International Journal of Agronomy and Plant Production. Vol., 4 (9), 2102-2110, 2013
Available online at http:// www.ijappjournal.com
ISSN 2051-1914 ©2013 VictorQuest Publications

Farm Decision Making by Applying a Constraint multi Objective Model: a Case Study in Iran

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Abstract

The main objective of this paper is to create, apply and evaluate a multi objective model that aims at the simultaneous maximization of farmer's welfare and employment in region and the minimization of the consequent environmental burden. More specifically, constraint multi objective programming technique is employed. This technique is implemented on a representative farm area around "Tayebad" in Iran to seek for a solution - in terms of area and water allocation under different crops. Results showed that application of a multi-criteria analysis may lead to an improved water resources use and less water overexploitation or pollution.

Keywords: multi objective, constraint method, water resources, optimization.

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 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. 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. 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. 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).

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). Finally, Bravo and Gonzalez used a decision support model to help public water agencies allocate surface water among farmers and authorized the use of groundwater for irrigation (Bravo and Gonzalez, 2008).

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. In fact, the inadequacy of the resources available as well as presence of multiple objectives that farmers seek to optimize makes multiple objective-programming

(MOP) model an appropriate tool to guide decision maker in such a situation. The MOP model is a method of generating efficient solutions in a multi-criteria decision-making paradigm. It permits optimization of several objective functions rather than try to force the model to derive a single objective optimization solution .Unlike linear programming (LP) for instance, where a single optimal solution to the problem is derived, the MOP solutions consist of a set of alternative efficient solutions, each of which are considered equivalent in the absence of further information regarding the relative importance of each of the objectives in the solution vectors (Francisco and Ali, 2006).

The objective of this study is to use a new MOP model solution called constrained method and find best efficient solution from a set of land use options in rural area of Tayebad, Khorasan-Razavi province of Iran where Farming and agricultural activities are faced with several natural problems such as irrigation water scarcity and socio-economic issues like unemployment and poverty in rural population.

Material and Methods

Multi-objective programming (MOP) or vector optimization technique involves the simultaneous optimization of several (often competing) objectives subject to sets of resource constraints. MOP replaces the notion of optimality in LP with the concept of efficiency or non-dominance (Cohon and Marks, 1973).

The present study was done for 16668 hectares of rural region of “Tayebad” in province of khorasan-Razavi located in northeastern of Iran. Data used in this study is collected from a survey in 2011. Based on socio-economic situation of area, the main goals are: maximization of income, maximization of employment, minimization of irrigation water and minimization of fertilizer. Therefore, these were considered the objective functions of the farmers in the MOP application.

MOP models theoretical framework

The MOP model can be expressed in mathematical form as:

$$
\begin{aligned}
&MaxZ(x) = [\ Z_1(x), Z_2(x), \ldots\ldots, Z_k(x) \\
&st: \\
&Z_2(x) = Z2(x_1, x_2, \ldots\ldots, x_n) \\
&\vdots \\
&Z_h(x) = Zh(x_1, x_2, \ldots\ldots, x_n) \\
&\vdots \\
&Z_k(x) = Zk(x_1, x_2, \ldots\ldots, x_n) \\
&X \in F \\
&X \geq 0
\end{aligned}
\qquad (1)
$$

where Z=(Z_1, Z_2 ,...,Z_k)is the vector of objective functions with elements; Z_i, i=1,2,..,k are individual objective function; X_i, i=1,2,…n, is the area allocated to the cultivation of crop i. There are three ways to generate the efficient set from multi-objective programming models. These are the weighting, constraint, and multi criterion simplex methods. Details of these methods can be found in Cohon (1978). The constraint method is the most intuitively appealing technique because it does not require prior knowledge on the preference of the decision makers. Francisco and Ali (2005) designed and developed a constraint multi-objective programming (MOP) model to illustrate the dynamic relationship among technologies, productive activities, constraints and farmers objectives in the peri-urban vegetable production system in Philippines. In the constraint method, the hth objective function in (1) will be optimized while The remaining (k-1) objectives form parts of the constraints of the model. The constrained problem can be formulated as (Francisco and Ali, 2006):

$$
\begin{aligned}
& Max Z_h(x_1, x_2, \ldots.. x_n) \\
& st: \\
& Z_1(x_1, x_2, \ldots\ldots, x_n) \geq b_1 \\
& Z_2(x_1, x_2, \ldots\ldots, x_n) \geq b_2 \\
& \vdots \\
& Z_{h-1}(x_1, x_2, \ldots\ldots, x_n) \geq b_{h-1} \\
& Z_{h+1}(x_1, x_2, \ldots\ldots, x_n) \geq b_{h+1} \\
& Z_k(x_1, x_2, \ldots\ldots, x_n) \geq b_k \\
& \vdots \\
& X \in F \\
& X \geq 0
\end{aligned}
\tag{2}
$$

Where b_j is the limit set on the objectives that were considered constraints in the constrained optimization.

The efficient set is generated by parametric variations of b_j, $j = 1,2,\ldots,(h-1),(h+1),\ldots k$. The incremental values of parameter b_j are derived from the following relationship, as proposed by Cohon(1978):

$$b_{jt} = n_j + t(r-1)^{-1}(m_j - n_j) \quad (3) \quad j=1,2,\ldots,h-1,h+1,\ldots,k$$

t=0,1,2,…,(r-1)

Where L_{jr} are parametric values assumed by b_j at interval $t(r-1)^{-1}(m_j - n_j$; r is the number of interval for b_j; m_j is the best value of objective j; n_j is the worst value of objective j.

Cluster analysis

The constraint method yields a large number of efficient solutions for a DM to choose from. A similar method to reduce the size of the efficient set is cluster analysis. Cluster analysis partitions a given set of Pareto efficient solutions into groups (cluster) of relatively homogeneous efficient sets.

Raju and Kumar (1999) applied this methodology to trim down the number of efficient irrigation plans in India. The formed clusters are then merged in stepwise fashion. At each step, the sum of the squared deviation from the group mean for each criterion issued as basis for assignment. Observations are transferred from one cluster to other so that within cluster the sum of the squared deviations from cluster mean is minimum.

Compromise programming

To help the DM select the best solution, Zeleny (1973) and Yu(1973) proposed a Technique called compromise programming (CP).

The operative structure of CP is summarized in the following way. First, the degree of closeness d_j between the j th objective and its ideal is defined by:

$d_j = Z_j^* - Z_j(x)$ When the j th objective is maximized, or as:

$d_j = Z_j(x) - Z_j^*$ When the j th objective is minimized.

Where Z_j is the ideal value.When the units used to measure the objectives are different, relative deviation Rather than absolute deviations must be used (Zeleny, 1973). Thus, the degree of closeness is given by:

$$d_j = \frac{Z_j^* - Z_j(x)}{Z_j^* - Z_{*j}} \tag{4}$$

Where Z_{*j} is the anti-ideal value (worst) for the j th objective.

To measure the distances between each solution and the ideal point, CP introduces the following family of distance functions:

$$L_p(¢, k) = \left[\sum (¢_j d_j)^p\right]^{1/p} \tag{5}$$

Where $¢_j$ weights the importance of the discrepancy between the j th objective and its ideal value. For L_p metric $(p = 1,2,...)$, the best compromise or closest solution to the ideal point is obtained by solving the following non-linear programming problem (Cohon, 1978):

$$MinL_p(¢, k) = \left[\sum (¢_j d_j)^p\right]^{1/p} \; st : X \in F \tag{6}$$

Where F is the feasible set.

For the L_∞ metric ($p = \infty$), the maximum of the individual deviations is minimized. For this metric, the best compromise solution is obtained by solving the following LP problem (Cohon, 1978):

$$Min \quad L_\infty = d\infty$$

$$\vdots \qquad st: \quad \frac{¢_1(Z_1^* - Z_1(x))}{Z_1^* - Z_{*1}} \le d_\infty \qquad X \in F \qquad \frac{¢_k(Z_k^* - Z_k(x))}{Z_k^* - Z_{*k}} \le d_\infty \tag{7}$$

Yu (1973) has shown that L_1 and L_∞ metrics define a subset of the efficient set, which Zeleny (1974) calls the compromise set. Accordingly, the best compromise solution fall between the solutions corresponding to L_1 and L_∞ metrics for specific Weights of importance of the distance of objectives from the ideal point.

Formulation of multi-objective goals

Objective1: Maximize net farming income (NFI)

The net return to management, operator and family labor (net farm income in this paper) under different crops is obtained by subtracting total variable costs (hired labor cost, fertilizer, pesticides, irrigation, and other costs) from gross revenue. Maximization of net farm income can be expressed as:

$$Max\ NFI = \sum (R_i - Ci)X_{i,}\ i = 1,2,...,12$$

Where R_i is average of gross return from crop i by hectare in the area, C_i average of the total variable costs incurred in the production of crop i by hectare in the area, X_i the area allocated to production of crop i.

Objective 2: Maximize labor employment

According to socio-economic situation in the region that unemployment in rural area is a problem, maximizing farm labor employment is considered as an objective in this study.

$$Max\ L = \sum L_i X_i, \quad i = 1,2,...,12$$

Where L_i is the average of labor required for crop i by hectare in the area.

Objective 3 and 4: Minimize irrigation water use and fertilizer use

As an environmental consideration, two objective of minimization of irrigation water and fertilizer use has been introduced in multi objective model. Scarcity of irrigation water and underground water pollution is explicitly appeared in the region recently and it is required to take suitable policies motivating farmers to change and reform their land allocation pattern such that reducing these environmental externalities.

$$Min\ IW = \sum IW_i X_i\ i = 1,2,...,12$$

Where IW_i indicates the average of Water need for crop i by hectare in the area.

$$Min\ FER = \sum FER_i X_i \quad i = 1,2,...,12$$

Where FER_i is the average of fertilizer use for crop i by hectare in the area.

Results and Discussion

In the first step, the single objective optimization was performed to find the best and worst value of each goal, then multi objective model formulated and performed to achieve a set of efficient solution, cluster analysis was used to reduce number of solutions, and finally the compromise programming employed to find the best solution.

Single objective optimization

Optimization of each individual objective function was performed within the simple linear programming (LP) framework to determine the optimum value of each objective function. According to Results shown in table 1 if income maximization is the objective of model, farm land will be allocated to 12 crops and three crops will be removed from cropping pattern. This crop mix will yield a net income of 1,095,068,000 thousand Rials and would require 712535 man-days of hired labor, 251610300 cubic meter of irrigation water and 6318942 kg of fertilizer consumption. When the goal is to maximize hired labor employment, the production mix in the solution is composed of more labor demanding crops .These crops would yield a net income of 967659600 thousand Rials with hired labor of 743981 32man days and associated total irrigation water use of 273770000 cubic meter and 6106011 kg of fertilizer.

Minimization of irrigation water use will yield 711161400 thousand Rials with associated labor demand of 482006 man-days and 171867200 cubic meter of irrigation water and fertilizer use of 4380438 kg. in the last linear programming model with the objective of minimization of fertilizer consumption, the net farm income that can be derived is 711161400 thousand Rials and correspondent labor demand is 482006 man-days, irrigation water of 171867200 cubic meter and 4380438 kg of fertilizer consumption.

As shown in the table 1, there are tradeoffs among the first three objectives but there is no difference between results of minimization of water use and minimization of fertilizer. However these objectives and their best and worst values will be used in the multi objective and compromise programming models to find the best efficient solution that is closest to achieve the best values of all four objectives.

Table1- Results of single objective optimization

	Objective function			
	Max income	Max employment	Min irrigation water use	Min fertilizer use
Income (thousand Rials)	1095068000 (m_1)	967659600	711161400	711161400 (n_1)
Hired labor (man-day)	712535	743981 (m_2)	482006	482006 (n_2)
Irrigation water (cubic meter)	251610300	273770000 (n_3)	171867200 (m_3)	171867200
Fertilizer (kilogram)	6318942 (n_4)	6106011	4380438 (m_4)	4380438
Crop/hectares				
Wheat	8306	5414	5257	5257
Barely	2177	2177	2177	2177
Sugar meet	419	419	226	226
Cotton	2672	2672	1439	1439
Watermelon	44	44	23	23
melon	1952	3625	1952	1952
Alfalfa	100	100	53	53
Corn	49	26	26	26
Potato	1.3	1.3	0.7	0.7
Onion	7.8	7.8	4.2	4.2
Tomato	19.5	19.5	10.5	10.5
cumin	920	495	495	495
Lentil	0	16666	0	0
chickpea	0	0	0	0
rapeseed	0	0	0	0

m_j indicates the best value of objective j and n_j the worst value of the objective j

Constrained optimization

A constrained optimization was performed to generate the efficient (Pareto non dominated) solution sets. The different efficient sets are generated by solving (2) and parametrically varying the bounds on b_j .

Specifically, total net income was optimized and the bounds on hired labor and income variance were parametrically varied according to (3) for r =4, and t=0,1,2,3. Solving the MOP model 64 times and discarding redundant solutions for those that are not efficient, yielded 33 non-dominated solutions. These efficient solutions are presented in Table 2. The efficient solutions represent various combinations of income, hired labor utilization, irrigation water and fertilizer consumption. This set of information provides a wide range of options from where the DM could choose. However, the DM might still find it difficult to come to a decision given the still relatively large set of choices. The set, therefore, needs to be trim down to a manageable number. Thus, In order to determine the best compromise solution for the MOP problem, cluster analysis and compromise programming is performed using the outputs from individual optimization of the four objective functions and the constrained optimization.

Table 2- objective values achieved from constraint method

option	Net farm income (thousand Rials)	Employment (man-day)	Irrigation water use (cubic meter)	Fertilizer use (kilogram)
1	1011590000	661906	246111100	6318942
2	1037875000	718595	253412600	6344492
3	1028330000	711680	249850800	6365020
4	957718000	679859	245422700	6318942
5	1095070000	712536	251610500	6318942
6	1072910000	731448	261962200	6318942
7	1095070000	712536	251610500	6318942
8	967660000	743981	273770000	6106013
9	972490000	743981	273770000	6105448
10	972448000	743974	273770000	6105486
11	972450000	743981	273771800	6105504
12	944652000	687992	260899500	5964668
13	1095070000	712535	251610300	6318942
14	979530000	662628	232378200	6223363
15	1037875000	719170	261650500	6005527
16	967659800	743981	273770000	6106011
17	1095070000	712535	251610500	6318942
18	886601000	576625	216444700	5672774
19	886576000	656656	242553500	5695642
20	972490000	743976	273770000	6105448
21	972541000	743977	273770000	6105501
22	977922000	680468	239793400	6524233
23	1030360000	711929	250551800	6365856
24	995175000	672498	237043900	6261465
25	855059000	640138	234133400	5272920
26	948285000	70395	260920000	6020511
27	972490000	743976	273770000	6105505
28	939127000	665032	246690500	5895413
29	961000000	649616	227180300	6060562
30	1082090000	704621	247186400	6286378
31	995175000	672498	237043900	6261465
32	955378000	648765	226897600	6052535
33	961413000	649616	227180300	6060562

Cluster analysis

The hierarchical cluster analysis, specifically Wards minimum-variance clustering method (Ward, 1963) is used to trim down the non-dominated solutions into the desired number. Prior to cluster analysis, the values of the different criteria were first normalized using the range of values for the corresponding criteria. The 33 efficient solutions derived from constrained optimization were subjected to cluster analysis to arrive at representative solutions. The dendrogram produced is presented in Fig.1. Deciding on five clusters and computing for the minimum squared deviation from group mean resulted in the selection of O8, O12, O14 and O23, as the representative solutions.

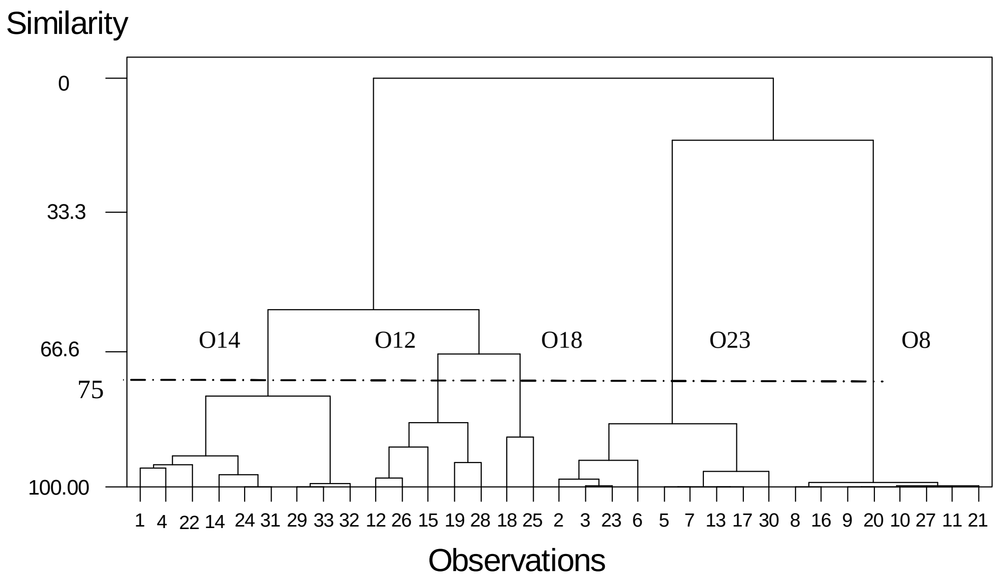

Figure 1- dendrogram of efficient solutions and representatives

At this point, the DM has the following information: the ideal point, produced by single objective optimization for the different objectives and the various efficient solutions generated from cluster analysis. The DM, however, has no idea about the degree of closeness of these alternative solutions to the ideal point. Compromise Programming is performed to determine this degree of closeness.

In order to obtain the best compromise solution for $p = 1,2$ metric Eq. (6) and for $p = \infty$ metric, Eq. (7) is solved assuming equal importance of the objective functions. The compromise programming results are shown in table 3.

Table 3-Euclidean distances of options for $p = 1,2,\infty$

	$p = 1$	$p = 2$	$p = \infty$
option			
8	2.22	1.38	1
12	2.29	1.28	0.87
14	2.15	1.20	0.95
18	2.28	1.16*	0.66*
23	2.08*	1.29	1.02

As Yu (1973) pointed out, the best compromise solution lies between the L_1 and L_∞ metric solutions. According to minimum values of Euclidean distances of each metrics, option number 23 is selected for $p = 1$ and option number 18 for $p = 2,\infty$. Since the larger value of p metric shows more sensitivity in analysis of closeness to ideal point, option number 18 is considered as the best solution.Crop mix and objective values for this solution are shown in table 4 and compared with current situation.

Results implies that selected efficient solution caused income to decrease to 906661000 thousand Rials and farming employment to 576625 man-day while irrigation water use and fertilizer use utilize by 21644700 cubic meter and 5672774 kg respectively. Irrigation water and fertilizer consumption have a better values because of allocating land to crops need less water and fertilizer with resulting less income for farmers.

In fact results confirms that although a relatively little decrease in farm income, amount of environmental objectives include optimizing irrigation water and fertilizer use going to have a improved levels.

Table 4-Crop mix and objective values of best efficient solution

particular	Best solution	Current situation
wheat	5257	7511
barely	4043	3110
Sugar meet	226	323
cotton	1439	2056
watermelon	23	34
melon	1952	2789
alfalfa	53	77
corn	26	38
potato	3.1	1
onion	3498	6
tomato	2957	15
cumin	920	708
lentil	541	0
chickpea	0	0
rapeseed	0	0
Net farm income	906661000	916629919
employment	576625	688842
Irrigation water use	21644700	245627910
fertilizer	5672774	6259970

Conclusion

This paper used a multi objective programming model, constraint method, to optimize objective functions include maximize net farm income, maximize employment, minimize irrigation water use and minimize fertilizer use in a dry region in northeastern of Iran, Tayebad. Minimizing irrigation water and fertilizer use has introduced into model because of importance of these production factors in agricultural activities in this area so that scarcity of water resulted from low level of annual rains and groundwater pollution is an increased problem. Solving constraint method gave a wide range of efficient solutions so cluster analysis was applied to reduce number of solutions. With Deciding on five clusters, five options were selected and compromise programming was performed to find the best one.

According to results, the best efficient solution have a little decreased net farm income and employment but crop mix caused to have improved values of irrigation water and fertilizer consumption in area.

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