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ORIGINAL PAPER

Minimizing adverse environmental effects of agriculture: a multi-objective programming approach

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Abstract The mitigation of adverse effects of agriculture on ecosystems, due to the use of agrochemicals and irrigation water, is expected to have implications on farm incomes. This study examines the possibilities of simultaneously achieving environmental goals such as the reduction of agrochemical and irrigation water use as well as acceptable farm incomes. The empirical analysis employs the multi-objective programming method in order to define alternative crop plans for River Strymonas region in Greece. The results reveal considerable possibilities for reducing input use as well as severe impact on incomes in terms of gross margin, which indicate a wide range of policy options. It is argued that the choice of the ideal solution should be based on several criteria including non-market values of environmental benefits, the particular objectives of policy makers and human preferences, especially the acceptance of each crop plan by stakeholders.

Keywords Multi-objective programming · Agrochemical use · Water resources · Irrigation

Mathematics Subject Classification (MSC) 90C29

1 Introduction

Agriculture is characterized by the performance of a wide range of functions, which constitute its multifunctional character (OECD 2001). During the past few years it

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has been established that, apart from its productive role, the agricultural sector is the main source of income and employment in rural areas, especially where the economy is not adequately diversified. However, the benefits from sustaining agriculture in rural areas are not deprived of negative effects, as agriculture is more than often a considerable source of pressure on natural ecosystems. Particularly when it comes to protected areas, pollutants from agriculture, such as residuals of fertilizers and pesticides, impose serious threats to ecosystems, while the poor management of irrigation water directly affects surface and underground water resources.

The protection of agriculture's multifunctionality is linked to compromising conflicting policy goals: the achievement of acceptable incomes as opposed to the mitigation of threats on the environment. Hence, the introduction of an environmental-friendly model of agriculture that will also promote its social and economic role constitutes a major policy subject. The Water Framework Directive (Dir. 60/2000/EC), the bird Directive (Dir. 79/409) and NATURA 2000 Network have established several interactions between agriculture and environmental degradation. Furthermore, changes in the crop plans that stem from changes in agricultural markets due to the revised Common Agricultural Policy (Reg. 1782/2003) are expected to affect income levels and total input requirements in the sector so changes are expected in the accomplishment of the aforementioned policy objectives.

These conflicting policy objectives can be achieved by introducing new farming practices or new crops. Nevertheless, they can also be achieved by changing the crop plan alone, keeping existing crops and current farming practices. The latter is a rather interesting issue, given the pattern of mediterranean agriculture, consisting of a considerable range of crops (Muthmann 2002). An examination of effects from introducing alternative crop plans yields important policy considerations which can inform decision-making for agriculture on catchment scale.

The established method for examining the possibilities for reconciling such objectives is multi-criteria analysis, which provides a useful tool in policy-making. Applications of such methods in agriculture include the weighted goal programming approach (Begum et al. 2007) and the studies by Piech and Rehman (1993) and Romero and Rehman (1989) who employed the multi-objective programming method. Within the latter, conflicting objectives are simultaneously optimized subject to constraints in order to define an efficient set of solutions. Other applications of such methods are presented by Manos (1991), Manos and Gavezos (1995), Berbel and Rodriguez-Ocana (1998), Gomez-Limon et al. (2002) and Manos et al. (2006).

The purpose of this paper is to examine the possibilities of reducing the use of noxious pesticides, fertilisers and irrigation water, while sustaining incomes from agriculture in Strymonas basin in Greece. The empirical analysis employs a multi-objective programming approach and is based on technical and economic indicators from a sample of local farms. It is demonstrated that the alternative crop plans vary substantially in terms of economic and environmental performance. It is proposed that the choice of the most preferred management scenario can be based on several criteria, including human preferences and expert judgements.

The paper unfolds as follows. The following section provides a description of agriculture in Strymonas region, as well as of interdependencies between input use in agriculture and environmental quality. Section 3 provides the methodological framework for the analysis including data collection. In Sect. 4 the results of the empirical analysis are reported and a discussion is presented. Section 5 includes the conclusions of the analysis.

2 The area of Strymonas basin

Strymonas basin is situated in northern Greece, near the border with Bulgaria. It covers an area of 640,000 ha, where River Strymonas and artificial Lake Kerkini are main surface water bodies. The natural ecosystem they formulate is one of the most important in Greece and is protected under the RAMSAR Convention and EU Regulations and Directives. It provides a wide variety of habitats to protected bird and animal species and supports important fauna.

The main feature of agriculture in Strymonas basin is the predominance of few irrigated crops, mainly cotton, maize, lucerne, sugar beet, tomato, tobacco and rice, while non-irrigated areas are cultivated with winter cereals, mainly wheat. The majority of locals are full-time farmers or supplement their incomes by undertaking some agricultural activity so agriculture supports the incomes and the employment in the catchment. However, agriculture is a major source of environmental pressure in the region (Halkidis and Papadimos 2007) due to overuse of natural resources, especially irrigation water, and agrochemicals, whose residuals pollute water resources. These non-source points of pollution (Hitchens et al. 1978; Thampapillai and Sinden 1979; Burton and Martin 1987; Pretty et al. 2000) threaten water ecosystem functions and biodiversity. In addition, ineffective irrigation methods impose further threats to water reserves. This intensive pattern of agriculture in the area merely deteriorates its, otherwise adverse, effects.

Minimizing agricultural pressure on the ecosystem is linked to decreasing the use of fertilizers, especially nitrogen, pesticides and the direct use of irrigation water, which seriously threatens surface or underground water reserves. Nevertheless, the use of these inputs is the basis of agricultural productivity in the area, as the agricultural policy measures in force until 2003 encouraged the extension of input-intensive crops. It is expected that a reduction in the area cultivated with these crops in favor of others, with less requirements in agrochemicals and irrigation water, will mitigate pressure on the ecosystem but will also bring about income losses. Hence, the introduction of environmental-friendly farming schemes is expected to influence local economy.

This study examines the effects of changing the crop plan in the region on the level of agrochemical and irrigation water use, by maintaining the current farming practices and crops. Apart from being the result of a long-term procedure, this approach is also justified in terms of the adaptation of these crops on local conditions and on the construction of necessary infrastructure. Furthermore, the introduction of new farming systems and of new crops, however, desirable, is not expected to substitute existing crops and practices in great extend, which would yield trivial changes in the level of input use. In this context, this study employs the multi-objective programming method in order to examine the possibilities of safeguarding benefits from agriculture while minimizing the adverse effects of intensive agriculture. This method enables the investigation of the possibilities of simultaneously achieving these conflicting policy objectives by changing the crop plan alone. It is expected that changes in the acreage of each crop will bring about changes in incomes and in the level of input use.

3 Methodological framework

The construction of the multi-objective programming model is based on a farm management survey over a random sample of 250 farms in Strymonas region. The survey was conducted during a 3 year period (2004–2006), with in-person interviews, using a questionnaire designed to account for the prevailing farming practices in local farms. Data from this survey were analyzed in order to estimate technical and economic indicators of farm management practices in each one of 12 local irrigation networks. The derived indicators include yield and prices for each crop, which are used to calculate the gross margin (gross return minus variable costs), labor requirements, variable costs (including fertilisers, herbicides, insecticides, fungicides, fuel and seeds), the costs of hired machinery labor, the quantity of irrigation water requirements and irrigation costs. The subsidies provided in the 2004–2005 period are not included in the prices; therefore the gross margin does not include the result of price policy measures.

These indicators are the basis for the implementation of the multi-objective programming method, employed to elaborate alternative management schemes for agriculture in the region. Multi-objective programming is an optimization method which produces a set of non-inferior optimal solutions that achieve a set of conflicting goals under a set of constraints. The conflicting policy objectives under examination in this study are maximization of income, in terms of gross margin (Z_1), minimization in the quantity of nitrate fertilizers (Z_2), minimization in the use of pesticides (value of herbicides, insecticides, fungicides) (Z_3) and minimization in the use of irrigation water (Z_4).

Among the approaches for the solution of a multi-objective problem, this application is based on the constraint method, within which one of the objectives is optimized while the others are specified as constraints (Cohon 1978; Romero and Rehman 1989). The multiobjective programming problem for p objectives is formulated as follows

$$\text{maximize } Z(x_1,x_2,\ldots,x_n) = [Z_1(x_1,x_2,\ldots,x_n), Z_2(x_1,x_2,\ldots,x_n),\ldots,Z_p(x_1,x_2,\ldots,x_n)]$$

$$\text{subject to } (x_1,x_2,\ldots,x_n) \in F_d$$

where F_d is the decision space and (x_1, x_2,..., x_n) are activities.

This problem can be converted to the constrained problem, which is single-objective, so it can be solved by means of conventional methods.

$$\text{maximize } Z_h(x_1, x_2, \ldots, x_n)$$
$$\text{subject to } (x_1, x_2, \ldots, x_n) \in F_d$$
$$Z_k(x_1, x_2, \ldots, x_n) \geq L_k$$
$$k = 1, 2, \ldots, h-1, h+1, \ldots, p$$

In this problem, objective Z_h is arbitrarily selected for maximization. The remaining $p - 1$ objectives (Z_k) are set as constraints.

The objectives under consideration in this study formulate a set of four separate optimization problems. Each problem has uniform constraint matrix and uniform variables and is formulated as follows

$$\max(\min) \sum_{j=1}^{M} c_j x_j = Z$$

$$\text{subject to} \sum_{j=1}^{M} a_{ij} x_j \leq A_i$$

$$x_j \geq 0$$

where c_j represents the contribution of each activity (x_j) to the objective function (Z_1–Z_4) (i.e., gross margin in €/ha, quantity of nitrogen in kg/ha, value of pesticides in €/ha, quantity of water in m^3/ha) and α_{ij} are technical and economic coefficients for each activity.

The optimal value of each objective function as well as the values of the other functions under the same solution $x_k = (x_{1k}, x_{2k}, \ldots, x_{nk})$, that is

$$Z_1(x_k), Z_2(x_k), \ldots, Z_p(x_k) \quad k = 1, 2, \ldots, p$$

yield a 4×4 square matrix (pay-off matrix), of which the elements on the diagonal indicate an optimal, although infeasible, solution to the multi-objective problem. Following the pay-off matrix one determines the minimum (n_k) and the maximum (M_k) value of each function, which define the range of each objective.

The multiobjective problem can then be converted to the constrained problem. The right-hand side of the constraints, L_k, is varied in the range (n_k, M_k), which guarantees feasibility and non-inferiority for the solutions. This procedure yields three parametric programming problems, where Z_1 (maximization of gross margin) is arbitrarily chosen as the objective function and L_k (the right-hand side value of each one of the three remaining objectives) is parametrized. This procedure normally yields a large number of solutions all of which constitute an approximation of the noninferior set (Cohon 1978) and can be interpreted as the transformation curve. The next step is to reduce the efficient set of solutions by choosing the ones that differ substantially from the others, by means of a filtering technique (Romero et al. 1987).

The remaining solutions are all optimal and non-inferior, however, the bounds within which a solution compromises the conflicting objectives are defined by minimizing the distance from the optimal infeasible solution. These bounds are set by metrics L_1 and L_∞, where (1) and (∞) stand for the dimensions of the coordinates (Yu 1973). The metrics L_1 and L_∞ incorporate preferences in the analysis, of which they constitute proxy measures, therefore enabling the choice of the ideal solution from the efficient set.

This choice is also contingent upon the pursuits of policy makers. Although all solutions are alternative management schemes that achieve the conflicting objectives at various degrees, other factors, such as site-specific characteristics, may influence this choice. For this purpose, the multi-objective programming model in this study is analytically constructed over twelve blocks of variables and constraints, one for each of twelve irrigation networks, in order to simulate differences in farming conditions among networks. This specification, then, allows monitoring the implications of each scheme on the whole area as well as on each network. The objectives, variables and constraints of the multi-objective programming model are explained in Table 1.

A by-product of the analysis with the constraint method is the estimation of trade-offs among objectives, which are reflected in the reduced cost (shadow price) of each parametrized constraint (Cohon 1978). These trade-offs reflect the opportunity costs of each objective, hence they represent the amount of one objective that needs to be sacrificed in order to achieve a unit change in another objective. It is obvious that the trade-offs are expected to vary following the level of use of each input.

4 Results

The pay-off matrix is presented on the left-hand side of Table 2. The columns represent the objectives and the rows the four optimal solutions. The highlighted elements on the diagonal represent the infeasible optimal solution, by which all conflicting goals would be optimally achieved. This solution entails a gross margin of 67.58 mil €, the use of nitrogen at 4.05 mil kg, the value of agrichemicals at 5.18 mil € and irrigation water consumption at 374.3 mil m^3. Hence, a reduction of 68.9 percent can be achieved in the use of nitrogen (from 227.3 kg/ha, 13.02 mil kg to 70.7 kg/ha, 4.05 mil gr), of 59.3% in the use of pesticides (from 12.72 mil €, 222.1 €/ha to 5.81 mil €, 101,4 €/ha) and of 16.4% in the use of irrigation water (from 448.0 mil m^3, 7,821.2 m^3/ha to 374.3 mil m^3, 6,535.5 m^3/ha). Consequently, the considerable range of reduction possibilities in input use implies that the introduction of an environmental-friendly management scheme of agriculture in the region would result in substantial benefits. However, the degree of irrigation water consumption reduction possibilities is considerably smaller than other inputs, which implies inelastic demand.

The right-hand side of Table 2 presents the crop plans that correspond to the four solutions of the pay-off matrix. The first row represents the baseline solution which maximizes income. In this case gross margin is 67,58 mil € (1179.9 €/ha) which is the result of extending the area cultivated with cotton, lucerne and sugar beet (80% of total cultivated area).

The crop plan reported in the second row results in the minimization of nitrogen use (70.7 kg/ha). Its main characteristic is a substantial decrease in the area

Table 1 Objectives, variables and constraints of the multi-objective programming model

Objectives	Description
Gross margin (Z_1)	Gross margin of each crop in each irrigation network (€/ha)
Quantity of nitrogen (Z_2)	Nitrogen requirements of each crop in each irrigation network (kilos/ha)
Value of pesticides (Z_3)	Value of pesticide requirements of each crop in each irrigation network (€/ha)
Quantity of water (Z_4)	Irrigation water requirements of each crop in each irrigation network (m^3/ha)

Constraints	Coefficients	Right-hand side	Description
Irrigated land		Irrigated land in each irrigation network	12 constraints (one for each irrigation network)
Total land		Total land in each irrigation network	12 constraints (one for each irrigation network)
Labor	Labor requirements per month (h/ha) for each crop in each irrigation network	Available labor (h) in each irrigation network	144 constraints (one for each irrigation network for each month)
Variable capital	Variable capital requirements of each crop in each irrigation network (€/ha)	Total variable capital available	12 constraints (one for each irrigation network)
Gross margin	Gross margin of each crop in each irrigation network (€/ha)	Mk (maximum gross margin)	Included in the parametric programming models where objectives Z_2, Z_3 and Z_4 are optimized
Quantity of nitrogen	Nitrogen requirements of each crop in each irrigation network (kilos/ha)	Mk (minimum nitrogen use)	Included in the parametric programming models where objectives Z_1, Z_3 and Z_4 are optimized
Value of pesticides	Value of pesticide requirements of each crop in each irrigation network (€/ha)	Mk (minimum value of pesticide use)	Included in the parametric programming models where objectives Z_1, Z_2 and Z_4 are optimized

Table 1 continued

Constraints	Coefficients	Right-hand side	Description
Quantity of water	Irrigation water requirements of each crop in each irrigation network (m^3/ha)	Mk (minimum quantity of irrigation water use)	Included in the parametric programming models where objectives Z_1, Z_2 and Z_3 are optimized

Variables	Description
Cotton (ha)	Acreage of cotton in each irrigation network (12 variables)
Maize (ha)	Acreage of maize in each irrigation network (12 variables)
Tobacco (ha)	Acreage of tobacco in each irrigation network (12 variables)
Tomato (ha)	Acreage of tomato in each irrigation network (12 variables)
Lucerne (ha)	Acreage of lucerne in each irrigation network (12 variables)
Sugar beet (ha)	Acreage of sugar beet in each irrigation network (12 variables)
Rice (ha)	Acreage of rice in each irrigation network (12 variables)
Wheat (ha)	Acreage of wheat in each irrigation network (12 variables)

Table 2 Pay-off matrix and related cropping patterns

Solutions	Gross margin (mil €)	Fertilisers (mil kg N)	Pesticides (mil €)	Irrigation water (10 mil m^3)	Crops (1,000 ha)								
					Cotton	Lucerne	Maize	Rice	Sugar Beet	Tobacco	Tomato	Wheat (non irr.)	Wheat (irr.)
Max Gr.Margin	**67.58**	6.00	12.72	44.80	19.0	14.2	3.1	1.7	12.5	0.6	5.7	0.4	–
Min. Fertilisers	47.32	**4.05**	12.21	43.17	40.0	11.8	–	2.0	0.2	2.1	–	0.4	0.7
Min. Pesticides	38.20	10.87	**5.18**	43.07	–	14.2	35.3	1.7	–	0.0	–	0.4	5.7
Min. Water	33.77	13.02	10.64	**37.43**	0.0	–	41.6	1.7	–	2.1	5.7	0.4	5.7

The bold values represent the diagonal, which is the optimal but infeasible solution cultivated with sugar beet, which is substituted by cotton, while lucerne and tomato are also decreased. However, apart from a considerable income loss (30.0%), the introduction of this plan entails high levels of irrigation water and pesticide use.

Minimization of pesticide use (90.4 €/ha) can be achieved with the expansion of the area cultivated with maize, which is less agrochemical-intensive that cotton. Sugar beet is excluded, while irrigated wheat is cultivated in 10% of total cultivated area. As a result of the abatement of cotton, average gross margin is reduced by 43.5% (667.0 €/ha), while nitrogen use is substantially increased to 189.8 kg/ha, which is about 1.7 times higher than the previous crop plan.

Minimum consumption in irrigation water use can be achieved with the fourth crop plan in Table 2. In this case, the main crop is maize (approximately 73% of total cultivated area) and is followed by tomato (10%) and wheat (10%), while lucerne and cotton are excluded, due to high requirements in irrigation water. Within this crop plan, nitrogen and pesticide use are excessive (117.0% increase compared to the baseline scenario and 221.5% more than its minimum use for the former and 105.4% higher than the minimum for the latter) and gross margin is reduced in half, which implies that water consumption heavily affects income. This suggests that irrigation water is an input of vital importance in the region and policy measures are needed to ensure its efficient allocation.

The implementation of the multi-objective programming method yielded 144 non-inferior solutions, which were reduced to 25 after the employment of the filtering technique. The latter are reported in Table 3. The solutions are sorted in ascending order, according to the gross margin. Each one of these solutions represents an alternative management scheme for local agriculture (the crop plans for each irrigation network are available from the authors). Policy makers may choose the preferred scenario by monitoring the impact of each one separately on every irrigation network. In all, the sector is likely to adjust to one of these schemes and factors such as policy measures and infrastructure are likely to severely influence this adjustment.

Preferences concerning the four objectives are very important in the choice of the ideal management scenario. However, the solutions in Table 3 do not account for them, as the constraint method assumes equal weights. Preferences are incorporated in the estimation of metrics L_1 and L_∞, which allow the choice of an ideal solution from the efficient subset. These metrics encompass the limits in which the conflicting objectives are compromised. These limits are 39,97–56,72 mil € (697,7–990,0 €/ha) for gross margin, 422,5–434,4 mil m^3 (7.376,0–7.584,0 m^3/ha) for the quantity of irrigation water, 5,29–5,76 mil units N (92,4–100,6 units N/ha) for the quantity of nitrogen and 9,35 –11,33 mil € (163,2–197,8 €/ha) for the value of pesticides. The bounds imposed by these metrics are relatively narrow, therefore the choice of the preferred solution for policy-making should be based on other factors as well, such as stakeholders characteristics.

The solutions reported in Table 3 are not adequately informative concerning the impact of minimizing input use on income, nor do they reveal consequences of changing the level of one input on other objectives. These relationships are better reflected on the trade-offs between objectives Z_2–Z_4 and income (objective Z_1), reported in Table 4. In all cases, the trade-offs are increased for lower levels of

Table 3 Results of multi-objective programming

	Gross margin (mil €)	Fertilisers (mil units N)	Pesticides (mil €)	Irrigation water (10 mil m^3)	Crops (1,000 ha)								
					Cotton	Lucerne	Maize	Rice	Sugar Beet	Tobacco	Tomato	Wheat (non irr.)	Wheat (irr.)
1	33.77	37.43	13.02	10.64	0.2	–	416.4	17.1	–	21.3	56.9	4.0	56.9
2	37.48	37.48	12.09	10.83	58.7	–	357.9	17.1	–	21.3	56.9	4.0	56.9
3	39.47	37.52	11.22	11.22	99.3	–	317.3	17.1	–	21.3	56.9	4.0	56.9
4	40.45	37.56	10.40	11.65	147.2	–	269.4	17.1	–	21.3	56.9	4.0	56.9
5	42.23	37.66	8.60	12.52	245.6	–	171.1	17.1	–	21.3	56.9	4.0	56.9
6	43.64	40.24	9.36	5.53	87.8	142.2	264.9	17.1	–	0.3	–	4.0	56.5
7	44.59	37.85	7.85	12.72	284.9	–	131.7	17.1	–	21.3	56.9	4.0	56.9
8	45.39	37.95	7.71	12.72	290.3	2.7	123.6	17.1	–	21.3	56.9	4.0	56.9
9	47.32	40.10	4.05	12.21	400.5	117.9	–	20.2	2.2	21.0	–	4.0	7.1
10	48.68	40.29	4.05	12.17	392.8	125.6	–	20.2	2.2	21.0	3.0	4.0	4.1
11	50.20	40.77	4.08	11.37	392.8	133.1	–	20.2	2.2	17.6	3.0	4.0	–
12	51.32	40.57	9.10	6.41	103.2	142.2	243.0	17.1	15.0	0.3	14.0	4.0	33.9
13	52.74	39.37	6.92	12.72	267.0	49.5	77.9	17.1	22.5	21.3	56.9	4.0	56.6
14	54.06	39.71	7.18	12.72	251.1	53.3	88.1	17.1	31.1	21.0	56.9	4.0	50.2
15	55.38	40.41	8.44	7.24	131.1	142.2	204.0	17.1	15.0	0.3	29.0	4.0	30.1
16	56.78	40.36	4.32	11.35	374.1	139.5	–	17.1	2.2	12.8	23.2	4.0	–
17	58.29	40.21	8.60	7.98	117.3	142.2	203.9	17.1	15.0	0.3	49.0	4.0	24.0
18	59.66	40.36	4.52	12.12	340.6	139.5	–	17.1	20.7	12.8	38.1	4.0	–
19	60.82	40.82	8.15	8.75	122.4	142.2	173.7	17.1	50.1	0.3	49.0	4.0	14.0
20	62.11	42.32	5.86	12.72	221.9	134.6	39.2	17.1	43.9	21.3	56.9	4.0	33.9
21	63.43	41.42	8.11	9.68	114.1	142.2	164.3	17.1	78.9	0.3	52.0	4.0	–
22	64.84	43.35	6.01	12.72	187.6	142.2	36.8	17.1	85.6	16.6	56.9	4.0	26.0

Table 3 continued

	Gross margin (mil €)	Fertilisers (mil units N)	Pesticides (mil €)	Irrigation water (10 mil m^3)	Crops (1,000 ha)								
					Cotton	Lucerne	Maize	Rice	Sugar Beet	Tobacco	Tomato	Wheat (non irr.)	Wheat (irr.)
23	66.14	43.94	6.06	12.72	198.7	142.2	36.8	17.1	95.0	11.2	56.9	4.0	10.9
24	67.55	42.05	6.04	12.21	194.5	142.2	32.4	17.1	125.4	0.3	56.9	4.0	–
25	67.58	41.74	6.00	12.72	189.8	142.2	31.0	17.1	125.4	6.4	56.9	4.0	–
L1	56.72	42.25	5.76	9.35	273.5	124.7	44.9	17.1	0.0	0.3	51.3	4.0	56.9
L_∞	39.97	43.45	5.29	11.33	435.6	36.6	23.1	34.2	0.0	4.1	6.1	4.0	29.0

Table 4 Trade-offs between objectives

Fertilisers		Agrochemicals		Irrigation water	
kg/ha	Trade-offs (€/€)	€/ha	Trade-offs (€/€)	m^3/ha	Trade-offs (€/€)
70.70	329.00	96.55	11.76	6.54	27.73
70.75	105.65	111.89	5.43	6.55	5.15
71.19	40.16	126.48	4.40	6.56	4.91
75.37	16.19	139.33	3.70	6.57	2.22
78.99	11.87	152.71	3.27	6.58	1.81
		168.93	2.37	6.61	1.22
		213.17	0.47	6.62	0.70
		222.02	0.05	6.87	0.46
				6.93	0.37
				7.39	0.28
				7.57	0.24
				7.67	0.20

input use, which indicates that a further reduction in their use entails severe income losses. Furthermore, the impact of introducing an environmental-friendly management scheme on income is expected to be less severe the more intensive the current crop plan is. Despite the inelastic demand for irrigation water, the trade-offs between income and fertilizer use are the largest, which implies that measures for mitigating nitrate pollution particularly need to be complemented with income support schemes.

5 Conclusions

The purpose of this paper was to examine the possibilities of achieving conflicting policy goals such as acceptable incomes and the reduction in the use of noxious agrochemicals and irrigation water. The excessive use of such inputs imposes threats on the local ecosystem therefore such a reduction is essential in order to preserve its unique environmental characteristics. The implementation of the multi-objective programming method yield alternative management scenarios for local agriculture which achieve the conflicting objectives at various levels. The results reveal significant possibilities for reducing input use which, however, are expected to result in a reduction in gross margin up to 50%.

The consequences of achieving environmental goals on income from agriculture in the area are substantial; therefore farming needs to be supported in order to be continued in the region. However, the reduction in input use entails considerable benefits in terms of ameliorated environmental quality and preserving surface and ground water resources. These benefits are often non-marketed hence their values are not reflected in market prices. Such values are bound to partly offset, or even exceed, income losses, so their consideration in the decision-making process would enable policy makers to choose the ideal solution. Finally, the choice of the ideal solution lies upon the acceptance of local farmers, who are the key stakeholders. Discussions with stakeholders should yield important policy suggestions to be considered in the ultimate choice of the best management option. Such an option would guarantee a profitable farming pattern with significantly reduced adverse effects on local resources and on the environment.

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