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Application of Fuzzy Multi-Objective Programming in Optimization of Crop Production Planning

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ABSTRACT

Planning for the optimal use of productive resources in agricultural systems leads to the conservation in addition to the promotion of farmers' socio-economical conditions. Being certain or precise in any decision making in agricultural planning is impossible. Fuzzy mathematical programming techniques, developed in recent decades, are the most appropriate and applicable approaches to include the uncertainty in crop planning and productive resources management. Using the multi-objective Fuzzy Goal Programming (FGP) approach, the farming system of a rural region located in the central of Iran has investigated in this study in order to identify the optimal cropping pattern and land use planning under uncertainty. For this purpose, several objectives like maximizing the area under cultivation, net return and employment opportunities and simultaneously the land, capital, monthly water and labor force requirements and availabilities, crop rotation and a crop lower bound production constraint imprecisely considered as fuzzy goals. The needed data gathered through fieldwork operations. In multi-objective programming context, as the results revealed, the constraints of the productive resources are more determinant in land allocation than the objective functions. To illustrate the precedence of the cited FGP model, the results were quantitatively compared with the existing situation and a crisp goal programming model containing the same objectives and constraints. The precedence mainly pertained to the goals of objective functions. The crop-mix in FGP pattern change achieved considerable conservation of water and capital resources and improvement of income generation of the agricultural system, with almost no variation in the cultivation area.

Key words: Rural farming system, optimal cropping, uncertainty, fuzzy multi-objective programming

INTRODUCTION

Mathematical Programming (MP) has been a widely used tool for studying and analyzing agricultural systems. Beginning with the well-known Linear Programming (LP) model, operations research has supplied us with a great variety of theoretically sound models (Lara and Stancu-Minasian, 1999). Optimization procedures have been receiving much attention in agricultural economic research over several decades. The LP is a single objective optimization technique and most of the farm planning problems are multi-objective in nature. Crop area planning or agricultural planning arenas involve multiple, conflicting and non-commensurable criteria and a compromise satisfying decision is looking for. Issues of risk, resources conservation and sustainability, environmental quality and social aspects of farming systems are as important as economic efficiency. It is clearly impossible to develop a single objective that satisfies all interests, all adversities and all political and social viewpoints (Gupta *et al*., 2000). Multi-Objective Programming (MOP) involves the simultaneous optimization of several (often competing) objectives subject to sets of resource constraints (Francisco and Ali, 2006).

The Goal Programming (GP) approach is one of the prominent and robust tools for multi-objective decision analysis. In the multiple criteria setting, the special characteristic of GP models is the way the decision criteria dealt with. Instead of the direct evaluation of the criteria outcomes, GP models explicitly introduce the desired target value for each criterion and optimize the deviations of the criteria outcomes from these goals (Hu *et al*., 2007) in order to reach an acceptable solution. The unwanted deviations are measured using positive and negative deviation variables that are defined for each goal and they represent over achievement and underachievement of the goal, respectively (Akoz and Petrovic, 2007). Although, GP has been widely used for farm planning problems (Wheeler and Russel, 1977; Romero, 1986), the main weakness of conventional GP formulation is that all the parameters of the problem need to define precisely in the planning environment. However, much of decision making in the real-world takes place in an environment where the objectives, constraints or parameters are not known precisely and are often imprecisely defined. Hence, decisions in the real world are often making based on the vague information or uncertain data, are fuzzy rather than precise and are often imprecise by nature. Therefore, in order to reflect this uncertainty, the model of the problem is often constructing with fuzzy data, the fuzzy goals and/or fuzzy constraints regarded as fuzzy criteria (Gupta *et al*., 2000; Gupta and Bhatia, 2001).

In a fuzzy decision-making environment, the objectives are always described fuzzily, where aspiration levels of objectives are assigning in an imprecise manner. Again, the resource constraints may be crisp or fuzzy and that depends on the fuzziness of the available resources in the planning context. Inaccurate or fuzzy objectives and constraints, called fuzzy goals, represent by associated membership functions. To this, the lower or upper tolerance limit must be defined for each one and depend on the fuzzy restriction given to a fuzzy goal of the problem (Biswas and Pal, 2005; Hu *et al*., 2007; Li and Hu, 2009). In addition Zimmermann (1978), Mohamed (1997) has also discussed the relationship between goal programming and fuzzy programming and introduced another approach for solving FGP problems. In this approach, the membership functions transform into membership goals by assigning the highest degree (unity) as the aspiration level and introducing under and over-deviational variables to each of them. Then, in the goal achievement function, the under-deviational variables are minimized based on importance of achieving the aspired goal levels in the decision making context. In addition to the aspiration levels of the goals, applying the approach for fractional programming problems need to define admissible violation constants for each goal. The larger violation (or tolerance) of the goal indicates the less important of this goal. It is provable that every fuzzy linear program has an equivalent weighted linear goal program where the weights are the reciprocals of the admissible violation constants (Mohamed, 1997). The FGP approach has been extended by Sinha *et al*. (1988) and Pal and Moitra (2003) to agricultural and crop planning problems. Nevertheless, as Biswas and Pal (2005) have pointed out, the use of fuzzy programming approach for farm planning problems has not appeared extensively in the literature.

This article attempts to offer a solution to a crop planning problem by applying GP methodology in an imprecise context of the both of objectives and constraints. Study area is a region situated in the east of the city of Isfahan, Central Iran, which is perfectly rural with relatively high population density with almost 70% involved in agricultural sector. Limited irrigation water and rapid groundwater table fall of the region, due to the extensive withdrawal and generally low level of precipitation, cannot meet the requirements of common cropping pattern (Fasakhodi *et al*., 2010). Thus, there is an imminent need for a more efficient pattern of cropping on the regional scale to meet the overall objectives and sustainability of the farming system based on the available water resources. Crop planning and allocation of production resources performed in a comprehensive and imprecise manner to consider all of the conflicting environmental and socio-economic aspects of the farming system in the region. Here, the maximization of total area allocated to crops, net return and labor employment considered fuzzily as the problem objectives in order to maintain the population in the system and its durability. Monthly water availabilities also considered fuzzily as the main problem constraints regards to the recent drought periods and hence the crucial role of water in cropping pattern determination of the region. Moreover, monthly labor force availability and requirements, seasonality (crop rotation), capital requirement, a lower bound constraint on fodder crops' cultivated area and seasonal land availabilities are other fuzzy constraints of the problem. To consider these multiple fuzzy objectives and fuzzy constraints (fuzzy goals) simultaneously, the problem of the study has been modeled as a multi-objective fuzzy goal programming procedure. Therefore, the socio-economic aspects of the farming system considered in terms of maximizing the net return and labor employment opportunities fuzzily to include uncertainty.

MATERIALS AND METHODS

Multi-Objective Fuzzy Goal Programming (MOFGP): The general form of a multi-objective fuzzy programming model with fuzzy both objectives and constraints can formulated as (Mohamed, 1997):

$$\begin{gathered} z_k\,(X) \gtrsim \text{ or } \lesssim g_k \text{ (for maximizing or minimizing } z_k\,(X)\text{); } k = 1, 2, \ldots.., k \\ \text{s. t. } a_i\,(X) \lesssim b_i \text{ or } (AX \lesssim b)\text{; } I = 1, 2, \ldots..., m \end{gathered} \tag{1}$$

where, vectors X, z_k, $a_i \in R^n$ are respectively decision variables, kth objective function and ith constraint coefficients and b, vector of resources availabilities, is also $\in R^m$. Symbols $\gtrsim$ and $\lesssim$ are the fuzzification of $\geq$ and $\leq$, which indicate the fuzziness of the aspiration levels g_k and resources availabilities b_i, assigned to the kth objective z_k (X) and ith constraint, a_i (X), respectively, according to Zimmermann (1987). It means that these inequalities are flexible and should be described imprecisely like "it should be basically greater than or equal to g_k" or "basically smaller than or equal to", which can then be characterized by their membership functions by defining the lower or upper tolerance limits.

The most popular used (Mohamed, 1997) linear membership functions to solve (1), for each goal is as:

$$\mu_{1k}(z_k(X)) = \begin{cases} 1 & \text{if} \quad z_k(X) \geq g_k, \\ 1 - \dfrac{g_k - z_k(X)}{d_{1k}} & \text{if} \quad g_k - d_{1k} \leq z_k(X) \leq g_k, \\ 0 & \text{if} \quad z_k(X) \leq g_k - d_{1k} \end{cases} \tag{2}$$

and another linear membership function for the ith constraint in the system constraints, is:

$$\mu_{2i}(a_i(X)) = \begin{cases} 1 & \text{if} \quad a_i(X) \le b_i, \\ 1 - \dfrac{a_i(X) - b_i}{d_{2i}} & \text{if} \quad b_i \le a_i(X) \le b_i + d_{2i}, \\ 0 & \text{if} \quad a_i(X) \ge b_i + d_{2i} \end{cases} \tag{3}$$

where, d_{1k} (k = 1, 2, ..., k) and d_{2i} (i = 1, 2, ..., m) are chosen constants of admissible lower and upper violations respectively from and. The X is vector of decision variables, b, is the Right Hand Side (RHS) vector of constraints, represented resources availabilities and is the *i*th row of the technical coefficient matrix A.

Mohamed's approach to solve the above multi-objective fuzzy programming problem has developed based on the GP methodology. The basis of this approach is the fact that the maximum value of any membership function is 1, hence maximizing any of themis equivalent to making them as close as possible to 1 by minimizing its negative deviational variable from 1 (Mohamed, 1997). In this sense, by using the definitions of u_{1k} (z_k (X)) and u_{2k} (z_k (X)) and applying them to the conventional GP formulation, the problem (1) is converted to the following Fuzzy Goal Programming (FGP) program:

$$\begin{aligned} & \min \sum_{k=1}^{k} w_{1k} n_{1k} + \sum_{i=1}^{m} w_{2i} n_{2i} \\ & \text{s.t.} \\ & 1 - \frac{(g_k - z_k(X))}{d_{1k}} + n_{1k} + p_{1k} = 1 k = 1, 2, ..., k \\ & 1 - \frac{(a_i(X) - b_i)}{d_{2i}} + n_{2i} - p_{2i} = 1 \ i = 1, 2, ..., m \\ & X \ge 0, n_{1k} \ge 0, \ p_{1k} \ge 0, \ n_{2i} \ge 0, p_{2i} \ge 0 \\ & n_{1k}.p_{1k} = 0, n_{2i}.p_{2i} = 0 \end{aligned} \tag{4}$$

which its simplified formulation can be obtained as:

$$\begin{aligned} & \min \sum_{k=1}^{k} w_{1k} n_{1k} + \sum_{i=1}^{m} w_{2i} n_{2i} \\ & \text{s.t.} \\ & \frac{1}{d_{1k}}(z_k(X)) + n_{1k} - p_{1k} = \frac{g_k}{d_{1k}} \ k = 1, 2, ..., k \\ & \frac{1}{d_{2i}}(a_i(X)) - n_{2i} + p_{2i} = \frac{b_i}{d_{2i}} \ i = 1, 2, ..., m \\ & X \ge 0, n_{1k} \ge 0, \ p_{1k} \ge 0, \ n_{2i} \ge 0, p_{2i} \ge 0 \\ & n_{1k}.p_{1k} = 0, n_{2i}.p_{2i} = 0 \end{aligned} \tag{5}$$

where, n_{1k} and p_{1k} (k = 1, 2, ..., k) are respectively negative and positive deviational variables of fuzzy objectives n_{2i} and p_{2i} (i = 1, 2, ..., m) and are respectively negative and positive deviational variables of fuzzy constraints so on. These variables, which are not negative, measure the difference between the desired values (which are 1 in this scenes) and the obtained actual results for each of the fuzzy goals. w_{1k} and w_{1k} are also the relative weights of the kth objective and ith constraint, respectively. In order to measure of these relative weights, Mohamed (1997), in description of the relationship between goal programming and fuzzy programming, has been expressed and proved a theorem as: “every fuzzy linear program has an equivalent weighted linear goal program where the weights are the reciprocals of the admissible violation constants i.e.,:

$$W_{1k} = \frac{1}{d_{1k}} \text{ and } W_{2i} = \frac{1}{d_{2i}}$$

Study area: The study area is a perfectly rural region situated between the North latitudes of 32°19'06"-32°35'59" and East longitudes of 51°45'40"-52°06'32", a portion of the Zayandeh-Roud river basin in central Iran, named Baraan. The area covers 492.83 km^2 about 32 km in the southeast of the provincial capital Isfahan (Fig. 1). Climatically, this area belongs to the semi-arid category, with mean annual temperature of 16°C, annual rainfall ranging between 40.2 and 198.5 mm and the mean elevation of 1565 m above the mean sea level. Fifty villages are located in the area with a total population of 34730 (about 8809 households), of which about 70% are engaged in agriculture. Farming practices including animal husbandry are the main ways of life and driving force for development in this area. The area consists of two rural districts located in the Northern and Southern parts of the Zayandeh-Roud river, the most important central river of Iran, with fertile alluvial lands, namely Northern Baraan and Southern Baraan. Total arable lands of area are close to 27000 ha, of which about 26000 ha are currently allocated to 9 major crops cultivated in two cropping seasons under irrigation. The Winter major crops contain wheat, barley, onion and the spring crops are rice, corn, silage maize, sugar beet. Alfalfa is also the common annual crop, planted in spring season.

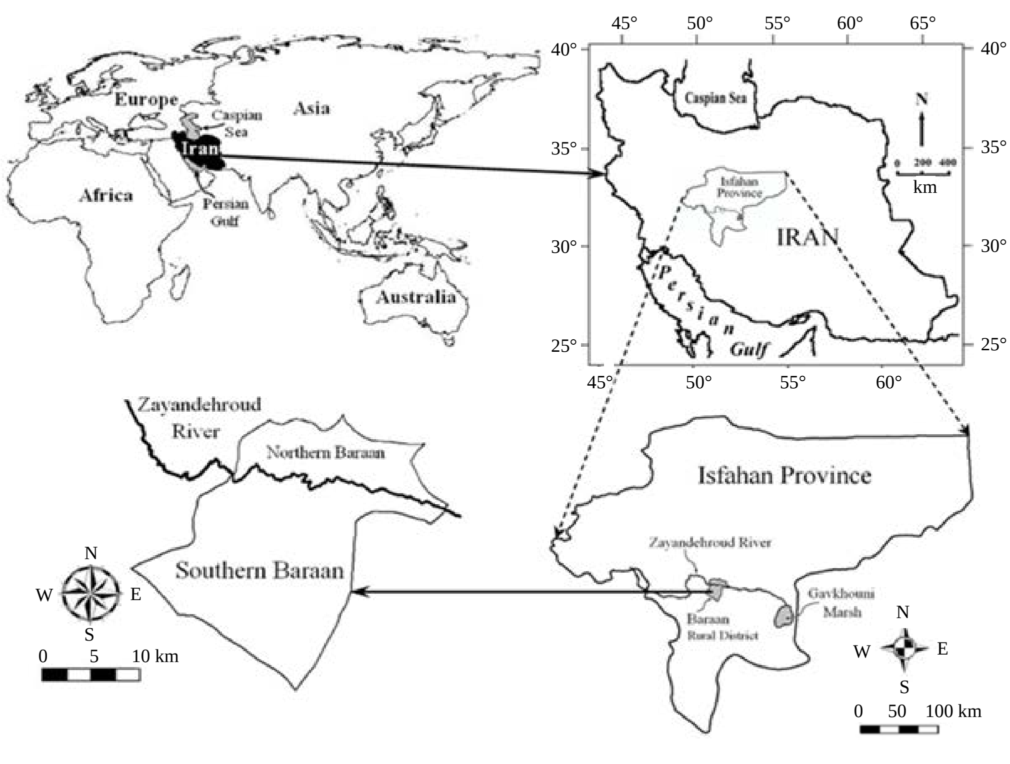

Fig. 1: Map of study area, Baraan rural districts, the East of Isfahan, Isfahan, Central Iran

Data sources: The data to formulate the study problem (objective functions, constraints and Right Hand Sides (RHS)) consisted of socio-economic and water data, presented concisely in Table 1 and 2. The net return (taking into account the potential yield, market price and the cost of production) and labor employment original data was collected by completing the standard cropping cost-benefit questionnaire (Ministry of Jihad-E-Agriculture, 2007), by interviewing the farmers and also experts of the Regional Center of Agricultural Services and provided finally per unit of area. Labor requirements data, was also estimated per unit of area, separately for each of planting, crop protection and harvesting periods in a cropping season. Then, these data were prepared monthly (Table 3) and added together to calculate the labor force technical coefficients for total cropping season duration (Table 1). Labor force availabilities also provided by field operations.

Table 1: Coefficients matrix and right hand sides for multiple goals

	Activities (main crops of the region)									
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	
Criteria (Goals)	Wheat	Barley	Rice	Corn	Maize	Alfalfa	Sugar beet	Potato	Onion	RSH
Net return (10^6Rs)	8.82	7.01	21.23	11.04	30.39	9.32	11.24	51.77	19.44	Maximum
Employment (man-day)	22.39	19.39	71.10	32.30	37.29	84.20	43.30	140.75	137.30	Maximum
Total water use (10^2 m^3)	48.00	40.60	151.93	78.58	63.24	104.20	105.67	61.52	60.20	Minimum
Land use (ha)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	≤26500
Fodder lower bound	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	≥8500
Seasonality (Rotation)	+1.00	+1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	+1.00	≥0
Capital (10^6Rs)	6.06	5.59	23.02	12.96	21.04	16.53	23.76	48.23	35.49	≤280000

RHS: Right hand side

Table 2: Coefficients matrix and right hand side for monthly water constraints and water availabilities

	Activities (main crops of the region)									
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	
Water use (10^2 m^3)	Wheat	Barley	Rice	Corn	Maize	Alfalfa	Sugar beet	Potato	Onion	RHS
Oct. (k = 1)	0.0	0.0	4.22	5.51	13.21	8.0	11.27	5.40	4.1	≤117965
Nov. (k = 2)	0.9	0.4	0.00	0.00	0.00	4.5	0.00	3.00	4.0	≤95222.6
Dec. (k = 3)	1.4	1.2	0.00	0.00	0.00	1.7	0.00	0.00	2.8	≤49654.8
Mar. (k = 4)	8.1	8.1	0.00	0.00	0.00	6.1	0.00	0.00	7.4	≤110848
Apr. (k = 5)	13.8	13.8	0.00	0.00	0.00	9.9	2.90	0.00	12.9	≤180156
May (k = 6)	15.6	11.3	12.32	2.36	0.00	13.4	8.50	1.13	17.1	≤206011.2
June (k = 7)	2.2	0.0	32.28	9.60	0.00	15.8	22.40	4.75	5.1	≤109839
Jul. (k = 8)	0.0	0.0	33.67	18.56	10.62	16.5	24.70	14.49	0.0	≤170126
Aug. (k = 9)	0.0	0.0	35.38	23.45	19.40	15.7	22.90	17.20	0.0	≤196108
Sep. (k = 12)	0.0	0.0	28.06	19.10	20.01	12.6	13.00	15.58	0.0	≤182744

RHS: Right hand side

Table 3: Coefficients matrix and right hand side for the monthly labor force requirements and availabilities

	Activities (main crops of the region)									
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	
Labor force (man-day)	Wheat	Barley	Rice	Corn	Maize	Alfalfa	Sugar beet	Potato	Onion	RHS
Oct. (k = 1)	1.57	3.53	0.0	4.0	2.5	13.5	4.2	10.10	4.52	≤99000
Nov. (k = 2)	3.15	1.76	0.0	5.0	2.5	1.5	2.1	2.05	4.52	≤99000
Dec. (k = 3)	1.57	0.0	0.0	5.0	0.0	1.5	15.0	53.00	0.00	≤99000
Jan. (k = 4)	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.00	≤99000
Feb. (k = 5)	2.0	2.0	0.0	0.0	0.0	1.5	0.0	0.0	3.25	≤99000
Mar. (k = 6)	4.0	4.0	0.0	0.0	0.0	1.5	0.0	0.0	6.50	≤99000
Apr. (k = 7)	4.0	4.0	0.0	0.0	0.0	1.5	0.0	0.0	6.50	≤99000
May (k = 8)	4.0	4.0	7.2	0.0	0.0	11.5	4.65	15.1	6.50	≤99000
June (k = 9)	2.0	0.0	14.4	6.3	0.0	11.5	4.75	30.2	3.25	≤99000
Jul. (k = 10)	0.1	0.1	14.4	4.0	10.2	11.5	4.2	10.1	50.00	≤99000
Aug. (k = 11)	0.0	0.0	14.0	4.0	10.76	13.05	4.2	10.1	50.00	≤99000
Sep. (k = 12)	0.0	0.0	14.0	4.0	11.33	14.6	4.2	10.1	2.26	≤99000

RHS: Right hand side

Monthly preparation of the Irrigation Water Requirements (IWR) data (Table 2) carried out by considering two major national available databases in this field, i.e., Farshi *et al.* (1997) and Alizadeh and Kamali (2007). Additional processing operations applied to calibrate them for the region, based on the climatologic circumstances and crop calendar. Adding together these monthly requirements, the seasonal IWR coefficients provided to calculate the total water consumption. The monthly water resources availabilities (Table 2) from both groundwater and surface sources were also computed using the records of the regional water organization of the Isfahan (RWOI., 2006; RWOI., 2007) and additional detailed geostatistical processing operations in GIS environment.

Definition of variables and parameters

Decision variable: x_i allocated land to ith crop (ha) (i = 1, 2,..., 8, 9)

Crisp coefficients:

c_i	:	Per unit of area cash expenditure for production of ith crop (10^6 RS ha^{-1})
N_i	:	Net return per unit area of ith crop during the farming season (10^6 Rs ha^{-1})
l_{ik}	:	Labor requirement per unit area of ith crop during kth month (man-day ha^{-1})
Em_i	:	Total employment creation per unit area of ith crop during the farming season (man-day ha^{-1})
IWR_{ik}	:	Net irrigation water requirement for ith crop during kth month (10^2 m^3 ha^{-1})
W_i	:	Net total water requirement for ith crop during the cropping season (10^2 m^3 ha^{-1})
η_a	:	Irrigation efficiency of surface water at the region (%)
η_b	:	Field water application efficiency of groundwater at the region (%)

Fuzzy productive resources:

A	:	Total arable lands of the study area (ha)
C	:	Total available capital in the area for farming activities (10^6 Rs)
L_k	:	Total available labor force in the study area in kth month (man-day)
SW_k	:	Available surface water in the kth month (10^2 m^3); k = 1, 2,..., 12
GW_k	:	Available groundwater in the kth month (10^2 m^3)

Total available capital, C parameter, could not estimate like the others via field query. So, it has obtained with regard to the existing cropping pattern of the area. To this purpose, a LP model formulated and solved for maximization of the net return in the objective function. In this model, the decision variables x_i take the given values as less than or equal to the current allocated lands to each of the crops in the existing pattern and hence considered as constraints. Contrarily, the unknown availability of the capital, or any other productive resources in the Right Hand Side (RHS) of the relevant constraints, are considered as decision variables where obtained by solving the model. Such models, which can also be formulate for each other objectives as well, called calibrated LP models.

Problem formulation

Description of fuzzy goals: As mentioned in previous sections, all objectives and constraints of the study problem have considered fuzzily and therefore treated as fuzzy goals. Expression of fuzzy goals in fuzzy programming environment is possible only by defining appropriate membership functions, which entail determination of aspired levels and admissible violation parameters.

Table 4 describes these parameters. Monthly fuzzy goals for water and labor force requirements have only been included for two cases in the table, the beginning of winter season (Oct., k = 1) and the end of spring (Sep., k = 12). Aspired levels of constraints fuzzy goals are the same as resources availabilities, which for fuzzy objectives specified by solving separate LP models to optimize them. Respective violations also considered as a proportion of aspiration levels, taking into account sensitivity analysis results.

Formulation of fuzzy goals: According to the data set provided in Table 1-3 and fuzzy parameters described in Table 4, fuzzy goals of the problem have formulated as bellow:

Land utilization maximization goal: The fuzzy goal for utilization of total cultivable land takes the form:

$$x_1+x_2+x_3+x_4+x_5+x_6+x_7+x_8+x_9 \gtrsim 25500 \quad (6)$$

Net return maximization goal: A certain level of profit is commonly aspired to by farmers and always prefer a cropping pattern, which can provide more benefit. It can fuzzily be formulate as:

$$8.82x_1+7.01x_2+21.23x_3+11.04x_4+30.39x_5+9.32x_6+11.24x_7+51.77x_8+19.44x_9 \gtrsim 401950 \quad (7)$$

Labor employment maximization goal: Maximizing number of laborers in agricultural sector is a social objective in developing countries especially in rural areas in order to minimize unemployment as well as under-employment, which can be fuzzily express as:

$$22.39x_1+19.39x_2+71.1x_3+32.3x_4+37.29x_5+84.2x_6+43.3x_7+140.75x_8+137.3x_9 \gtrsim 695000 \quad (8)$$

Land availability goals: The total area allocated to different crops in a season is utmost equal to the total cultivable area, i.e. fuzzily:

$$x_1+x_2+x_9 \lesssim 26500;\ \text{for Winter } (s = 1) \text{ season} \quad (9)$$

$$x_3+x_4+x_5+x_6+x_7+x_8 \lesssim 26500;\ \text{for Spring } (s = 2) \text{ season} \quad (10)$$

Fodder production lower bound goal: To cater the need of social, economic and regional factors of the dynamic system, upper and lower bound constraints are required to introduce into the model for better control on production of certain crops (Gupta *et al*., 2000). Due to the high population and importance of livestock in the agricultural economy of the region, a lower bound constraint of fodder production (maize and alfalfa) added to the model. Considering the average sum of areas allocated to these crops during the last 10 years ago, this goal can be express fuzzily as:

$$x_5+x_6 \gtrsim 8500 \quad (11)$$

Crop rotation (seasonality) goal: In the spring season, which water resources are dropping down, some of the lands left on fallow and the whole area does not completely cultivated. Thus, the seasonality or crop rotation constraint can fuzzily be consider as:

$$x_1+x_2-x_3-x_4-x_5-x_6-x_7-x_8+x_9 \gtrsim 0 \quad (12)$$

Monthly water consumption and water availability goals: In any month irrigation water demand of all the crops should not exceed the available water in that particular month, provided from both surface and groundwater resources. Due to the imprecise estimation of the crops irrigation water requirements coefficients and water resources availabilities (Table 2), these fuzzy goals appears as:

$$4.22x_3+5.51x_4+13.21x_5+8x_6+11.27x_7+5.4x_8+4.1x_9 \lesssim 117965 \quad (13)$$

$$0.9x_1+0.4x_2+4.5x_6+3x_8+4x_9 \lesssim 95222.6 \quad (14)$$

$$1.4x_1+1.2x_2+1.7x_6+2.8x_9 \lesssim 49654.8 \quad (15)$$

$$8.1x_1+8.1x_2+6.1x_6+7.4x_9 \lesssim 110848 \quad (16)$$

$$13.8x_1+13.8x_2+9.9x_6+2.9x_7+12.9x_9 \lesssim 180156 \quad (17)$$

$$15.6x_1+11.3x_2+12.32x_3+2.36x_4+13.4x_6+8.5x_7+1.13x_{8+}17.1x_9 \lesssim 206011.2 \quad (18)$$

$$2.2x_1+32.28x_3+9.6x_4+15.8x_6+22.4x_7+4.75x_8+5.1x_9 \lesssim 109839 \quad (19)$$

$$33.67x_3+18.56x_4+10.62x_5+16.5x_6+24.7x_7+14.49x_8 \lesssim 170126 \quad (20)$$

$$35.38x_3+23.45x_4+19.4x_5+15.7x_6+22.9x_7+17.2x_8+ \lesssim 196108 \quad (21)$$

$$28.06x_3+19.1x_4+20.01x_5+12.6x_6+13x_7+15.58x_8 \lesssim 182744 \quad (22)$$

The irrigation does not required in two months of Jan. (k = 4) and Feb. (k = 5).

Monthly labor force requirement and availability goals: Estimation of the crops requirements and the availabilities of the labor force around the region are performed monthly regards to the crops calendar and multiple operations plantation, plant protection and harvesting durations. Based on the imprecisely calculated data provided in Table 3, the goals can fuzzily be express as:

$$1.57x_1+3.53x_2+4x_4+2.5x_5+13.5x_6+4.2x_7+10.1x_8+4.52x_9 \lesssim 99000 \quad (23)$$

$$3.15x_1+1.76x_2+5x_4+2.5x_5+1.5x_6+2.1x_7+2.05x_8+4.52x_9 \lesssim 99000 \quad (24)$$

$$1.57x_1+5x_4+1.5x_6+15x_7+53x_8 \lesssim 99000 \quad (25)$$

$$2x_1+2x_2+1.5x_6+3.25x_9 \lesssim 99000 \quad (26)$$

$$4x_1+4x_2+1.5x_6+6.5x_9 \lesssim 99000 \quad (27)$$

$$4x_1+4x_2+7.2x_3+11.5x_6+4.65x_7+15.1x_8+6.5x_9 \lesssim 99000 \quad (28)$$

$$2x_1+14.4x_3+6.3x_4+11.5x_6+4.75x_7+30.2x_8+3.25x_9 \lesssim 99000 \quad (29)$$

$$0.1x_1+0.1x_2+14.4x_3+4x_4+10.2x_5+11.5x_6+4.2x_7+10.1x_8+50x_9 \lesssim 99000 \quad (30)$$

$$14x_3+4x_4+10.76x_5+13.05x_6+4.2x_7+10.1x_8+50x_9 \lesssim 99000 \quad (31)$$

$$14x_3+4x_4+11.33x_5+14.6x_6+4.2x_7+10.1x_8+2.26x_9 \lesssim 99000 \quad (32)$$

The equations of the Jan. (k = 4) and Apr. (k = 7) are eliminated (Table 3).

Cash expenditure goal: In rural areas where farmers access to very limit financial resources, the investment required to produce a particular crop plays a significant role in crop selection. Usually, farmers prefer a cropping pattern, which is less investment intensive. Based on the existing situation of the region and solving a calibrated LP model to estimate the available total capital, the respective fuzzy goal takes the form:

$$6.06x_1+5.59x_2+23.02x_3+12.96x_4+21.04x_5+16.53x_6+23.76x_7+48.23x_8+35.49x_9 \lesssim 280000 \quad (33)$$

This constraint refers to the restriction of the available capital at the region for these activities, which calculated based on the existing farming situation of the region by solving a calibrated LP model.

Non-negativity constraints: It is possible to allocate any area for a crop in an allocation zone, but it is impossible to allocate a negative size of an area for a crop. Therefore, decision variables of the model cannot take negative values.

$$x_1,x_2,x_3,x_4,x_5,x_6,x_7,x_8,x_9 \geq 0 \quad (34)$$

Now, the construction of membership functions and membership goals for the defined fuzzy goals and then the FGP formulation of the problem are demonstrated through the following two examples only for net return (7) as a maximization fuzzy goal and capital requirement (33) as a minimization fuzzy goal.

Based on the Eq. 2 and 3, the membership functions of the net return and cash expenditure goals constructed as:

$$\mu_{12} = 1-0.0000667\ (401950-8.82x_1-7.01x_2-21.23x_3-11.04x_4-30.39x_5-9.32x_6-11.24x_7-51.77x_8-19.44x_9) \quad (35)$$

$$\mu_{225} = 1-0.0000161\ (6.06x_1+5.59x_2+23.02x_3+12.96x_4+21.04x_5+16.53x_6+23.76x_7+48.23x_8+35.49x_9-280000) \quad (36)$$

By applying and simplifying the Eq. 5 on the above membership functions, the final membership goals of these functions computed as:

$$0.0000667\ (8.82x_1+7.01x_2+21.23x_3+11.04x_4+30.39x_5+9.32x_6+11.24x_7+51.77x_8+19.44x_9)+n_{12}-p_{12} = 26.8 \quad (37)$$

$$0.0000161\ (6.06x_1+5.59x_2+23.02x_3+12.96x_4+21.04x_5+16.53x_6+23.76x_7+48.23x_8+35.49x_9)-n_{225}+p_{225} = 4.51 \quad (38)$$

The constructing procedure of the remained membership goals has forgotten in order to avoid of manuscript lasting.

RESULTS AND DISCUSSION

Citing the described approach for solving the multi-objective fuzzy linear goal programming models by using the membership functions 2 and 3 and respective aspiration levels and tolerance limits parameters (Table 4) for fuzzy objectives and constraints, the problem was formulated finally comprising 28 membership goals, as e.g. demonstrated at the end of previous section. The objective function contained 28 weighted negative deviational variables, based on the minsum GP methodology. To illustrate the precedence of the explained fuzzy GP approach, the obtained cropping pattern has compared with the existing situation and the ordinary GP results. Both GP and FGP models have solved using LINDO software. Table 5 presents the allocated lands to the crops in these 3 patterns. According to the results, 25922 (97.82%) and 26102 ha (98.5%) of 26500 ha of region's arable lands are allocated in the classical and fuzzy GP patterns of cropping, totally in the Winter and Spring seasons. The total cultivated lands in existing pattern equal 26200 (98.86%). The differences of the current and determined GP patterns of cropping in area maximization goal does not considered significant. The manner of allocating the lands to the various crops has the main contribution to the appropriateness and reasonability of

Table 4: Description of fuzzy goals

		Tolerance limits (d_{1k} and d_{2i})	
Fuzzy goals	Aspiration levels (g_k and b_i)	Lower	Upper
Fuzzy objectives			
Land utilization	25500	1200	-
Net return	401950	15000	-
Labor employment	695000	80000	-
Fuzzy constraints			
Land availability (Winter season)	26500	-	1000
Land availability (Spring season)	26500	-	1000
Lower bound on fodder requirement	8500	500	-
Crop rotation (seasonality)	0	100	-
Water requirement (Oct. k = 1)	117965	-	13000
Water requirement (Sep. k=12)	182744	-	12000
Labor force requirement (Oct. k=1)	99000	-	5000
Labor force requirement (Sep. k = 12)	99000	-	11000
Capital availability	280000	-	62000

Table 5: Allocated lands in the existing, crisp GP and fuzzy GP based patterns of cropping

	Activities (ha)								
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
Patterns	Wheat	Barley	Rice	Corn	Maize	Alfalfa	Sugar beet	Potato	Onion
Existing	11000.0	1450	1500	400.0	7000.0	2200	50	400.0	2200
Crisp GP	15190.5	0	0	505.4	9878.3	0	0	348.6	0
Fuzzy GP	15245.8	0	0	1101.6	8931.5	0	0	823.0	0

an optimal given solution. Barley, rice and sugar beet have eliminated in both GP models. Decreasing the barley area coincides with an increasing of the wheat area, such that the wheat area in these models is more than both barley and wheat area in current situation. According to socio-economical data (Table 1), the least rate of job opportunities and income generation and water consumption belong to these crops in the region. Although, the rice is one of the high yield crops, it is also the most water consuming one per unit of area. Sugar beet has not a considerable contribution in the existing cropping pattern. In classical GP results, the alfalfa and onion are also eliminated in favor of the increasing the silage maize and potato area respectively. The situation of the potato and onion cultivation in recent ten years indicates a competition regarding land allocation to these two crops. In other words, the trade-offs between these two crops conforms to the cobweb curves behavior across the region. Potato and silage maize with the most incremental area changes are the most efficient and not high water consuming crops. Additionally, the potato has the most contribution to the farming job opportunities in the region.

The achievement level of each patterns to the area, income and employment goals accompanied by water consumption and cash expenditure measures have depicted in Table 6. A more appropriate solution to determine a cropping pattern in agricultural systems can be obtain with the best compromise between multiple objectives regarding the constraints, as incompatible set of criteria. To evaluate the simultaneous increment of the net return and employment and decreasing water consumption and cash expenditure, the comparative results of the solutions have displayed in Table 7.

Except for the employment creation goal, all other criteria have improved in both GP and fuzzy GP solutions. This indicates that the existing farming system of the region is labor rather than capital intensive. This can be explained according to the rurality and not so young structure of the region's population structure. Therefore, the exceeding labor intensity of the region's farming system is partly modified in the GP solutions. Considering the results of the multi-objective programming approaches compared to the current situation, it is found that the constraints of the productive resources such as water and capital availability are more determinant of land allocation and farming system identification with respect to the objective functions. On the contrary, the dominance of the fuzzy GP approach over the crisp one, mainly pertains to the goals of objective functions. The prominence of the fuzzy GP solution has depicted in Table 8, compared to the crisp GP results. As these results show, both benefit (net return and employment creation) and cost (water use and expenditure) criteria have increased in fuzzy GP solution. In other words,

Table 6: Goal achievement measures in existing and GP approaches patterns of cropping

Patterns	Area (ha)	Net return ($\times10^6$Rs*)	Employment (man-day)	Water use ($\times10^3$ m^3)	Capital ($\times10^6$Rs)
Existing	26200.0	440616.5	1200770.5	168044.8	396683.5
Crisp GP	25922.8	457686.8	773876.2	141501.5	323260.0
Fuzzy GP	26102.0	460547.3	825835.8	143382.7	334281.3

*10^6Rs≅30 USD

Table 7: Improvement of the goals in GP and FGP models compared to the existing situation

	GP model		Fuzzy GP model	
Criteria (Goals)	Increment (Decrement)	Percentage	Increment (Decrement)	Percentage
Net return	17070.3	3.87	19930.77	4.52
Employment	(426894.3)	(35.55)	(374934.67)	(31.22)
Water use	(265433.6)	(15.81)	(246621.25)	(14.68)
Expenditure	(73423.5)	(18.51)	(62402.18)	(15.73)

Figures in parenthesis indicate non-dominance or decrease percentage of measures

Table 8: Prominence of the goals achievement in fuzzy GP compared to the crisp GP solutions

	Criteria (Goals)			
Fuzzy GP dominance over crisp GP	Net return	Employment	Water use	Expenditure
Increase	2860.43	51959.64	18812.41	11021.32
Percentage	0.62	6.71	1.33	3.41

the net return and employment goals are improved at the cost of the some deviations of the water use and cash expenditure constraints, which has allowed in fuzzy programming.

Both the dominance of fuzzy GP over the crisp one and somewhat the in optimality of some high water consuming crops for sustainability of farming systems, have demonstrated in some other areas of Iran especially due to the relative similarity of determinant productive resources' situation of insufficiency. Notably, the results of Mohaddes and Mohayidin (2008), Daneshvar Kakhki *et al*. (2009), Soltani *et al*. (2011) and Mirkarimi *et al*. (2013) are some instances. Sharma *et al*. (2007) have also illustrated better recommendations on optimal land allocation for different crops in the planning process, based on the fuzzy GP compared to the ordinary GP and especially LP solutions in the rural region of Ghaziabad district of Uttar Pradesh, India. Finally, it is worth mentioning that the trade-offs between the maximizing goals and productive resources constraints better be discussed by defining and considering the ratio functions, optimizing the outputs of the agricultural systems in proportion to the unit of inputs. Optimizing the objectives divided especially by the more determinant productive resources, can dealt with through fractional programming models (Amini Fasakhodi *et al*., 2010; Gomez *et al*., 2006; Lara and Stancu-Minasian, 1999).

CONCLUSION

The multi-objective fuzzy goal programming approach to cropping plan in a rural agricultural system, demonstrated in this article, provides a new prospect in analyzing the different farm-related activities in an imprecise decision-making environment. The main advantage of this proposed approach is that the decision for proper allocation of cultivable land for production of seasonal crops can made based on the productive resources availabilities and needs of the society. In this proposed model, all the objective functions and different environmental and socio-economic constraints can imprecisely incorporated and a proper cropping plan can obtained without involving any computational difficulty. Applying the multi-objective programming framework, the objectives of area, net return and employment maximization and the constraints of land, water, manpower and capital availability, rotation and a lower bound production are all fuzzily considered to determine an optimal cropping plan in a farming system. The comparison of the goal achievements and productive resources consumption in existing situations with the obtained goals of fuzzy multi-objective programming plan indicated the in optimality of the current resources allocation and cropping pattern in the region. Changing the current cropping pattern of the rural study area corresponding to the identified FGP results can help to achieve considerable conservation of environmental and financial water and capital resources. Additionally, the income generation of the farming system is also increasing as a result while the total area under cultivation remains unchanged. The only inconsiderable drawback is that the employment rate is somewhat decreased.

It is based on the results, obviously evident and cognizable that the comprehensiveness of goals and constraints set based on the region's situation, has led to distinguish a more environmental conservative pattern of cropping. Considering the fact of climatically aridness of the study area and generally the whole region of Central Iran accompanied especially by occurrence of the recent sever scarcity of water resources, necessitates highly and urgently the alteration and modification of the limited water resources management. Eliminating of high water consuming crops such as rice, alfalfa and sugar beet and replacing exactly the area with low water consuming and simultaneously more socio-economically efficient adopted crops is the best procedure to adjust the production planning towards the relatively sustainable and optimal productive resources allocation and rural systems viability in order to better encounter the occurring environmental crisis. An extension of the investigated and applied fuzzy goal programming approach in agricultural systems planning for optimizing the ratio goal functions relating the outputs to the inputs may be one of the current research problems, which can be dealt with in the fields of fractional programming procedures.

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