Introducing a lexicographic goal programming for environmental conservation program in farm activities

A case study in Iran

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Abstract

Purpose – Prosperity of the agricultural sector is very crucial not only for the national economy but also for the regional development. However, this prosperity has quite often a significant environmental cost in terms of water resources overexploitation or pollution. The main purpose of this paper is to create, apply and evaluate a model that aims at the simultaneous maximization of farmer's welfare and the minimization of the consequent environmental burden.

Design/methodology/approach – Lexicographic goal programming technique is employed. This technique is implemented on a representative farm around Mashhad in Iran to seek for a solution – in terms of area and water allocation under different crops.

Findings – Results shows that application of a multi-criteria analysis may lead to a win-win situation.

Originality/value – A lexicographic goal programming is used to satisfy both goals of farm activity in a represented area in Iran.

Keywords Water, Resources, Iran

Paper type Research paper

Introduction

Agriculture is an economic activity that contributes significantly to the gross national product of a country, securing at the same time the viability of the rural sector and the social coherence. During the last decades, agricultural decision analysis studies have been primarily focused on farmers' welfare maximization. The reasoning is that the prosperity of the agricultural sector is very crucial not only for the national economy but also for the regional development. However, this prosperity has quite often a significant environmental cost in terms of water resources overexploitation or pollution (Latinopoulos and Mylopoulos, 2005). In fact, it can generate an environmental externality, especially concerning water resources that, in the name of higher crop productivity, are often overexploited or polluted. Most agricultural decision analysis studies are primarily focusing on farmers' welfare optimization.

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Therefore, this externality is only examined as a negative environmental effect of different farming and agricultural policy scenarios. However, a proper decision analysis in the field of agricultural policy should be guided by the goal of finding a unique "optimal" solution out of a great number of possible alternatives that arise from a complex-integrated socio-economic and environmental system, which incorporates significant conflicted interests and there is a stressing need to formulate decision-making models in agricultural planning that will recognize the multiplicity of objectives and goals and that will seek for "optimal" solutions in a complex socio-economic and environmental system. These optimal solutions could result from the use of multi-criteria analysis and they are actually solutions that satisfy the decision maker (Guitouni and Martel, 1998).

The main objective of this paper is to create, apply and evaluate a model that aims at the simultaneous maximization of farmer's welfare and the minimization of the consequent environmental burden. More specifically, lexicographic goal programming technique is employed. This technique is implemented on a representative farm around Mashhad in Iran to seek for a solution – in terms of area and water allocation (under different crops) – resulting in figures that will come as close as possible to the decision maker's economic, social and environmental goals.

There is a range of literature on resource allocation and the specific problem of its efficient use on irrigated land. As to related literature, previous multi-criteria approaches to irrigation systems and policies of drought mitigation can be analyzed as follows. Rossi considered a range of potential policies (long-term measures and actions before, during and after droughts) to be evaluated and ranked from a multi-criteria perspective (Rossi *et al.*, 2005). A case study to select irrigation subsystems of optimal performance in India is developed by using multi-criteria and fuzzy techniques (Raju and Kumar, 2005). Gomez-Limon and Martinez (2006) determined the optimal crop mix on irrigated farmland in a Spanish basin, and propose an equilibrium model maximizing farmers' welfare in an irrigated area.

Cai and Ringler (2007) dealt with compromise options for environmental requirements, food needs and economic impacts on irrigation farmers. Finally, Bravo and Gonzalez (2009) used A decision support model to help public water agencies allocate surface water among farmers and authorized the use of groundwater for irrigation.

Agricultural planning, depending on policy aims and decision makers' objectives, may have either the form of whole farm planning or of regional planning. Regional agricultural planning covers a larger area and has a wider range of characteristics, which are directly or indirectly connected with farming activities and should be taken into consideration in decision making. Thus, following multi-criteria analysis is applied on this level.

Theoretical framework and model

Goal programming and agricultural planning

Goal programming is one of the oldest multi-criteria decision-making techniques and perhaps the most frequently used one in agricultural planning. Its general aim is to optimize several goals and at the same time to minimize the deviation for each of the objectives from the desired targets. A goal has the following general form:

$$F_a(X) + n_a - P_a = g_a \tag{1}$$

where: $F_a(X)$ indicates linear decision-making function for goal (*a*), g_a shows target volume, and p_a, n_a show positive and negative deviational variables, respectively. In fact, deviational variables imply possible deviation from goal values in the results of running goal programming.

Lexicographic goal programming

The lexicographic method is based on the logic that in some decision-making systems some goals seems to prevail. Pre-emptive weights are attached to the sets of goals, which are classified in different priorities. The procedure begins with comparing all the alternatives with respect to the higher priorities goals and continues with the next priority until only one alternative is left. In other words, the fulfillment of a set of goals that is situated at a certain priority is immeasurably preferable to the achievement of any other set placed at a lower priority (Romero and Rehman, 2003). Because of this characteristic, there are no alternative optima if a higher priority could not be satisfied and excessive prioritization of goals can possibly lead to unrealistic models. So, the goals should be divided into a small number of pre-emptive priorities (Ignizio, 1976). So, the general form of lexicographic goal programming will be as follow:

$$\text{Minimize } Z = pr_a(n_a + p_a) \quad \text{subject to } F_a(X) + n_a - p_a = g_a \quad n_a, p_a \geq 0 \tag{2}$$

where pr_a and is pre-emptive priority factor for goal (*a*). n_a and p_a represent deviational variables.

The information that is incorporated into the selected goals includes farmers' welfare, characterized by securing income and employment levels, as well as environmental benefits, such as water resources protection from excessive application of fertilizers and from unsustainable use of irrigation water. Several weights or priority levels can be assigned on these goals, according to the intentions of the decision maker that are likely to differentiate the final allocation of resources. Hence, the analysis is undertaken under two policy scenarios include: environmental friendly and farmers' welfare-friendly.

It is advisable to be very selective regarding the number of objectives modeled, avoiding those that are closely related, for example, sales are closely related to gross margin (GM) (Gomez-Limon and Martinez, 2006). Most agricultural decision-making studies are focusing on farmer's welfare (utility) optimization and are using the goal programming techniques to satisfy economic, social and managerial criteria originated only from the farmer's viewpoint. On the other hand, the aim of this study is to formulate a decision-making model for the policy maker that intends to satisfy both farmers' welfare and environmental sustainability. For this reason, four objectives were defined (Table I). In relation with the farmers, two of the most frequent used

Table I.
Goal matrix

Goal 1	$\left(\sum_i I_i X_i\right) + n_1 + p_1 = g_1$	GM
Goal 2	$\left(\sum_i L_i X_i\right) + n_2 + p_2 = g_2$	Total labor input
G_3	$\left(\sum_i W_i X_i\right) + n_3 + p_3 = g_3$	Total irrigation water input
G_4	$\left(\sum_i N_i X_i\right) + n_4 + p_4 = g_4$	Total fertilizer input

Source: Research results

objectives were chosen (Goals 1 and 2 in Table I) include: maximum profit and minimum labor requirements.

Profit is approximated by means of GM, which in the short run is a good estimator of it (Berbel and Rodriguez-Ocana, 1998). On the other hand, the attribute of labor is estimated as the total time (in hours) that is necessary for the cultivation of all crops in the reference area. It is worth noting that the minimization of labor is sometimes opposed to social policies that are trying to safeguard the occupation in the primary sector and especially in agriculture, in order to ensure social stability and coherence in rural areas. Thus, the decision maker should pay attention that the total labor will not be substantially decreased and should be also ready, if necessary, to trade-off some working hours with the rest of the goals. Regarding the environment, quite a few past studies included some environmental objectives, but they rarely focused on water and fertilizer consumption (Hayashi, 2000). Besides, in most cases, these attributes are treated only as negative effects of various farming and agricultural policy scenarios and not as main objectives in agricultural planning. However, in this study, water and fertilizer attributes are included in model (Goals 3 and 4 in Table I). These two goal functions are used because just they are available as measures for water resources overexploitation or pollution and it is well known that in regions like vast parts of Iran which faces with water scarcity, overexploitation of water resources and fertilizer use will causes to water shortage or water pollution in long run.

In this model, as it is already noted, there are two main policies (economic and environmental). Each policy may constitute a priority level and weights if the decision maker had a strong preference to it but here weights of all goals are same. Thus, the set of four goals is divided into two pre-emptive priorities that will alternately take the first and second place in the minimization process and compromise solution that minimizes derivations of all goals simultaneously:

$$\begin{aligned} \text{Economic scenario} &: MinZ = [(n_1 + P_2), (P_3 + P_4)] \\ \text{Environmental scenario} &: MinZ = [(p_3 + P_4), (n_1 + P_2)] \\ \text{Compromise scenario} &: MinZ = [(n_1 + P_2 + P_3 + P_4)] \end{aligned} \tag{3}$$

Results and discussion

Case study farm, located in north-eastern of Iran, around the Mashhad city. Farm has 90 hectares under cultivated each cropping year. It is selected because of existence scarcity of water resources and urgent need of conservation programs especially for underground water resources in this area. Tables II and III show the results of three

Goals	Current values	Lexicographic goal programming		
		Economic sc.	Environmental sc.	Compromise sc.
GM (million rls)	912.654	1,100	714.556	1,100
Total labor input (day/labor)	1,300	1,084	1,919	1,370
Total irrigation water input (cubic metre)	810,135	817,326	511,903	607,765
Total fertilizer input (kilogram)	35,897	35,526	23,550	33,153

Source: Research results

Table II.
L.G programming results

scenarios in lexicographic goal programming. Specially, they display the goal values and deviational variables. In addition, Table II cites the current value of each attribute in order to better assess and comparison the results.

It is obvious that in the economic scenario, GM rises up to maximum value (1,100 million rls) such as consumption of irrigation water and fertilizer input is more than other scenarios. Comparison between current values and results of economic scenario indicates that they are close to each other, so as were expected; farm managers follow maximization of their profit. The main trade-offs are between GM and the two environmental goals (especially between GM and irrigation water). If decision maker faces with hard condition of water scarcity and pollution because of overexploitation of resources and excessive application of fertilizers, he can consider the environmental scenario to optimize his cropping pattern. In this case, GM will be decreased (714,556,000 rls); just as irrigation water and fertilizer use but there is more need to labor work. In Table IV is illustrated the resultant cropping pattern under the different scenarios and methodology choice. The economic scenarios are closer than the others to the real situations. This is a more or less expected outcome because the crop decisions are influenced just by farmers' welfare maximization up to now. Maize and Wheat have the most share of land allocated in economic scenario (27.87 hectares) but in two other scenarios, land allocated for these crops have been decreased. Soybean, sugar beet and bean have been removed from all cropping pattern and in the both environmental and compromise scenarios, hectares of gram has been raised. Because of

Table III.
Deviation values

	Lexicographic goal programming		
Deviations	Economic sc.	Environmental sc.	Compromise sc.
n_1(million rls)	0	38.544	0
p_2 (day/labor)	0	835	286
p_3 (cubic metre)	142,213	$n_3 = 163{,}210$	67,348
p_4 (kilogram)	13,675	1,699	11,302

Source: Research results

Table IV.
Cropping pattern in different scenarios (hectares)

		Lexicographic goal programming		
Crops	Current values	Economic sc.	Environmental sc.	Compromise sc.
Wheat	12	27.87	10	10
Barely	35	10	10	10
Alfalfa	20	10	10	10
Maize	8	31.56	5	32.44
Potato	2	2	2	2
Tomato	2	2	2	2
Sugar beet	5	0	0	0
Soybean	1	0	0	0
Gram	1	6.57	51	23.56
Bean	1.5	0	0	0
Total farm hectares	87.5	90	90	90

high consumption of water, maize has a small share in environmental pattern rather than others.

According to results of lexicographic goal programming and comparison the values in different scenarios, it is observable that the best solution that lead to a win-win situation is to consider the compromise scenario. If the decision maker wishes an integrated agricultural management, then the compromising solution seems to be a quite acceptable one. In this situation, both environmental and farmer's welfare concerns has been considered so that maximum value of GM is achieved and amount of irrigation water and fertilizer consumption decreased with respect to current situation.

Conclusion

It is well known that farmers' revenue is directly proportional to the use of irrigation water and fertilizer because they work as production factors that influence on amount of production. This relationship could be harmful for the environment in highly intensified agricultural systems or in very sensitive areas. Thus, some target values must take place for both environmental and economic attributes. In this study, a lexicographic goal programming is used to satisfy both goals of farm activity in a represented area in Iran. According to the goal programming results, it is important to point out that the economic and compromise scenarios may not satisfy all the environmental goals, but they end up to better numbers than the status quo. So, the application of a multi-criteria analysis may lead to a win-win situation, irrespective of the weighting system of preferences.

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Further reading

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