%
Total	**100,0**	**100,0**	

4.2. Application of Bilevel Linear Programming (BLP) Model

During the simulation of mathematical model of bilevel linear programming for "average farm", the first level "leader" is the farmer and his efforts to maximize his income. The "leader" is trying to maximize gross margin based on specific quantities of inputs (land, labour, capital). The second level "follower" is trying to minimize the fertilizers use. The level of "follower" desires to calculate the optimal crop plan for each product to have a minimal fertilizers use.

4.2.1. Results of Bilevel Linear Programming for S-cenario A

After applying the bilevel linear programming model for Scenario A, the optimal production plan was developed as shown in Table 6. The results suggested that farmers should abandon sugar beet, cotton and alfalfa cultivations. Then, there is a 35.66% decrease in the cultivated area of maize, and 6.30% decrease in the pear-growing area. There is an increase of 56.17% in the cultivated area of cherry trees, 52.77% in the area of barley, 50.39% in the area of durum wheat, 40.94% of soft wheat and a 19.36% increase in the cultivated area of vetch. The participation of set aside in optimal production plan increases as compared with the current production plan by 26.25% of the total cultivated area of the "average farm".

Table 5 - *Comparison between current and optimal production plan.*

Gross margin	**10,87%**
Fertilizers	**-30,00%**
Labour	**-13,25%**
Water demand	**-16,77%**

From the comparison of the current and optimal production plan we observe that gross margin is decreased by -3.90%. Also, we observe a reduction in fertilizers use by 33.97% which is in line with the conditions of participating in the action 2.1 "Protection of nitrates sensitive areas'. Regarding the labour use we observe a reduction of 45.38%, due to increased set aside and finally water demand decrease by 52.63%.

Table 6. *Comparison between current and optimal production plan.*

Crops	Current production plan	Optimal production plan	Difference
Soft Wheat	6,5	9,10	40,94%
Durum Wheat	13,3	19,95	50,39%
Barley	2,5	3,75	52,77%
Vetch	6,9	8,28	19,36%
Maize	49,2	31,66	-35,66%
Sugarbeet	1,7	0,00	-100,00%
Cotton	0,7	0,00	-100,00%
Alfalfa	15,7	0,00	-100,00%
Cherries	0,5	0,75	56,17%
Pear	0,3	0,25	-6,30%
Maize Set Aside		8,16	
Sugarbeet Set Aside		1,71	
Cotton Set Aside		0,69	
Alfalfa Set Aside		15,69	
Total Set Aside	2,8	26,25	822,94%
Total	**100,0**	**100,0**	

4.2.2. Results of Bilevel Linear Programming for S-cenario B

The results show that the farmer is suggested to abandon the cultivation of sugar beet and pear. We also note that we have a reduction of 18.47% in the cultivated area of maize, 13.28% in the cultivated area of cherries, 5.27% in cotton and 4.75% reduction in the cultivation of alfalfa. On the other hand, there is an increase by 52.77% in barley, 50.39% in durum wheat, 40.94% in soft wheat and 19.36% in vetch cultivation. The participation of set aside in optimal production plan was reduced compared with the current production plan -2.05%. The comparison between the current production plan and the optimal production plan resulting under Scenario B is presented in Table 8.

Table 7 - *Comparison between current and optimal production plan*

Gross margin	**-3,90%**
Fertilizers Use	**-33,97%**
Labour	**-45,38%**
Water demand	**-52,63%**

From the comparison of the current and optimal production plan we observe that gross margin is increased by 3.59%. Also, we observe a reduction in fertilizers use by 31.71% which is in line with the conditions of participating in the action 2.1 "Protection of nitrates sensitive areas'. Regarding the labour use we observe a reduction of -14.66%, due to increased set aside and finally water demand decrease by 16,88%.

Table 8 - *Comparison between current and optimal production plan.*

Crops	Current production plan	Optimal production plan	Difference
Soft Wheat	6,5	9,10	40,94%
Durum Wheat	13,3	19,95	50,39%
Barley	2,5	3,75	52,77%
Vetch	6,9	8,28	19,36%
Maize	49,2	40,12	-18,47%
Sugarbeet	1,7	0,00	-100,00%
Cotton	0,7	0,33	-52,43%
Alfalfa	15,7	14,94	-4,75%
Cherries	0,5	0,75	56,17%
Pear	0,3	0,00	-100,00%
Maize Set Aside		2,01	
Sugarbeet Set Aside		0,00	
Cotton Set Aside		0,03	
Alfalfa Set Aside		0,75	
Total Set Aside	2,8	2,79	-2,05%
Total	**100,0**	**100,0**	

5. Comparison of Results

The following table shows the results of linear programming and the bilevel linear programming for both scenarios applied to the action 2.1 "Protection of nitrates sensitive areas".

Table 9 - *Comparison between current and optimal production plan.*

Gross margin	3,59%
Fertilizers use	-31,71%
Labour use	-14,66%
Water demand	-16,88%

We can proceed in two different comparisons. First, the comparison between scenarios A and B in order to see which of the scenarios is more appropriate for farmers who participate in the action 2.1 and the second comparison between the bilevel linear programming with linear programming to see which model achieves both the two conflicting goals we have set for farmers and for society.

Table 10 - *Comparison between results of scenario A and scenario B.*

	Linear Programming		Bilevel Programming	
	A	**B**	**A**	**B**
Gross margin	1,17%	10,87%	-3,90%	3,59%
Fertilizers use	-30,00%	-30,00%	-33,97%	-31,71%
Labour use	-39,69%	-13,25%	-45,38%	-14,66%
Water demand	-46,18%	-16,77%	-52,63%	-16,88%

The comparison between the scenarios shows that the Scenario B, which includes a combination of rotation, reduction of fertilizers uses and set aside, seems to give better results for the farmers than Scenario A. Specifically, linear programming model, under scenario B, gives an increased gross margin by 10.87% compared with the current production plan, while Scenario A gives only 1.17% increase compared with the current production plan. Total fertilizers use in both scenarios decreased by 30% as set by the rules in participating into action 2.1. On the other hand, the bilevel linear programming shows that Scenario B has better results for farmers, since the total gross margin is increased by 3.59% while fertilizers use is reduced by 31.71% compared to Scenario A showing that total gross margin is reduced by 3.90% and gives higher reduction in fertilizers use 33.97%.

The second comparison between linear and bilevel linear programming shows that linear programming has better economic results for farmers in the maximization of total gross margin. On the other hand it does not achieve satisfactory social benefits in reducing the fertilizer use, since the reduction of fertilizer use is linked to the limits set by the constraints of the problem. The bilevel linear programming, by definition, is trying to achieve the perfect combination between two conflicting goals. Thus, the results show that BLP reduces the fertilizers use by more than 30% which was the limit set by action 2.1, while maintaining a nearly flat level compared with the current production plan in gross margin for the farmers. Specifically, the reduction in total gross margin is 3.90% in Scenario A and increases by 3.59% in Scenario B. The corresponding reduction in the fertilizers use is 33.97% in Scenario A and 31.71% in Scenario B.

Finally, regarding the total labour use we can see that both linear and bilevel linear programming in Scenario A shows a greater reduction than in Scenario B, since it uses set aside, compared with the rotation of the second scenario.

6. Conclusions

This paper presents a bilevel linear programming model for farm planning in agricultural areas that are sensitive to nitrates. The model developed consists of two levels of which the first goal is pursued by the farmers, and comprises the first level of BLP, and the second goal is pursued by the society, through the government, and comprises the second level of BLP. The first of the two hierarchical levels concerns the maximization of farm gross margin and the second level concerns the minimization of fertilizers use that we assume society cares for, since it results in a cleaner environment.

The results were compared with those of the simple linear programming model (LP) and we observed that the BL model satisfies the two goals we set, differently from the Linear model that is able to satisfy only one independent goal each time. On the other hand, results showed that the linear programming model gives better economic results for farmers, after achieving the unique goal, to maximize total gross margin. The drawbacks are that it ignores the social benefit, which we determined in this study as the environmental goal of reducing the fertilizers use. The bilevel linear programming under the second scenario manages to combine the two conflicting goals set in the model at the two different levels of the farmers and of the society as expressed by the action 2.1 "Protection of nitrates sensitive areas". BLP model achieved to increase the total gross margin of the farmer but also achieved to reduce fertilizers use. Regarding the comparison between the two scenarios proposed for the participation of farmers in action 2.1 we can conclude that Scenario B (combination of crop rotation – reduction of fertilizers use and set aside) has more economic benefits to farmers in relation to Scenario A (combination of permanent Set aside and reduction of fertilizers use). Regarding the reduction of fertilizers use for the social benefit we can conclude that scenario A has better results but they are very close to those of Scenario B. Finally, regarding the total labour use, the second social goal, we observe that Scenario B shows lower decrease in employment in comparison to Scenario A which is perfectly normal, since the permanent set aside (Scenario A) does not require many working hours in comparison to the rotation proposed by Scenario B.

Focusing on the policy issues of this research, we conclude that though Agrienvironmental Schemes policy as a single instrument is not enough, however it could reduce significantly the consumption of fertilizers. The results of simulation showed that when Agrienvironmental Schemes policy measures are implemented they cause important changes in the existing plans. This will obviously have a positive impact on the reduction of non-point chemical pollution by agriculture. Therefore, agri-environmental schemes policy is proposed in combination with an improvement of agricultural practices and the adoption of new technologies taking into account the particular characteristic of the region, and in accordance with other national policies.

7. References

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