Farm planning in nitrate sensitive agricultural areas

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Abstract: One of the main aims of the Rural Development Plan under the EU Common Agricultural Policy is the protection of nitrate sensitive areas through agri-environmental schemes. This paper presents a mathematical programming model for farm planning in agricultural areas that are sensitive to nitrates. A bilevel linear programming (BLP) model is developed, that can achieve the optimal farm production plan assuming two conflicting goals: the maximisation of farm gross margin and the minimisation of fertilisers' use. The first goal is pursued by farmers, and comprises the first level of BLP. The second goal is pursued by society, through the government, and comprises the second level of BLP. The model is applied to an agricultural area in Northern Greece, which belongs to the nitrate sensitive areas scheme of the Greek Rural Development Plan 2007–2013. The model is further used to simulate the impacts of the measure under two scenarios proposed for farms located in nitrate sensitive areas. The result shows that the model can achieve the two goals set by increasing gross margin and reducing fertilisers use.

Keywords: farm planning; bilevel linear programming; BLP; nitrate sensitive areas; NSAs; agri-environmental schemes; AESs.

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1 Introduction

Excessive use of agricultural fertilisers has been found to damage human health and the environment. In order to reduce the negative consequences of fertilisers, the European Union (EU) has adopted measures to reduce nitrate use in agriculture. In 1991, EU legislated the nitrates directive in order to promote the optimal use of nitrate fertilisers in agriculture, relying upon all future agri-environmental schemes (AESs) for its implementation (Grossman, 2000). In addition, the concept of AESs was introduces, as a main part of the second pillar of the EU Common Agricultural Policy (CAP) (Mettepenningen, 2010). AESs financially compensate farmers for their income losses associated with measures that aim to benefit the environment (Kleijn and Sutherland, 2003). Furthermore, EU members states are obliged to evaluate their AESs with respect to their socioeconomic, agricultural and environmental aspects [Article 16, Regulation

(EC) No. 746/96]. According to Kleijn and Sutherland (2003) main objectives of AESs include reducing nutrient and pesticide emissions, protecting biodiversity, restoring landscapes, preventing rural depopulation, and protecting nitrate sensitive areas (NSAs).

NSAs according to Dobbs and Pretty (2001) were designed to limit nitrate leaching into aquifers used to supply drinking water. One of the measures of the agri-environmental schemes is the protection of NSAs. This measure belongs to the second pillar of CAP and especially in the Rural Development Plan measures. Rural Development Plan sets out measures that attempt to tackle the challenges facing rural areas (Salvioni and Sciulli, 2011). The participation of farmers in AESs is voluntary and were offered incentives for following strict farming practices that limit leaching (Dobbs and Pretty 2001).

Damianos and Giannakopoulos (2002) examined the factors influencing the farmers' uptake of agri-environmental measures. Factors such as agricultural education/training of the farmers, the farm's economic size, participation by neighbours or relatives, age and general education, can influence the voluntary participation in the agri-environmental measures, and more precisely in the protection of NSAs action. Thus, both the EC Nitrates Directive and the AESs help reduce the use of nitrate fertilisers in NSAs. All these measures help farmers achieve maximum efficiency of nitrate fertilisers in cultivation, using methods and environmentally friendly practices, by altering the farm plan.

Farm planning usually employs linear or non-linear mathematical programming models. The classical mathematical programming model is used mainly in problems with one decision maker and for this reason has one objective function. 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 farmers give weight to more than one factor, a goal programming model is more suitable. Goal programming includes a linear programming (LP) model, 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). In addition, 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, 2008, 2010). On the other hand, in the case of multilevel mathematical programming, more than one decision makers are 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 bilevel linear programming (BLP) model is a multilevel mathematical programming problem with two levels. The first appearance of BLP was in 1973 in the work of Bracken and McGill (1973), although the first who used the term bilevel, and multilevel programming was the Candler and Norton (1977). However, only in the early 1980s due attention was given to these problems. The Stackelberg (1952) game is a problem of mathematical game theory identical to the BLP. Taking motivation from Stackelberg, many authors studied the BLP intensively contributing to the mathematical programming literature.

The main objective of this paper is to estimate the optimal farm plan in a NSA, employing a BLP model that can achieve the optimal production plan assuming two

conflicting goals: the maximisation of gross margin and the minimisation of fertilisers' use. The first goal is pursued by the farmers and comprises the first level of BLP. The second goal is pursued by the society, through the government, and comprises the second level of BLP. The model is applied to an agricultural area in Northern Greece, which belongs to the NSAs scheme of the Greek Rural Development Plan 2007–2013.

The paper is organised as follows. In the following section, a literature review of agri-environmental schemes across Europe is presented. In Section 3, the BLP model is presented, followed by the application in Section 4. Section 5 discusses the main results of the BLP model, followed by a comparison between scenarios in Section 6. The final section concludes.

2 Agri-environmental schemes across Europe

This section analyses the implementation of agri-enviromental schemes across Europe according to a study made by Kleijn and Sutherland (2003). The agri-environmental schemes vary between EU member-states. According to Louloudis et al. (2000), in Greece agri-environmental schemes address primarily organic plant production, organic livestock production, 20-year set aside, reduction of nitrogen pollution and conservation of endangered breeds (Kleijn and Sutherland, 2003). In the UK, agri-environmental schemes are aimed to maintain wildlife in the countryside, to protect NSAs and to provide organic aid (Kleijn and Sutherland, 2003). There is a strong emphasis in the UK AESs on wildlife conservation. Wildlife conservation in the wider countryside is addressed by the countryside stewardship scheme (Hart and Wilson, 2000). In Spain, paying special attention to agri-environmental schemes is mainly related to landscape conservation in the prevention of fires in extensive grasslands (Kleijn and Sutherland, 2003). Preliminary data from a study made by Peco et al. (2000) indicate that landscape conservation and fire prevention in grasslands are the two AESs with the highest uptake rates. Kleijn and Sutherland (2003) argue that in Germany agri-environmental schemes mainly include actions aimed at changing agricultural practices and schemes aimed at the protection of the environment, natural resources, countryside and landscape, which are zonal in some of the states. German AESs can be divided in two main types. The first type aim is to change the farming practices and second type aim is to preserve specific environmentally vulnerable areas, biotopes or species (Grafen and Schramek, 2000). In Italy, each region has its own agri-environmental schemes. Highest concentration is given in the reduction of fertiliser and pesticides use in agricultural practices and in the maintenance of countryside and landscape (INEA, 1999). France AESs aims to maintain agricultural activities in areas with high possibility of agricultural land abandonment and rural depopulation (Buller and Brives 2000).

3 Bilevel linear programming

The classic Mathematical Programming model refers mainly to decision problems with one decision maker and for this reason has one objective function, or in the case of Multiobjective Mathematical Programming, more than one objective functions (Bracken and McGill, 1973). All the objective functions are controlled by one decision maker, which tries to balance his priorities between them. In the case of Multilevel Mathematical

Programming more than one decision makers are involved at different hierarchical levels in the decision making process and the mathematical model must maintain the structure of the respective levels of hierarchy. According to Dempe (2003) "Bilevel programming problems are hierarchical optimisation problems in the sense that their constraints are defined in part by a second parametric optimisation problem". Thus, in this case the constraints of the problem involve other mathematical models that represent decision-makers who are lower in the hierarchy.

In the case of bilevel linear programming, the upper level corresponds to the 'leader' and the lower to the 'follower'. $x \in XCR^n$, $y \in YCR^m$, $F: X \times Y \rightarrow R^1$ For the bilevel linear problem can be written in the following format (Dempe, 1996):

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

subject to $A_1 x + B_1 y \leq b_1$

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

subject to $A_2 x + B_2 y \leq b_2$

where c_1, $c_2 \in R^n$, d_1, $d_2 \in R^m$, $b_1 \in R^p$, $b_2 \in R^q$, $A_1 \in R^{p \times n}$, $B_1 \in R^{p \times m}$, $A_2 \in R^{q \times n}$, $B_2 \in R^{q \times m}$ Sets x and y are additional constraints on the variables, e.g., the upper and lower limits.

The BLP model consists of two sub problems: 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 $f(x, y)$. According to Floudas and Pardalos (2004) "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 minimises 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 makes use of the complete information set, including the follower's possible reaction to the leader's decision in the decision making process (Dempe, 2002).

4 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 (2002) in his book *Foundations of Bilevel Programming* presents a model of bilevel linear programming as the ideal model for problems of environmental conflict, where the farmer pollutes the environment during the production period and the consumer demands a clean environment in which he acts and consumes the farmers' products. In this context, present applications of bilevel linear programming problems in environmental policy (Dempe, 1996) approach the problem that we study.

In farm planning, the farmer is usually interested to maximise their gross margin. On the other hand, society cares for a clean environment in which it operates and acts. These two criteria are conflicting, as the farmer tries to achieve maximisation of farm gross

margin using plant protection products, pesticides and fertilisers and their excessive use pollutes the environment. The model developed consists of two levels of which the first goal is pursued by the farmers and comprises the first level of the BLP and the second goal is pursued by the society, through the government, and comprises the second level of the BLP.

We chose these two goals under the following assumptions. We assume that farmers belong to the first level and they have only one goal, to maximise their gross margin. Therefore, in order to maximise their gross margin they produce crops that will generate the maximum economic benefit, without regard for environmental consequences from the cultivation of these products. On the other hand, society wants to reduce the environmental burden. In order to analyse farm planning in nitrate sensitive agricultural areas we have developed a case study at an agricultural area in Northern Greece. The role of defending the demands of 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. With the implementation of this action, several environmental goals are achieved by reducing the amount of fertilisers 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 programme defines to the farmers the price levels of subsidies and the restrictions on land use, nitrate fertiliser and water use and sets two different scenarios of 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.

4.1 Goals

The bilevel linear programming is similar to the linear programming model, with the difference being the area of constraints, which include a limitation as a linear objective function, creating a nested optimisation 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:

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

where the goal of the second level is a conflicting goal of the first level:

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

where y solves the:

$$\max_y \left\{ -cx - dy \right\}$$

subject to:

$$Ax + By \le b$$

$$x, y \ge 0$$

The goals included in the bilevel linear programming model are:

1 Maximisation of the farmer' gross margin and belongs to the first level ('leader'). The objective function to maximise gross margin which is included in the model is:

$$\max GM = \sum GMi\ x\ Xi$$

2 Minimising the fertilisers' use and belongs to the choices of society, since it is a social goal, and belongs to the second level ('follower'). The objective function to minimise the fertilisers' use:

$$\min FER = \sum FERi\ x\ Xi$$

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

$$\min FER = -\left(\sum FERi\ x\ Xi\right)$$

The two goals mentioned above are sufficient to develop a model for farm planning which involves more than one decision maker and uses two conflicting criteria.

The model can be written in the following mathematical form:

$$\max_{GM} = \left\{\sum GMi\ x\ Xi\right\}$$

where y solves the:

$$\max_{FER} = \left\{-\sum FERi\ x\ Xi\right\}$$

subject to:

$$Ax + By \leq b$$

$$x, y \geq 0$$

4.2 Constraints and scenarios

The constraints arise from a questionnaire survey of farms, from farmer's data, but also from the conditions for participating in the Action 2.1 "Protection of nitrate sensitive areas". Thus, we used constraints for the total cultivated land, for irrigated and non-irrigated land, for variable costs, for total labour, from CAP constraints and for the market and other constraints. In addition, constraints for participating in the Action 2.1 "Protection of nitrate sensitive areas" are used.

As described in previous section the participation in the action for farmers is voluntary. Farmers who want to participate in the action receive a payment as a compensation for any loss of income associated with measures that aim to benefit the environment. Participating in the measure requires the acceptance of the conditions from the farmers' side. One of the current conditions is to choose between the two proposed scenarios. There are two scenarios, pursuant to which we put constraints on the bilevel linear programming model. Same levels of payments in both scenarios are used.

- *Scenario A:* 'Combination of permanent set aside and reduction in fertilisers 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 Fertilisers use. Reduce 30% of the total fertilisers use in relation to the fertilising action of the respective programs to the remaining 75% of the area.
- *Scenario B:* 'Combination of rotation – reduction of fertilisers 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 five 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 Fertilisers use. Reduce 30% of the total fertilisers use in relation to the fertilising action of the respective farm plan, both at 75% of main crop and 20% of the crop rotation.

5 Application of the farm planning model

The model is applied to an agricultural area in Northern Greece, which belongs to the nitrate sensitive areas scheme of the Greek Rural Development Plan 2007–2013. Specifically, we based our analysis on data from a survey of a random sample of 24 farms in areas that participate in the agri-environmental schemes of the Greek RDP 2007–2013, and particularly in its Action 2.1 "Protection of nitrate sensitive areas". The existent production plan of the average farm (Table 1), 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 hard 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 trees cultivated area was covered by 0.5% cherries and 0.3% pears. Finally, the average farm had set aside 2.8% of the total cultivated area.

Table 1 Production plan of the average farm

Crops	*ha*	*%*
Soft wheat	14.0	6.5
Hard 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

Table 2 Comparison between existent and optimal production plans under Scenario A
between existent and optimal production plans under Scenario A

Crops (ha)	*Existent production plan*	*Optimal production plan*	*Difference*
Soft wheat	6.5	9.1	40.94%
Hard wheat	13.3	20.0	50.39%
Barley	2.5	3.8	52.77%
Vetch	6.9	8.3	19.36%
Maize	49.2	31.7	–35.66%
Sugarbeet	1.7	0.0	–100.00%
Cotton	0.7	0.0	–100.00%
Alfalfa	15.7	0.0	–100.00%
Cherries	0.5	0.8	56.17%
Pear	0.3	0.3	–6.30%
Maize set aside		8.2	
Sugarbeet set aside		1.7	
Cotton set aside		0.7	
Alfalfa set aside		15.7	
Total set aside	2.8	26.3	822.94%
Total	*100.0*	*100.0*	
Gross margin (€)	43,948.2	42,235.0	*–3.90%*
Fertilisers use (kg)	18,181.3	9,930.6	*–33.97%*
Labour (hours)	23,320.8	15,398.5	*–45.38%*
Water demand (m^3)	384,362.9	182,071.0	*–52.63%*

5.1 Results of bilevel linear programming for Scenario A

The results of the bilevel linear programming for Scenario A suggest the abandonment of sugar beet, cotton and alfalfa cultivations (Table 2). There is a decrease of 35.66% in the cultivated area of maize, and 6.30% in the cultivated area of pears. In addition, 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 hard wheat, 40.94% of soft wheat and an increase 19.36% in the cultivated area of vetch. The participation of set aside in the optimal production plan increases, as compared with the existent production plan, by 26.25% of the total cultivated area of the average farm.

From the comparison of the existent and optimal production plans we observe that gross margin decreased by –3.90%. In addition, we observe a reduction in fertilisers' use by 33.97%, which is in line with the conditions of participating in the Action 2.1 "Protection of nitrate sensitive areas". Regarding labour use, we observe a reduction of 45.38%, due to increased set aside and finally water demand decreased 52.63%.

5.2 Results of bilevel linear programming for Scenario B

The results of the bilevel linear programming for Scenario B suggest abandonment of the cultivations of sugar beet and pear (Table 3). We also note a reduction of 18.47% in the cultivated area of maize, 13.28% in the cultivated area of cherries, 5.27% in the cultivated area of cotton and 4.75% reduction in the cultivated area of alfalfa. On the other hand, there is an increase of 52.77% in barley, 50.39% in hard wheat, 40.94% in

soft wheat and 19.36% in vetch cultivation. The participation of set aside in the optimal production plan is reduced, compared with the existent production plan, by –2.05%.

Table 3 Comparison between existent and optimal production plans under Scenario B

Crops (ha)	*Existent production plan*	*Optimal production plan*	*Difference*
Soft wheat	6.5	9.1	40.94%
Hard wheat	13.3	20.0	50.39%
Barley	2.5	3.8	52.77%
Vetch	6.9	8.3	19.36%
Maize	49.2	40.1	–18.47%
Sugarbeet	1.7	0.0	–100.00%
Cotton	0.7	0.7	–52.43%
Alfalfa	15.7	14.9	–4.75%
Cherries	0.5	0.4	56.17%
Pear	0.3	0.0	–100.00%
Maize set aside		2.0	
Sugarbeet set aside		0.0	
Cotton set aside		0.0	
Alfalfa set aside		0.7	
Total set aside	2.8	2.7	–2.05%
Total	*100.0*	*100.0*	
Gross margin (€)	43,948.2	45,525.9	3.59%
Fertilisers use (kg)	18,181.3	12,416.0	–31.71%
Labour use (hours)	23,320.8	19,902.0	–14.66%
Water demand (m^3)	384,362.9	319,482.4	–16.88%

From the comparison of the existent and optimal production plans we observe that gross margin is increased by 3.59%. In addition, we observe a reduction in fertilisers' use by 31.71%, which is in line with the conditions of participating in the Action 2.1 "Protection of nitrate sensitive areas".

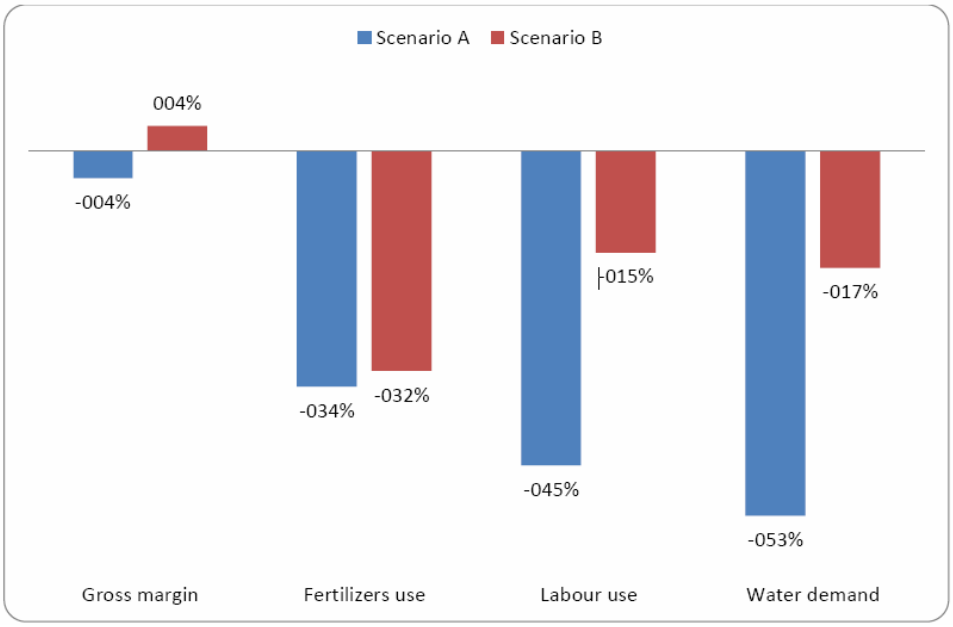
Regarding labour use, we observe a reduction of –14.66%, due to increased set aside and finally water demand decreased by 16.88%.

5.3 Comparison between scenarios

The comparison between the two scenarios shows that Scenario B, which includes a combination of rotation – reduction of fertilisers uses and set aside, seems to give better results for the farmers than Scenario A. More specifically, the bilevel linear programming shows that Scenario B has better results for farmers, since the total gross margin is increased by 3.59% while fertilisers use is reduced by 31.71%, compared to Scenario A, showing total gross margin is reduced by 3.90% and gives higher reduction in fertilisers' use by 33.97% (Figure 1). Regarding labour use, Scenario A achieves a 45.38% reduction and Scenario B a 14.66% reduction. The water demands for Scenario A are reduced by 52.63% and for Scenario B are reduced by 16.88%. To conclude, the BLP in Scenario B

model achieved to increase the total gross margin of farmers but also achieved to reduce the fertilisers' use for society.

Figure 1 Comparison between results of Scenario A and Scenario B (see online version for colours)



6 Conclusions

This paper presents a mathematical programming model for farm planning in agricultural areas that are sensitive to nitrates. A BLP model is developed, that can achieve the optimal farm production plan assuming two conflicting goals: the maximisation of farm gross margin and the minimisation of fertilisers' use. The model developed consists of two levels of which the first goal is pursued by the farmers, and comprises the first level of BLP (concerns the maximisation of farm gross margin), and the second goal is pursued by the society, through the government, and comprises the second level of BLP (concerns the minimisation of fertilisers use').

Regarding the comparison between the two scenarios, proposed from the nitrate sensitive areas scheme of the Greek Rural Development Plan 2007–2013, we can conclude that Scenario B (combination of crop rotation – reduction of fertilisers use and set aside) has more economic benefits to farmers in relation to the Scenario A (combination of permanent Set aside and reduction of fertilisers use). Since the AES is based on voluntary mechanism and profit maximisation is essential for farmers we can conclude from the results that farmers will adopt the second scenario proposed by the participating conditions. Scenario B is expected to achieve both goals set by the model definition. Regarding the reduction of fertilisers' use which is essential for society, we can conclude that Scenario A has better results but these are very close to those of

Scenario B. On the other hand, regarding total labour use, which consists the second social goal, we observe that Scenario B results have lower decrease in labour use in comparison to Scenario A. This is due to the permanent set aside proposed by Scenario A which requires less working hours in comparison to the rotation proposed by Scenario B. Finally, the water demand has higher decrease when the Scenario A is implemented than Scenario B. This reduction is the result of the high percentage of set aside in the optimal production plan. Therefore, the results suggest that Scenario B manages to best combine the two conflicting goals set in the model at the two different levels, of farmers and of society.

The results of this study may have shortcomings but could be a useful tool for farmers who want to participate in AESs Action 2.1 "Protection of nitrate sensitive areas". The contribution of this study helps the farmers in choosing between the two proposed scenarios despite the remarkable differences among nitrate sensitive agricultural areas.

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