J. Appl. Environ. Biol. Sci., 4(3s)21-25, 2014

ISSN: 2090-4274
Journal of Applied Environmental
and Biological Sciences
www.textroad.com

The Determination of Optimal Cropping Pattern Using Mathematical Programming with an Emphasis on Sustainable Agriculture (Case Study: Boroujerd City)

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Received: March 29, 2014
Accepted: June 27, 2014

ABSTRACT

One of the ways to increase agricultural production is to increase the acreage. The increase of acreage regardless of production limiting factors causes non-optimal use of available resources and therefore will lead to cropping program failure. According the role and importance of crop units management, using mathematical models have significant role in determining optimal cropping pattern. Hence, in this study, use of fuzzy linear programming model to determine the optimal model in Boroujerd city was considered. For this purpose, to maximize program efficiency regarding the existing systematic limits for different products in the region, different values of λ was considered. Data of this study was related to 2010-2011. The results showed value of $\lambda = 0/89.$ for the optimum cropping pattern. The current planting pattern with the cultivation patterns of wheat, sugar beet and fodder corn acreage compared with the available situation should be increased and it should be reduced for barley acreage and have no significant change for broad beans.

KEYWORDS- ***Boroujerd City, Fuzzy Linear programming, optimal cropping pattern***

I. INTRODUCTION

Sustainable agriculture is a kind of agriculture for the benefit of humans which is more efficient in using resources and is in harmony with the environment [1]. Indeed, sustainable agriculture means using the most appropriate method of production in accordance with the natural ecosystems as well as with the highest level of production in agriculture. Generally speaking, sustainable agriculture is one of the goals which should be achieved quickly and reduce the need to expensive and malicious chemicals by continuing it [2]. Due to the growing demand for agricultural products, more efficient use of scarce resources is inevitably necessary. Currently, scarcity of water is maybe the most serious problem about important inputs among the resources used in agriculture. To meet the ever increasing demand for water, resources development and water supply increasing policies have always been considered [3]. Although the sustainable use of scarce water resources is highly considered by the policy makers as a target, following the policy of sustainable water use should also be addressed regarding the preferences of operators. Furthermore, as a policy making recommendation, it is necessary to reduce the use of water due to the current situation [4]. Designing cropping pattern i.e. determining the acreages is specifically important and should be done in such a way that in addition to optimal use of existing and available capacity satisfies part of the regional and national needs. Designing cropping pattern is a complex process influenced by multiple and various factors investigation of which makes the pattern designer collect a lot of data and information [5]. Programming crops production in one of the most determining programs in agriculture and depends on land, water, labor and capital resources [5]. In the real world, most of imprecise and vague information is expressed by certain numbers which is incorrect for the attention and consideration of uncertainty [6]. Fuzzy Programming (FP) and Interval Programming (IP) are the two techniques introduced to solve this problem. Because Fuzzy Programming gives the possibility of unambiguous and accurate data involvement in the parameters of the model, it has more application and flexibility for the use in pattern optimization of cropping pattern compared to the classical models of mathematical programming and has more reliable results [7]. So far, many studies have been done on determining cropping pattern for sustainability agriculture in the country and abroad some of which are as follows:

Kohansal & Firuz Zare [1] studied the cropping pattern in Northern Khorasan Province with the objectives of sustainable agriculture using fractional fuzzy programming with multiple purposes. The results showed that the pattern resulted from Linear

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programming was close to current cropping pattern while the pattern from fractional Fuzzy Programming pattern and current cropping pattern were significantly different in achieving sustainability. Ghasemi et al. [4] determined the optimal cropping pattern in Marvdasht city with a focus on water restrictions. In this study, forage maize and vegetables acreages were obtained more than their current patterns but that of the barley cropping was reduced. Broad bean acreage was also close to the current level. [8] Examined the cropping pattern in the direction of sustainable agriculture using fractional Fuzzy Programming with multiple objectives in the Piranshahr city. The results indicated that the optimal cropping pattern using a fractional Fuzzy Programming with multiple objectives was greatly inconsistent with the current cropping pattern in achieving sustainability. Also, studies of Bayat [9], Kohansal and Mohammedian [10], and Berim nejad and Mirzaii [11] can be pointed out. Sing et al. [12] used a linear programming model with the objective of maximizing net income in a region of Pakistan to determine the cropping pattern. Based on the obtained results, the most profitable cropping of the area was cropping wheat. Doppler et al. [13] provided an optimal cropping pattern and water allocation to Jordan Valley using the Motad risky programming approach. It was shown by the results that if risky considerations are entered into the model, due to the lack of price volatility in grains in risky pattern, the share of cereals would increase. Masood et al. [14] and Daneshvar et al. [15] also conducted a study sought to determine the optimal cropping pattern. In this study, considering the objectives of sustainable agriculture and available limits in the study area, providing a suitable cropping pattern is necessary. Therefore, in the present study it was attempted to determine the optimal cropping pattern of Boroojerd city using fuzzy linear programming model.

II. METHODS AND MATERIALS

Data for this research was collected through face to face interviews with Jihad agricultural experts and farmers of Boroojerd city. Variables in this study included the acreage, water, labor, chemical fertilizer and pesticides. Data analysis was performed using the Excel - Solver Software pack.

A. Fuzzy Linear Programming Method

Purposes of decision maker in a fuzzy decision making environment is always expressed fuzzy. However, resources limits may be either fuzzy or definite. It should be noted that there are many ways to make these models fuzzy. A classical model of linear programming can be as follows:

(1)

$$F(x) = c^T x = \sum_{j=1}^{n} c_j x \,\tilde{\geq}\, b_o$$
$$S.t.$$
$$(Ax)_i = \sum_{j=1}^{n} a_{ij} x_j \,\tilde{\leq}\, b_i \qquad \forall i = 1,\ldots,m$$
$$x_j \geq 0 \qquad \forall j = 1,\ldots,n$$

In this equation, **F** is the objective function, **C***j* is efficiency program, a *ij* is technical coefficients of activities and b*i* is right side restrictions value. A fuzzy linear programming model is as follows (Salsky and Noel 2001, Zimmerman 1978).

(2)

$$F(x) = c^T x = \sum_{j=1}^{n} c_j x \,\tilde{\geq}\, b_o$$
$$S.t.$$
$$(Ax)_i = \sum_{j=1}^{n} a_{ij} x_j \,\tilde{\leq}\, b_i \qquad \forall i = 1,\ldots,m$$
$$x_j \geq 0 \qquad \forall j = 1,\ldots,n$$

X is the vector of decision variable, and " $\tilde{\geq}$ " and " $\tilde{\leq}$ " show fuzzy limits of $\geq$ and $\leq$. In a fuzzy decision making condition, functions of objective and limits position are expressed as fuzzy set with linear form from membership functions and are determined by membership functions and by determining the high or low limit range for each one. b_o and d_o are considered as high and low limit range to achieve the desired objective, respectively.

For fuzzy objective, membership function of $\mu_o(x)$ is as follows (Salsky and Noel, 2001):

(3)

$$\mu_o : R^n \to [0,1]$$

$$\mu_o(x) = \begin{cases} 1 & c^T x \succ b_o \\ 1 - \dfrac{b_o - c^T x}{d_o} & b_o - d_o \le c^T x \le b_o \\ 0 & c^T x \prec b - d \end{cases}$$

In which $b_o, d_o \in R$ and b_o represent the expected level of decision -making unit and d_o is the value which is determined intellectually by the decision- making unit. Membership function for the limitation of equation (2) is defined as follows [16]:

(4)

$$\mu_i(x) : R^n \to [0,1], i = 1, \ldots, m$$

$$\mu_i(x) = \begin{cases} 1 & (Ax)_i \le b_i \\ 1 - \dfrac{(Ax)_i - b_i}{d_i} & b_i < (Ax)_i \le b_i + d_i \\ 0 & (Ax)_i > b_i + d_i \end{cases}$$

Fuzzy decision making based on Balman and Zadeh (1970) approach can be expressed as follows [16, 17]:

(5)

$$\mu_D(x) = \min[u_0(x), \min u_i(x)], \quad x \in R^n$$

Next step is to find the optimal solution of $x_{opt} \in R^n$ with the highest membership value. In other words, we have [16]:

(6)

$$\begin{aligned} & Max \quad \lambda \\ & S.t. \\ & \qquad \mu_0(x) \ge \lambda \\ & \qquad \mu_i)x) \ge \lambda \qquad \forall i = 1, \ldots, m \\ & \qquad x_j \ge 0 \\ & \qquad \lambda = \mu_D(x) = \min\{\mu_0(x), \mu_1(x), \ldots, \mu_m(x)\} \\ & \qquad x \in R^n \end{aligned}$$

Variable of λ can be considered as a common factor for all Limits of fuzzy models.
So we have:

(7)

$$\begin{aligned} & Max \quad \lambda \\ & S.t. \\ & c^T x = \sum_{j=1}^{n} c_j x_j \ge b_o - (1-\lambda) d_o \\ & (Ax)_i = \sum_{j=1}^{n} a_{ij} x_j \le b_i + (1-\lambda) d_i, \qquad \forall i = 1, \ldots, m \\ & x_j \ge 0, \qquad \forall j = 1, \ldots, n \\ & \lambda \in [0,1] \end{aligned}$$

Finally, the fuzzy linear programming model forms as below to obtain x_{op} (optimal values of x) [16]:

(8)

$$\lambda \le \mu_o(x) \Leftrightarrow c^T x = \sum_{j=1}^{n} c_j x_j \ge b_o - (1-\lambda)d_o$$

$$\lambda \le \mu_i(x) \Leftrightarrow (Ax)_i = \sum_{j=1}^{n} a_{ij} x_j \le b_i + (1-\lambda)d_i$$

Therefore, x_{op} can be obtained using standard linear model.

III. RESULTS AND DISCUSSION

According to the mentioned model, the cropping pattern of the area under study is presented as follows. The total area of land under cultivation is 13051 hectares irrigated land from which 66/5% is specified for wheat cultivation, 16/24 % is specified for barley cultivation, 5.3% is specified for sugar beet cultivation and 5.3%, 48.6% and 2.4% are specified for forage maize, broad beans and alfalfa, respectively. As it can be seen, most of cultivation is dedicated to wheat and barley cultivation. Table 1 shows the data related to gross margin (million Rials) and consumed inputs for the cultivation of these crops per hectare. Gross margin of various crops per hectare was achieved by multiplying the performance by market price and fraction of the current production costs was obtained from it. In this study, maximizing gross margin of the farmer and emphasis on water restriction in the area were considered as objectives.

I. TABLE - data related to gross margin and consumed inputs (per hectare)

consumed inputs					gross margin	Product name
pesticide (liter)	*Chemical fertilizer (Kg)*	*water Cubic) (meter*	*labor people) (daily*	*land (hectare)*		
3/0	240	5500	15	1	17/266	**Wheat**
2/0	200	5000	18	1	13/442	**Barley**
5/0	350	18000	73	1	29/755	**Sugar beet**
2/5	500	25000	25	1	16/255	**Forage maize**
3/0	150	5000	37	1	13/670	**Broad bean**
3/5	350	15000	48	1	16/550	**Alfalfa**

Source: Statistics and data of Jihad Agriculture of Boroojerd city

In Table 2, the results of solving the fuzzy linear programming model with sustainability objectives for the products under study are shown. According to the table, most of the acreage was devoted to the cultivation of sugar beet, forage maize and wheat. Although barley had a large acreage in the current cropping pattern except for wheat of other products in the current model, it did not have a large acreage in the optimal programming current model. Small acreage of barley in optimal pattern was due to its low gross margin. Wheat acreage had no significant change in optimal pattern but sugar beet and forage maize acreage increased, barley acreage declined by 13.39 %, and broad bean got less importance in optimal pattern as its acreage decreased from 846 hectares to 500 hectares. Alfalfa crop also remained unchanged.

II. TABLE - Results of the current cropping pattern compared with existing cropping pattern.

Alfalfa	***broad bean***	***Forage maize***	***sugar beet***	***barley***	***wheat***	***product***
314	846	392	701	2120	8678	**Current acreage**
314	500	955/5	1562/5	373	8733	**Model resulted acreage**

Source: Data and findings of the research

IV. CONCLUSIONS AND RECOMMENDATIONS

In this study, a fuzzy linear programming method with the objective of sustainable agriculture and determining the cropping pattern is used. Because fuzzy linear programming model gives the possibility of involving imprecise data in the parameter of the model to decision-makers, it is more applicable and flexible with more reliable results compared with classical models of programming in cropping pattern optimization of farms crops due to the high risk and imprecise in this section. As it was observed, wheat acreage can change between 8678 and 8733 hectares and barley acreage can change between 373 and 2120 hectares. Due to the mentioned limits and the aim of obtaining the maximum profit, farmers can cultivate sugar beet to maximum acreage of 1562.5 hectares. In the presented cropping pattern, the highest amount of available irrigation water is used for sugar beet which gives more gross income for water use. Forage maize, broad beans and alfalfa acreage were estimated 955.5, 500 and 314 hectares, respectively. Considering that sustainable cropping pattern caused no reduction in the maximum gross income and also considering that in status quo objectives such as minimizing water use to protect rare natural water sources, sustainable agriculture by reduction of and chemical pesticides and fertilizers and providing food security is considered more by policy-makers and managers in the agricultural sector, it is suggested that policy of meeting these objectives should be transmitted to the farmers using promotional strategies.

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