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# Determining optimum cropping pattern using Fuzzy Goal Programming (FGP) model

J. Soltani<sup>1</sup>, A. R. Karbasi<sup>2</sup> and S. M. Fahimifard<sup>3\*</sup>

<sup>1</sup>Civil Engineering Department, University of Zabol-Iran.

<sup>2</sup>Agricultural Economics Department, Fedowski University of Mashhad-Iran.

<sup>3</sup>Department of Agriculture, Shirvan branch, Islamic Azad University, Shirvan-Iran.

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Efficient management of the agricultural resources is becoming the key issue to feed the increasing population from the limited resources. The purpose of this study was to find the optimal cropping pattern, in Bardsir region of Kerman-Iran, which maximizes the crop production and net return, and minimizes the employing of labor, water and machinery inputs. A Fuzzy Goal Programming (FGP) model was applied and compared with goal programming (GP) and linear programming (LP) models. The results of optimization based on LP model suggested that total area of land (22620 ha) should be allocated to wheat (4639.01 ha), maize (10238.04 ha) and potato (3884.21 ha). The GP model optimization suggested that total area should be allocated to wheat (5943.18 ha), maize (3720.36 ha), sugar beet (4313.88 ha) and potato (4600.45 ha). Also, FGP model optimization indicated that total area should be allocated to wheat (9341.40 ha), maize (10607.42 ha) and potato (2562.24 ha). Finally, results indicated that the cropping pattern of FGP was found to be the best and gave maximum net return.

**Key words:** Cropping pattern, goal programming, linear programming, fuzzy goal programming, Bardsir regions, net return.

## INTRODUCTION

The agricultural products represent the main alimentary source for 6.7 billion people. Therefore agriculture represents that fundamental sector of the world economy that has to supply food for all mankind (FAO United Nations, 2009). Beside, today growing population of world has increased the need for agricultural products and consequently increased the pressure on based resources that is required for those products. In order to feed the growing population, agricultural production is to be increased. This can be achieved either by increasing the area under cultivation or by increasing the production per unit area through optimal crop planning using the available land, water resources and other agricultural inputs (Sharma et al., 2007). Not excepted the other

world, agriculture is very important sector in Iran in order that this sector contributed 11% of the gross domestic product (GDP) in 2004 and employed a third of the labor force. In addition benefiting from 123,580 square kilometers of land suitable for agriculture, the agricultural sector is one of the major contributors to Iran's economy. It accounts for almost 13% of Iran's GDP, 20% of the employed population, 23% of non-oil exports, 82% of domestically consumed foodstuffs and 90% of raw materials used in the food processing industry (Iran's Ministry of Agricultural Jihad, 2009). On the other hand, roughly one-third of Iran's total surface area is suited for farmland, but because of poor soil and lack of adequate water distribution in many areas, most of it is not under cultivation. Only 12% of the total land area is under cultivation but less than one-third of the cultivated area is irrigated; the rest is devoted to dry farming (Iran's Ministry of Agriculture Jihad, 2009). Therefore, according to the lack of Iran's cultivatable land, cropping pattern optimization has the key role in order to satisfy the Iranian food security. In order to optimize the cropping pattern, a number of approaches, such as, benefit-cost, functional, programming, simulation, etc are commonly

\*Corresponding author. E-mail: [mfahimifard@gmail.com](mailto:mfahimifard@gmail.com).

**Abbreviations:** FGP, Fuzzy goal programming; GP, goal programming; LP, linear programming; GDP, gross domestic product; FMOLF, fuzzy multi-objective fractional programming; FPG, fuzzy programming goal.

available to optimize the cropping pattern with available land and water (Srinivasa and Nagesh, 2000). This study follows the FGP model.

In addition, a number of research studies have been carried out for optimization of cropping pattern using programming approach. Abadi et al. (2009) studied the optimal cropping pattern, in Taybad-Iran. They concluded that fuzzy multi-objective fractional programming (FMOLFP) models can be used as an effective tool for optimal cropping pattern when in addition to economical goals, environmental goals are noticed. Mohaddes and Mohayidin (2008) applied fuzzy multi-objective mathematical programming model to the Atrak-Iran watershed agricultural development plan. The model focused on attaining three objectives simultaneously, namely, profit maximization, employment maximization and erosion minimization and these are subjected to 88 constraints. Results of the model indicated that, when compared with the current cropping structure, the implementation of the optimal cropping pattern could increase profit and employment and decrease soil erosion significantly. Sharma et al. (2007) presented a FGP model for optimal allocation of land under cultivation and proposes an annual agricultural plan for different crops. In this study, they demonstrated that the FGP approach is a better technique over a single objective criterion when multiple conflicting objectives are involved. Also, the model developed provided the best possible solution subject to the model constraints. Hassan and Ahmad (2006) selected the irrigated areas of Punjab province for determining optimum cropping pattern under various price options using LP model. Crops included in the models were wheat, basmati rice, IRRI rice, cotton, sugarcane, maize, potato, gram and mong/mash. They reported that the irrigated agriculture in the Punjab is more or less operating at the optimal level (Biswas and Pal, 2005) presented how FGP can be efficiently used for modeling and solving land-use planning problems in agricultural systems for optimal production of several seasonal crops in a planning year. As the lack of Iran's cultivatable land, we study the usefulness of cropping pattern optimization based on land allocation using FGP model which has more consistence with fuzzy sense of agricultural planning. As an empirical research we apply the Fuzzy programming goal (FPG) model to optimize the Bardsir region's cropping pattern in comparison with LP and GP models.

## MATERIALS AND METHODS

### Study area

The Bardsir region is located in Kerman province of Iran. The geographical area of Bardsir region is 6324 sq. km and agricultural activities are its dominant job. The required data (production of crops, cultivated land for each crop, water consumption, labor, requirement of machinery and cash requirement for all crops gathered from Iran's Ministry of Agriculture Jihad. The main crops of

this region are wheat (c=1), barley (c=2), maize (c=3), sugar beet (c=4), alfalfa (c=5) and potato (c=6). And its total area of land under cultivation is 22620 hectares (Iran's Ministry of Agriculture Jihad, 2009). Finally the project has been conducted from 2010/03/10 to 2011/01/01.

### Fuzzy goal programming (FGP) model description

The LP model with the optimization of a given objective subject to a number of environmental and/or system constraints had been stated by Jain et al. (1988). Also, GP originally developed by (Charnes and Cooper, 1961) is a mathematical programming technique with the capability of handling multiple objectives following a satisfaction criterion rather than an optimization one, that satisfaction criterion leading to the concept of goal (Umamahesh and Raju, 2002). In GP model, parameters of the problem need to be defined precisely while in most agricultural planning problems; values of some parameters may not be known precisely. They are rather defined in a fuzzy sense hence in order to successfully handling such problems, FGP techniques must be used. In formulating the considered cropping pattern optimization based on land allocation problem, goals and requirements used to formulate the FGP model are defined in Table 1. Narasimhan (1980) was the first to give FGP formulation using the concept of membership functions which are defined on the interval [0, 1]. The membership function for the k<sup>th</sup> goal has a value of 1 when this goal is attained and the decision making is completely satisfied; otherwise the membership function assumes a value between 0 and 1. Linear membership functions are used in literature and practice more than other types of membership functions.

In fuzzy goal programming, the membership function corresponding to the k<sup>th</sup> fuzzy goal of type  $G_k(x) \geq b_k$  is defined as:

$$\mu_{Z_k}(x) = \begin{cases} 1 & \text{if } G_k(x) \geq b_k \\ \frac{G_k(x) - (b_k - L_k)}{L_k} & \text{if } b_k - L_k \leq G_k(x) < b_k \\ 0 & \text{if } G_k(x) < b_k - L_k \end{cases}, k = m+1, \dots, n \quad (1)$$

Also, the membership function corresponding to the k<sup>th</sup> fuzzy goal of type  $G_k(x) \leq b_k$  is defined as:

$$\mu_{Z_k}(x) = \begin{cases} 1 & \text{if } G_k(x) \leq b_k \\ \frac{(b_k + U_k) - G_k(x)}{L_k} & \text{if } b_k < G_k(x) \leq b_k + U_k \\ 0 & \text{if } G_k(x) > b_k + U_k \end{cases}, k = m+1, \dots, n \quad (2)$$

Where  $L_k$  ( $U_k$ ) is lower (upper) tolerance limit for k<sup>th</sup> fuzzy goal  $G_k(x)$  which are either subjectively chosen by decision makers or tolerances in a technical process (Chen and Tsai, 2001).  $\mu_{Z_k}(x)$  represents the membership grade of achieving the goal with 0 and 1 representing the lowest and highest grade, respectively. The membership grade depends on the specified tolerance value given in the decision making context. In considered FGP model of cropping pattern based on land allocation, crop production goal and

**Table 1.** Goals and essential requirements for considered FGP problem.

Goals	Description	Simple goals formula
Crop production	Sum of the productions for all the crops should be greater or equal to the expected production target.	$\sum_{c=1}^c AP_c A_c \geq \sum_{c=1}^c TP_c$
Net profit	Farmer requires special level of profit from the crops.	$\sum_{c=1}^c NP_c A_c \geq NP$
Labor requirement	Farmer hires approximated number of agricultural laborers.	$\sum_{c=1}^c L_c A_c \leq L$
Water requirement	To achieve the production target of each crop, adequate water should be ensured.	$\sum_{c=1}^c W_c A_c \leq TW$
Machine utilization	The machine-hours should not exceed the machine-hours available.	$\sum_{c=1}^c M_c A_c \leq TM$
<b>Requirements</b>	<b>Description</b>	<b>Formula</b>
Cultivable land availability	The sum of available land for all crops must not exceed total cultivable land available.	$\sum_{c=1}^c A_c \leq TA$
Capital requirement	A set amount of money must be reserved for fertilizers, seeds, etc.	$\sum_{c=1}^c I_c A_c \leq TI$

net profit goal are of type  $G_k(x) \geq b_k$ . In addition, labor requirements, water requirements and machine utilization goals are of type  $G_k(x) \leq b_k$ . If crop production and net profit goals are completely achieved then no tolerances for them are needed and the grades of membership for the goals should be unity. When these goals are either perfectly or partially unachieved, tolerances for them are required. (Kim and Whang, 1998) used the concept of tolerance to convert an FGP model to a single objective LP problem. If  $U_i^{-(+)}, i = 1, 2$  are the lower (upper) tolerances and  $\beta_i^{-(+)} \in [0, 1], i = 1, 2$  are the grades of membership, then the corresponding crop production, net profit, labor requirement, water requirement and machine utilization goals can be transformed as fuzzy goals. The fuzzy goals for the problem are transformed to their respective linear constraint form. Therefore, the objective function for cropping pattern optimization based on land allocation is defined as follow (Kim and Whang, 1998):

$$\min : \sum_{i=1}^2 w_i \gamma_i^- + \sum_{i=3}^5 w_i \gamma_i^+ \tag{3}$$

Where  $w_i, i=1, 2, 3, 4$  and  $5$  are the respective weights corresponding to the fuzzy goals and the sum of all weights is one. The final LP form of our cropping pattern optimization included of fuzzy goals is as follows:

$$\min: \sum_{i=1}^2 w_i \gamma_i^- + \sum_{i=3}^5 w_i \gamma_i^+ \tag{4}$$

S.t:

$$\sum_{c=1}^c AP_c A_c + \gamma_1^- U_1^- \geq \sum_{c=1}^c TP_c \tag{5}$$

$$\sum_{c=1}^c NP_c A_c + \gamma_2^- U_2^- \geq NP \tag{6}$$

$$\sum_{c=1}^c L_c A_c - \gamma_1^+ U_1^+ \leq L \tag{7}$$

$$\sum_{c=1}^c W_c A_c - \gamma_2^+ U_2^+ \leq TW \tag{8}$$

$$\sum_{c=1}^c M_c A_c - \gamma_3^+ U_3^+ \leq TM \tag{9}$$

$$\sum_{c=1}^c A_c \leq TA \tag{10}$$

$$\sum_{c=1}^c I_c A_c \leq TI \tag{11}$$

$$0 \leq \gamma_1^-, \gamma_2^-, \gamma_1^+, \gamma_2^+, \gamma_3^+ \leq 1 \tag{12}$$

$$\sum_{i=1}^5 w_i = 1 \tag{13}$$

$$A_c \geq 0 \tag{14}$$

Where :

**Table 2.** Characteristics of FPG cropping pattern optimization of Bardsir region.

Crops	AP <sub>c</sub> (ton/ha)	L <sub>c</sub> (person/ha)	W <sub>c</sub> (liter/ha)	M <sub>c</sub> (hrs/ha)	I <sub>c</sub> (1000 Rials)	NP <sub>c</sub> (1000 Rials)
Wheat	3.39	37	7600	18.5	2229	3088
Barley	2.75	26	4400	11.5	1725	1120
Maize	9.98	37	17300	17.5	3723	5760
Sugar beet	27.24	73	21300	30.5	3830	5980
Alfalfa	9.9	43	14100	15	2021	1640
Potato	17.2	92	15300	18.5	13270	10775

Source: Iran's Ministry of Agriculture Jihad, 2010.

**Table 3.** Goals properties.

Goals	Target	Tolerance
Production (ton)	267,967	32,033
Net profit (1000Rials)	150,148,700	35,000,000
Labor requirement (person-days)	1,000,000	95,706
Machine utilization (hrs)	4,000,000	24,054.5
Water requirement (liter)	200,000,000	71,803,000

Source: Iran's Ministry of Agriculture Jihad, 2010.

$$\gamma_i^- = 1 - \beta_i^-, i=1,2 \quad \text{and} \quad \gamma_i^+ = 1 - \beta_i^+, i=1,2,3$$

## RESULTS AND DISCUSSION

As the lack of Iran's cultivatable land, this study quantifies the usefulness of cropping pattern optimization based on land allocation using FGP model which has more consistence with fuzzy sense of agricultural planning. As an empirical research we apply the FPG model to optimize the Bardsir region's cropping pattern in comparison with LP and GP models. Also, in this section the LP, GP and FPG models which developed before, is applied to real data related to the Bardsir region. Table 2 illustrates the characteristics and requirements of cropping pattern in this region: This study maximizes the crop production and net return, and minimizes the employing of labor, water and machinery inputs in Bardsir region. The goals properties of our cropping pattern optimization and their tolerance have been stated in Table 3. Finally, the FGP model formulated using the above data and WinQsb software. The optimal cropping pattern resulting from the application of FGP model in comparison to GP, LP and the existing cropping patterns for sex crops and membership grades for FGP have been presented in Table 4. The aforementioned results show that the:

1. Total area and net profit of existing cropping pattern are 22,620 ha and 91,316,920,000 Rials, respectively;

2. The results of cropping pattern optimization based on LP model suggests that total area of land should be allocated to wheat, maize and potato through 4639.01, 10238.04 and 3884.21 hectare, respectively. And the achieved net profit based on this model is 115,148,694,500 Rials which is again more than existing cropping pattern and less than cropping pattern optimization using FGP model;

3. The cropping pattern optimization based on GP model suggests that total area of land should be allocated to wheat, maize, sugar beet and potato through 5943.18, 3720.36, 4313.88 and 4600.45 hectare, respectively. And the achieved net profit based on this model is 115,148,664,600 Rials which is more than existing cropping pattern but less than cropping pattern optimization using FGP model;

4. Finally, the results of cropping pattern optimization based on FGP model indicate that tolerance is required only for net profit goal and no tolerances are required for crop production, labor requirement, water requirement and machine utilization because they are achieved completely. On the other hand, the cropping pattern optimization based on FGP model suggests that total area of land should be allocated to wheat, maize and potato through 9341.40, 10607.42 and 2562.24 hectare, respectively. And the achieved net profit based on this model is 117,553,118,400 Rials which is more than existing cropping pattern and cropping pattern optimization using LP and GP models;

5. FGP cropping pattern optimization based on land allocation outperforms the LP and GP models.

**Table 4.** Cropping pattern optimization based on land allocation using FGP, GP and LP models

FGP	GP	LP	Existing cropping pattern	Variable
1				$\beta_1^-$
0.4445				$\beta_2^-$
1				$\beta_1^+$
1				$\beta_2^+$
1			7820	$\beta_3^+$
0	5943.18	4639.01	3002	A <sub>1</sub>
10607.42	0	0	753	A <sub>2</sub>
0	3720	10238.04	4612	A <sub>3</sub>
0	4313.88	0	4097	A <sub>4</sub>
2562.24	0	0	2336	A <sub>5</sub>
	4600.45	3884.21		A <sub>6</sub>
22511.06	18577.87	18761.26	22620.00	Total area of land for cultivation(ha)
117553118.40	115148664.60	115148694.50	91316920.00	Net profit (1000 Rials)

Source: Research findings.

Therefore the results of this study support the previous studies through the better performance of FGP model in comparison with LP and GP models.

## Conclusion

In this paper we studied the usefulness of cropping pattern optimization based on land allocation using FGP model which has more consistence with fuzzy sense of agricultural planning. As an empirical study we optimized the cropping pattern in Bardsir region of Kerman-Iran using FGP model in comparison with LP and GP models. The results of optimization based on FGP model indicated that tolerance is required only for net profit goal and no tolerances are required for crop production, labor requirement, water requirement and machine utilization because they are achieved completely. In addition optimization based on FGP model suggested that total area of cultivatable land should be allocated to wheat, maize and potato. Finally this study concludes that FGP model outperforms the LP and GP models.

**Notations:** **A<sub>1</sub>**, The area of land cultivated for wheat; **A<sub>2</sub>**, the area of land cultivated for barley; **A<sub>3</sub>**, the area of land cultivated for maize; **A<sub>4</sub>**, the area of land cultivated for sugar beet; **A<sub>5</sub>**, the area of land cultivated for alfalfa; **A<sub>6</sub>**, the area of land cultivated for potato; **A<sub>c</sub>**, the area of the land cultivated for crop *c* (ha); **AP<sub>c</sub>**, average production per unit area of crop *c* (ton/ha); **AI<sub>c</sub>**, average investment per unit area for crop *c* (Rial); **b<sub>k</sub>**, linear vector stipulation;  $\beta_1^-$ , membership grade for production goal;  $\beta_2^-$ , membership grade for profit goal;  $\beta_1^+$ , membership grade

for labor goal;  $\beta_2^+$ , membership grade for machine goal;  $\beta_3^+$ , membership grade for water goal; **c**, indice for the crop; **L**, expected labor availability (person-days); **L<sub>c</sub>**, labor requirement per unit area for crop *c* (person-days/ha); **M<sub>c</sub>**, annual machine-hours per unit area for crop *c* (hrs/ha); **NP**, expected net profit for all crops (Rial); **NP<sub>c</sub>**, net profit for crop *c* (Rial); **N<sub>c</sub>**, number of crops cultivated; **TA**, total area of land for cultivation (ha); **TI**, total investment available (Rial); **TM**, expected total machine-hours available (hrs); **TP<sub>c</sub>**, total production target of crop *c* (ton); **TW**, Expected total ground water available for irrigation (liter); **W<sub>c</sub>**, amount of water requirements for the crop *c* (liter/ha).

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