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Application of the Fuzzy Approach for Agricultural Production Planning in a Watershed, a Case Study of the Atrak Watershed, Iran

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Abstract: Watersheds are large-scale regions where the agricultural production planning is associated with multiple objectives, usually, including economic, social and environmental targets. Uncertainty plays an important role in all agricultural planning because some factors are not fully controllable while some input data or parameters such as demand, resources, costs and objective functions are imprecise. This paper applies fuzzy multi-objective mathematical programming model to the Atrak watershed agricultural development plan. The model focuses on attaining three objectives simultaneously, namely, profit maximization, employment maximization and erosion minimization and these are subjected to 88 constraints. Results of the model indicate 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.

Key words: agricultural planning % sustainable development % cropping pattern % mathematical programming % fuzzy programming % watershed % soil erosion % economic % social and environmental objectives

INTRODUCTION

A crop planning exercise is usually carried out to determine the type of crops that should be cultivated and the area to be planted for each crop. The crop-planning issue is usually formulated as a linear programming problem in which profit is maximized. However, at a regional level and in term of sustainable agricultural development, profit is not the only objective that a planner should take into consideration. In this case, crop planning pursues multiple economic, environmental and social objectives where each objective or goal has to be monitored and measured using the appropriate criteria [1]. Multiple objectives decision-making or in short, MADM is an example of such models and it serves as a framework for the evaluating and selecting land use planning [2]. In addition, Tasuku, *et al*. [3] state that the agricultural production planning is dependent on many factors such as weather, temperature, rainfall, marketing and resources availability, which are not easily quantified and very often are not fully controllable. These factors are the common sources of uncertainty [4].

In actual planning exercise, the input data and other parameters such as demand, resources, cost and objective functions are also imprecise (fuzzy) because some information are incomplete or unobtainable. Since uncertainty plays an important role in any land-use programming and crop planning [5], a model with multiple objectives that takes into account uncertainty should be used in any crop planning initiative. Conventional mathematical programming schemes clearly cannot handle all these issues. It is expected that a fuzzy mathematical programming approach should result in more realistic and flexible optimal solutions for the water resources systems planning, specifically for the sustainable development and management of land use [6].

The objective of this paper is to apply the fuzzy mathematical programming approach in sustainable agricultural production planning in the Atrak watershed, Iran. The objective of the planning model, in turn, is to develop an optimal crop planning that minimizes soil erosion and maximizes profit and employment.

2 Description of the Case Study Area: The Atrak basin is a sub-zone located at the east of the water catchments area of the Caspian Sea, northeast of Mazandaran Province and northwest of Khorassan Province, Iran. The total area of this water catchment area is 26,700 square kilometers, out of which 20,700 square kilometers are mostly mountains and highland regions whereas the

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remaining 6,000 square kilometers are mountainsides, plains and coastal areas. The watershed is divided into two sub-basins: Olya (Upper) and Sofla (Lower). The study area (Figure 1), which is known as Atrak Olya, is further divided into 8 hydrological units Agricultural Economics Research Centre of Iran, [7]. The average annual precipitation in the Atrak watershed is 283mm. About 23 percent of the rainfall occurs in autumn, 39 percent in winter, 34 percent in spring and 5 percent in summer. The mean annual temperature of the study area range from 12°C to 17.5°C. Together, the temperature and precipitation affect the physiological and ecological status of the types of plants found in the area. The study area has about 826.6 million cubic meters of water, of which 622 cubic meters were from the ground water and 206.6 cubic meters were from the surface water.

In 2000, the total population of Atrak Olya was close to 700,000; 62% of them lived in the rural areas while the rest in the urban areas. The majority of those in the rural areas are farmers. The most important crop in the Atrak watershed area is wheat. Grown mainly as a single crop (mono-crop), it covers about 55% of the total cropped area. This is followed by alfalfa (10%) and grape (7%). In most parts of Iran, the natural resources are generally over-exploited mainly due to unplanned conversion of land for agriculture, overgrazing, excessive tree felling, removal of shrubs and bushes for fuel, road construction and mining. These problems often lead to increased flooding and erosion as well as decreased fertility and productivity of the land. The Atrak watershed is one of the most critically affected watersheds in Iran, where erosion levels are at 17 to 23 tons per ha per year. In order to have an ecologically sound erosion management in Atrak, the level of erosion should not be more than 10 tons per ha per year. Soil erosion in this watershed is a major environmental problem due to its serious threat to agriculture and food security. Erosion is one of the main causes of the soil degradation in this watershed area.

3.Database: The present study undertook an extensive data gathering effort, as a planning usually requires an enormous amount of data. The data used in the present study came from different sources including the Statistics Center of Iran, the Central Bank of Iran, the Watershed Management Studies of Atrak and CSRDANR of Atrak watershed. All data are in Persian. Some parts of this study also used data from the FAO database. The statistical framework used in this study was obtained from the CSRDANR of the Atrak watershed. These studies were done by consulting engineers (Visan Consulting Engineers) for, the Agricultural Ministry of Iran in 1995 but have been adjusted several times (1997, 2000 and 2002) by Agricultural Economics Research Centre of Iran. This study also obtained some up-to-date from other resources collected by Jihad-e-Agriculture Organization of the Khorassan Province. Both published and unpublished database and studies were used for this current research. The data in this study were limited to the study region. In many cases, needed to be adjusted and handled to ensure that the data were consistent with the assumptions of the model. Hence, the estimation and simulation were limited to this region and any general conclusion has to be avoided, even though the results provided a good perspective of Atrak watershed. Some data have been explained in chapter 4; while some data used in the empirical model are presented here.

4Basic Concepts and Definitions

4.1 Definition of Fuzzy: The term fuzzy was first proposed by Zadeh in [8], when he published the famous paper on the Fuzzy Sets. The fuzzy set theory was developed to improve the oversimplified model, thereby developing a more robust and flexible model in order to solve the real world complex systems involving human aspects. In this approach, an element can belong to a set to a degree k "(0 < k < 1)" in contrast to the classical set theory where an element must definitely belong or not belong to a set. For instance, one can be definitely ill or healthy in the classical set theory whereas in the fuzzy set theory, we can say that someone is 60 percent ill or healthy, i.e. with the degree of 0.6 [9]. This is in the classical set theory where membership in a set or a class is crisp and defined only as either incomplete (equals 0) or complete (equals 1). In the fuzzy set theory, membership is in a set or a class which can range from incomplete (equals 0) to complete (equals 1) [8]. The characteristic function thus allows various degrees of membership for the elements of a given set. The fuzzy set is identified as an alternative approach to supplement the vagueness in describing the planning goals and other uncertainties involved in the parameter values. In the last two decades, the fuzzy set theory has received a wide attention in the field of environmental planning and management [5,6,10,11,12,14,15].

4.2Fuzzy Multi-Objective Linear Programming (FMOLP): The general multi-objective optimization problem with *n* decision variables, *m* constraints and *p* objectives is as follows:

Max or Min

$$\left[Z_1(x_1, x_2, \ldots, x_n), Z_2(x_1, x_2, \ldots, x_n), \ldots, Z_p(x_1, x_2, \ldots, x_n) \right] \qquad (1.a)$$

subject to:

$$g_i(x_1, x_2, \ldots, x_n) \le 0 \quad for \;\; i = 1, 2, \ldots, m \qquad (1.b)$$

$$x_j \ge 0 \quad for \;\; j = 1, 2, \ldots, n \qquad (1.c)$$

where $Z_1(\ldots), Z_2(\ldots), Z_p(\ldots) =$ Objective functions, x_j = Decision variables

Bellman and Zadeh [16] and Zimmermann [17] introduced the fuzzy programming while Young and Ching [18] and Chang *et al*. [5] provided a detailed explanation for it.

Consider Equations (1.a) - (1.c) as:

Find Z i (2)

Such that f_k(x) $ $f_k o$, œ5
X>0

Where, f_k^o, œ5 are corresponding goals and Zi objectives

Here, the objective functions of the equation are considered as the fuzzy constraints. If the tolerances of the fuzzy constraints are given; we could establish their membership function μ_k (x). Under the concept of the min-operator, the feasible solution set is defined by the interaction of the fuzzy objective set. This feasible solution set is then characterized by its membership μ_D(x), which is: μ_D(x)=min (μ_1(x),…., μ_k(x)).

Furthermore, a decision maker makes a decision with a maximum μ_D(x) value in the feasible decision set. The chosen solution can then be obtained by solving the problem of maximize μ_D(x), subjective to X>0, that is:

Max [$\min_k \mu_D$(x)] (3)
s.t. X>0

Now, let " = $\min_k \mu_k$(x) be the overall satisfactory level of compromise, then the equivalent model will be as follows:

Max " (4)
s.t. "# (x), œ5
X>0

To establish the membership functions of the overall objective function, we must first obtain the payoff table of the Positive Ideal Solution (PIS), which indicates the most preferable alternative as shown in Table 1. The pay-off table shows the maximum and minimum value of each objective that is taken as the aspired level of achievement and the lowest acceptable level of achievement. The most preferable solution is nothing more than a hypothetical vector of the "best" feature of each metric, but is not a realizable solution [19]. The relative closeness of alternatives to the positive ideal solution can be used to rank the alternatives or to find the fuzzy preference relations between them [20].

Table 1: The Payoff Table of the Positive Ideal Solution

	f1	f2	f3 ………	fk	X
Max f1	f1*	f2(x')	f3(x)	fk(x')	X'
Max f2	f2(x^2)	f2*	f3(x^2)	fk(x^2)	X2
Maxf3	f3(x^3)	f2(x^3)	f2*	fk(x^3)	X3
.	...				.
.	………				.
Max fk	f1(x^k)	f2(x^k)	f3(x^k)	fk*	Xk
	f1'	f2'	f3'	fk'	

Note: fk' is the minimum value in each column

Assuming that the membership functions are linear and non-decreasing betweenand, then they would be:

$$m_k(x) = \begin{cases} 1 & \text{if } f_k(x) > f^*_k \\ [f_k(x) - f'_k]/[f^*_k - f'_k] & \text{if } f'_k \le f_k(x) > f^*_k \\ 0 & \text{if } f_k(x) > f'_k \end{cases} \qquad (2)$$

These membership functions are essentially based on the concept of preference or satisfaction. It is worth noting that the only feasible solution region of the practical relevance includes those elements in the critical area, {x | f'_k# f_k(x) f^*_k#, œ5 and x0X }. Finally, the following problem is obtained [18]:

Max " (6)
Subject to μ_k(x)= [f_k(x)- f_k]/[f^*_k-f_k] > "
X>0

The fuzzy objective function is characterized by its membership functions and the constraints. To satisfy the objective functions, as well as the constraints, the solution in a fuzzy environment is the selection of activities, which simultaneously satisfy the objective functions and the constraints. The optimal solution is the intersection of fuzzy constraints and fuzzy objective functions [16]. In this paper, the fuzzy optimization technique was applied: firstly, to represent flexibility in the objective functions for planning in short term and secondly, to represent flexibility, both in the constraints and the objective functions, this is suitable for planning in the medium term.

4.3 Formulation of the Problem: Assuming linearity of the objective functions, this paper used the fuzzy multi-objective linear programming formulation. The general multi-objective optimization problem with n decision variables, m constraints and p objectives are given in equations (7.a) through (7.f) below:

$$\text{Max} \sum_{k=1}^{n} p_k * (\sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \cdot q_{ijk}) - (\sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \cdot c_{ij}) \quad (7.a)$$

$$\text{and Max} \sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \cdot L_{ij} \quad (7.b)$$

$$\text{and Min} \sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \cdot S_{ij} \quad (7.c)$$

subject to:

$$\sum_{j=1}^{n} x_{ij} * lad_{ij} \leq LAD_J \quad (7.d)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \cdot wtr_{ijm} \leq WTR_{jm} \quad (7.e)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \cdot \ln d_{ijk} \geq A_k \quad (7.f)$$

where: p_k = price of product k, x_{ij} = amount of activity i in zone j (decision variable), q_{ijk} = production of product k in unit activity i in zone j, c_{ij} = production cost in unit activity i in zone j, S_{ij} = cover management index in unit activity i in zone j, L_{ij} = labor requirement in unit activity I in zone j, lad_{ij} = land requirement for unit activity I in zone j, LAD_J = total land availability in zone j, wtr_{ijm} = volume of water consumption in activity i in zone j in month m, WTR_{jm} = total volume of current water in zone j in month m, A_k = minimum surface of product k and, In di_{jk} = surface area of product k in unit activity i in zone j.

Others resources such as the capital and management capacities were assumed to be adequate for the region. Capital is usually not considered as a constraint in most common areas, such as the watersheds [21-24].

Details of the model are discussed in the following sections.

5 Decision Variables: Generally, in agricultural production planning cases, growing the same crops in succession on the same piece of land is either not allowed or not advisable as this may result in a decrease in the soil fertility or an increase in the susceptibility of the crops to diseases, pests or weeds. Thus, crop rotation is recommended. It is a crop production system where several crops (e.g. wheat, cotton, cumin) are grown in succession on the same piece of land [25]. The representation of the rotation requirements into the mathematical model is done in four ways, namely (1) compounding rotations into single activities, (2) setting constraints on individual crops, (3) specifying links between crops and (4) allowing land of differing types or quality. These are discussed by Barnard and Nix [26]. The first approach defines compounded activities, such as the wheat-cotton-cumin-vegetable, as a single variable. By representing an entire crop rotation as a single activity, the effects on the yield and resource requirements of its individual crop may be specified precisely in accordance with the experience and rotation. Compound rotation activities are easily structured for a year. A four-year rotation could include wheat, cotton, cumin and vegetable. This rotation can then be defined as a single activity, namely, Xij= ¼ wheat + ¼ cotton + ¼ cumin+ ¼ vegetable, for one hectare in one year. This approach is adopted in this paper. There are altogether 134 decision variables.

5.1Objective Functions: There are three objectives in this study: profit maximization, labor employment maximization and erosion minimization. In this study, profit maximization is assumed to be an important objective of every decision-maker involved in the planning process. In Iran, the unemployment rate, at about 15 %, is relatively high. The government of Iran has advocated a labor-intensive cropping pattern to minimize unemployment as well as under-employment, specifically in the agricultural sector. As mentioned earlier, the lands of the Atrak watershed are seriously threatened by high erosion rate. Thus it is appropriate that one of the objectives of the model is to minimize soil erosion. The Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) are erosion models predicting the average annual soil loss (A). According to the USLE and RUSLE.The expected average annual erosion can be estimated using the following equation [27]:

$$A = R\mathbf{P} K\mathbf{P} L\mathbf{P} S\mathbf{P} C\mathbf{P} P \quad (8)$$

where: A = Average annual soil loss, R = Rainfall, K = Soil erodibility, L = Slope length, S = Slope steepness, C = Cover management and P = Supporting practices.

Rainfall, soil erodibility and topography are regional parameters. They are usually beyond the control of the decision-makers as well as the farmers. The most important factors in soil erosion control are cover management and its supporting practices. The USLE and RUSLE use the C factor to reflect the effects of cropping and management practices on the erosion rates and it is also the most important factor to compare the relative impacts of the management options in most land conservation plans. Values of the C factor vary from almost zero for well-protected soils and up to 1.5 for the finely tilled, ridged surfaces which are highly susceptible to erosion. The RUSLE software provides an extensive database, which can be used to estimate the C factor for various crops, especially when the plant growth characteristics were already known or when the user may develop a more appropriate database from the available experimental data [28]. The *C* factor measures the effects of all interrelated cover and management variables [29].

5.2 Constraints: The model is subjected to the following constraints:

5.2.1 Land Availability Constraints (constraints 1-8): In each hydrological unit, the total area to be allocated to the different irrigated crops is almost equal to the total cultivable area in that unit.

5.2.2Minimum Surfaces of Produce Constraints (Constraints 9-24): In short term planning, the surface of the irrigated and orchard land should not be less than the current land use. On the other hand, the current land use should not change but the cropping pattern can change. These data are used in the right hand side values in constraints 9 to 24.

5.2.3Water Availability Constraints (Constraints 25-88): In any month, the demand for irrigation water for all crops should not exceed the water available in that particular month. In other words, the total water requirement for crops at any level of the water application in any period should be at most equal to the total water supplied from the water resources (ground and surface water) during that particular period. The total water requirements for all the activities in the months of October, November, April, May, June, July, August and September were calculated. Crops do not need irrigation in the months of December, January, February and March in the Atrak watershed.

Table 2: The Payoff Table of the Positive Ideal Solution

Functions	Profit (Rls)	Employment (man/days/y)	Erosion (C factor)
Max profit	8.9E10	2.6E6	3.0E4
Max employment	4.6E10	3.8E6	2.4E4
Min erosion	4.9E10	3.2E6	1.1E4

5.3The Fuzzy Formulation: As discussed, the first step in the formulation and solution of the problem is to transform the base line model to a vector maximum model. Then, a pay-off table is prepared. The maximum and minimum values of each objective are taken, respectively, as the aspired level of achievement and the lowest acceptable level of achievement. The pay-off table representing this transformation is shown in Table 2. The upper and lower limits of the achievement of each objective function are presented in addition to the differential values.

From the payoff table, the fuzzy membership function μ_i is associated with each objective. The form of the fuzzy membership function may be either linear or non-linear. In this study, a linear form was used so as to transform the fuzzy model into the linear programming model. The membership function for these three objectives can then be obtained from table 2 as follows:

$$m_1(x)\begin{cases} 1 \ \ if\ 8.9E10 < f(profit) \\ f(profit) - 4.6E10/4.3E10\ if\ \ 4.6E10 <= f(profit) <= 8.9E10 \\ 0\ if\ \ f(profit) < 4.6E10 \end{cases} \tag{9}$$

$$m_2(x)\begin{cases} 1 \ \ if\ 3.8E6 < f(employment) \\ f(employment) - 2.6E6/1.1E6\ if\ \ 1.9E6 <= f(employment) <= 2.3E6 \\ 0\ if\ \ f(employment) < 3.0E4 \end{cases} \tag{10}$$

$$m_3(x)\begin{cases} 1 \ \ if\ \ f(erosion) < 1.1E4 \\ f(erosion) - (3.0E4/-1.9E4\ if\ \ 1.1E4 < f(erosion) < 3.0E4 \\ 0\ if\ \ f(erosion) < 3.0E4 \end{cases} \tag{11}$$

The membership functions μ_1(x), μ_2(x) and μ_3(x) of the fuzzy sets characterizing the objective functions rise linearly from 0 to 1 at the highest achievable value of Z_1= 8.9 E^{10} Z_2,=3.8E^6 and Z_3= 1.1E^4, respectively. The level of satisfaction with respect to the profit rises from 0 if the profit is 4.6 E^{10} or less to 1 if the total profit is 8.9 E^{10} or more and the satisfaction level with respect to the employment rises from 0 for 2.6 E^6 or less to 1 for employment 3.8 E^6 and more. Maximum satisfaction level from the membership functions of participating objectives has been designated the 'best' achieved solution.

Similarly, this means that the level of satisfaction with respect to erosion declines from 1 if the erosion is 1.1 E^4 or less to 0 if the erosion is 3.0 E^4 and more. From these membership functions, $\mu_1(x)$, $\mu_2(x)$ and $\mu_3(x)$, the intermediate control variables are also introduced, which correspond to the representation of the decision maker's satisfaction levels for the different types of objectives. The max-min convolution can be modified as:

$$\text{Max } \mu_D(x) = \{\max [(x) \min [\mu_1(x),\mu_2(x),\mu_3(x]]\}.\ œ_i \qquad (12)$$

Thus, for a given solution of *X* in the fuzzy model, the minimum value of $\mu_i(x)$ is to be maximized. It means that the worst underachievement of any goal is to be minimized. Finally, we compute the following linear programming problem using a dummy variable μ= min $[\mu_1(x),\mu_2(x),\mu_3(x]$ such that the objective is to

Max μ (13)

subject to μ<= f (profit) - 4.6E10/4.3E10

μ<= f (employment)-2.6E6/1.1E6

μ<= f(erosion)-(-3.0E4)/-1.9E4

$f_k(X)\$f^{\prime}k,\ œ_i$

μ0[0, 1] and x0X

5.3.1 The Membership Functions for the Constraints: The resource vectors have a range of "approximately larger than or equal to" and "approximately smaller than or equal to" a particular limit of the constraints. Each fuzzy constraint of the model has a membership function $F_i(x)$ associated with it. Each membership function ranges between zero and one and expresses the degree of satisfaction of the constraint. In other words, the membership function denotes the degree of satisfaction of the decision-maker in achieving the aspiration levels of his/ her fuzzy goals. If the membership function takes the value of one, then, the associated goal is completely achieved and if it takes the value of zero, the associated goal is completely not being achieved. The range between zero and one can be viewed as the percentages of the satisfaction of the decision-maker in satisfying the goal. Since the membership functions of the fuzzy objectives and fuzzy constraints are defined as shown in Table 3, we can obtain the final formulation of the fuzzy multi-objective programming in the following model:

Table 3: The Determination of the Fuzzy Membership for the Objectives and Constraints

Objectives	fuzzy objective function value μ=0	μ=1
Z1	[0, 46470953011]	[89716199159,4]
Z2	[0, 2666148]	[3833347,4]
Z3	[30809,4]	[0, 11595]

Equation no of constraints	fuzzy right –hand side value μ=0	μ=1	type of fuzzy relation
(1)	[111600,4]	[0, 75050]	#–
(2)	[19715,4]	[0, 16098]	#–
(3)	[45950,4]	[0, 34250]	#–
(4)	[24717,4]	[0, 18950]	#–
(5)	[6605,4]	[0, 4505]	#–
(6)	[15450,4]	[0, 9000]	#–
(7)	[37967,4]	[0, 20800]	#–
(8)	[31500,4]	[0, 31500]	#–
(9)	[0, 33046]	[41038,4]	–$
(10)	[0, 11040]	[13800,4]	–$
(11)	[0, 12425]	[15531,4]	–$
(12)	[0, 9292]	[11615,4]	–$
(13)	[0, 3231]	[4039,4]	–$
(14)	[0, 1522]	[1990,4]	–$
(15)	[0, 1600]	[2000,4]	–$
(16)	[0,961]	[1201,4]	–$
(17)	[0, 5240]	[6550,4]	–$
(18)	[0, 1838]	[2298,4]	–$
(19)	[0,961]	[1201,4]	–$
(20)	[0, 1342]	[1678,4]	–$
(21)	[0,372]	[466,4]	–$
(22)	[0, 54]	[68,4]	–$
(23)	[0,328]	[410,4]	–$
(24)	[0, 22]	[28,4]	–$
(25)	[18251,4]	[0, 18168]	#–
(26)	[7213,4]	[0, 7180]	#–
(27)	[42793,4]	[0, 42598]	#–
(28)	[78940,4]	[0, 78581]	#–
(29)	[86704,4]	[0, 86310]	#–
(30)	[61055,4]	[0, 60777]	#–
(31)	[59497,4]	[0, 59227]	#–
(32)	[35797,4]	[0, 35934]	#–
(33)	[8499,4]	[0, 5205]	#–
(34)	[2913,4]	[0, 1784]	#–
(35)	[22423,4]	[0, 13732]	#–
(36)	[43762,4]	[0, 26800]	#–
(37)	[51345,4]	[0, 31444]	#–
(38)	[40123,4]	[0, 24572]	#–
(39)	[37697,4]	[0, 23086]	#–
(40)	[21351,4]	[0, 13076]	#–
(41)	[9125,4]	[0, 6762]	#–
(42)	[3321,4]	[0, 2461]	#–
(43)	[17529,4]	[0, 12989]	#–
(45)	[36052,4]	[0, 26714]	#–
(46)	[45668,4]	[0, 33839]	#–
(47)	[26991,4]	[0, 20000]	#–
(48)	[28194,4]	[0, 20891]	#–
(49)	[17436,4]	[0, 12920]	#–
(50)	[4722,4]	[0, 3523]	#–
(51)	[1888,4]	[0, 1409]	#–
(52)	[15468,4]	[0, 11541]	#–
(53)	[29040,4]	[0, 21668]	#–
(54)	[31418,4]	[0, 23442]	#–
(55)	[19944,4]	[0, 14881]	#–
(56)	[18053,4]	[0, 13470]	#–
(57)	[8886,4]	[0, 6630]	#–

Table 3: Continued

(58)	[1678,4]	[0, 995]	#–
(59)	[860,4]	[0, 510]	#–
(60)	[8309,4]	[0, 4928]	#–
(61)	[12989,4]	[0, 7703]	#–
(62)	[12857,4]	[0, 7625]	#–
(63)	[5704,4]	[0, 3383]	#–
(64)	[5478,4]	[0, 3249]	#–
(65)	[3121,4]	[0, 1851]	#–
(66)	[357,4]	[0, 258]	#–
(67)	[254,4]	[0, 184]	#–
(68)	[4252,4]	[0, 3071]	#–
(69)	[6311,4]	[0, 4558]	#–
(70)	[6183,4]	[0, 4466]	#–
(71)	[2409,4]	[0, 1740]	#–
(72)	[2364,4]	[0, 1708]	#–
(73)	[916,4]	[0, 662]	#–
(74)	[442,4]	[0, 166]	#–
(75)	[301,4]	[0,113]	#–
(76)	[4394,4]	[0, 1648]	#–
(77)	[6573,4]	[0, 2465]	#–
(78)	[6288,4]	[0, 2358]	#–
(79)	[2184,4]	[0, 819]	#–
(80)	[2285,4]	[0, 857]	#–
(81)	[1008,4]	[0, 378]	#–

Max μ (14)

Subject to μ<= f (profit) - 4.6E10/4.3E10

μ<= f (employment)-2.6E6/1.1E6

μ<= f(erosion)-(3.0E4)/-1.9E4

$$\sum_{j=1}^{n} x_{ij} * lad_{ij} \le LAD_J + (1 - m_j) d_j$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \cdot wtr_{ijm} \le WTR_{jm} + (1 - m_j) d_j$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \cdot \ln d_{ijk} \ge A_k + m_k d_k$$

μ0[0, 1] and x0X

where: ä$_i$ and ä$_k$ *are* tolerance in constraints and μ is the membership function. Other variables are the same as the previous Equations.

RESULTS AND DISCUSSIONS

5.1 Cropping Pattern for Short Term Planning: Results of the fuzzy model are presented in Table 4. The table shows the optimal cropping pattern under existing physical condition. During the short term planning, which is considered to be 1-2 years, land use for the annual crops cannot be changed to orchards and vice versa. The results shows that the most important crops were wheat (47%), alfalfa (11%), grape (9%), orchard (7%), potato (6%), rice (5%), sugar beet (5%) and vegetables (5%). The areas under wheat, alfalfa and grape reached the maximum constrained area. This result is consistent with the fact that wheat is the basic crop in the rotational requirements and it is the main product of the Atrak watershed.

Using the proposed land-use values, the annual profit (Z_1), the total labor requirement (Z_2) and the sum of C factor (erosion) (Z_3) were 74.61 billion Rls/y, 3.43 million man/day and 18310 sum *C* factors, respectively. The maximum "overall satisfaction" (μ=0.65) was achieved for this optimal solution.

6.2. Cropping Pattern for Medium-Term Planning: According to the comprehensive studies of the Atrak watershed, some of the resources can be increased such as land availability and water availability. For example, the first constraint shows that maximum land available is 75,050 hectare but it can develop until 101,600 hectare. The decision makers also consider 20% tolerance in land use planning. In other words, the minimum that each land use (irrigated land and orchard) can change is 20% [7]. The water resources also have a range because rainfalls vary in this watershed. Therefore it should define a membership function for the constraints. Table 3 presents the summary of the membership functions for the objectives and the constraints. The model to determine the optimal cropping pattern for Atrak watershed was run after considering the tolerance in the constraints.

Table 4: Optimal Cropping Pattern for the Atrak Watershed by Hydrological Units (hectares)

Zone	Wheat	Rice	Corn	Sugar beet	Cotton	Cumin	Sun flower	Potato	Alfalfa	Forage corn	Vegetables	Grape	Walnut	Other Orchard	Total	Total available cultivable
1	24150	0	0	2703	0	0	0	5981	5407	0	1209	0	1816	4734	46001	75050
2	2712	2953	0	2537	174	0	0	0	5424	0	0	0	0	2298	16098	16098
3	8368	2066	0	0	644	644	0	0	0	0	644	5596	0	0	17961	34250
4	6921	408	0	219	124	0	0	0	248	0	3476	1678	0	0	13074	18650
5	3044	148	0	0	192	135	135	0	385	0	0	338	0	128	4505	4505
6	1618	372	0	0	0	0	0	0	0	0	0	68	0	0	2058	9000
7	1532	0	0	234	0	0	0	234	0	0	0	1615	0	0	3615	20800
8	941	41	37	0	31	0	0	0	0	62	52	0	0	28	1192	31500
Total	49285	5988	37	5694	1165	779	135	6215	11463	62	5382	9294	1816	7188	104504	209853

Table 5: Cropping Pattern of the Medium-Term Planning in the Atrak Watershed (hectares)

Zone	Wheat	Rice	Corn	Sugar beet	Cotton	Cumin	Potato	Alfalfa	Forage corn	Vegetable	Forage	Grape	Walnut	Other Orchard	Total
1	27.150	0	0	3.185	0	0	3.185	0	0	1.752	1.777	0	751	9.423	47.221
2	2.180	3.345	0	2.180	0	716	0	4.359	0	716	1.433	0	0	2.171	17.100
3	9.636	0	0	0	326	0	0	4.708	0	0	0	3.126	0	0	17.797
4	7.816	0	0	0	0	0	0	0	0	3.932	0	3.009	0	0	14.757
5	3.405	181	105	316	0	28	0	422	0	133	57	440	0	0	5.087
6	1.878	224	0	0	0	0	0	173	0	0	0	64	0	0	2.339
7	2.273	0	0	212	0	0	212	537	0	0	0	944	0	0	4.177
8	1.353	71	0	0	63	0	0	0	126	84	0	0	0	26	1.724
Total	55.691	3.822	105	5.892	389	745	3.396	10.199	126	6.618	3.266	7.582	751	11.619	110.202

Table 6: Changes in the Cropping Patterns for the Short-Term Planning and the Medium-Term Planning in the Atrak Watershed (hectares)

	Medium-Term Cropping Pattern		Short-Term Cropping Pattern		Current Cropping Pattern	
Crops	Area	Percent	Area	Percent	Area	Percent
Wheat	55,691	50.54	49,285	47.16	58,114	55.01
Rice	3,822	3.47	5,988	5.73	431	0.41
Corn	105	0.10	37	0.04	492	0.47
Sugar beet	5,892	5.35	5,694	5.45	4,952	4.69
Cotton	389	0.35	1,165	1.12	5,193	4.92
Cumin	745	0.68	779	0.75	209	0.20
Potato	3,396	3.08	6,215	5.95	5,615	5.32
Alfalfa	10,199	9.26	11,463	10.97	10,673	10.10
Forage corn	126	0.11	62	0.06	96	0.09
Vegetable	6,618	6.01	5,382	5.15	3,450	3.27
Forage	3,266	2.96	-	0.00	-	0.00
Grape	7,582	6.88	9,294	8.89	7,079	6.70
Walnut	751	0.68	1,816	1.74	247	0.23
Other Orchard	11,619	10.54	7,188	6.88	5,378	5.09
Cereals	-	-	-	0.00	1,967	1.86
Sunflower	-	-	135	0.13	1,741	1.65
Total	110,202	100	104,504	100	105,637	100

Table 7: Profit, Labor Requirement and Erosion under Current, Fuzzy Model for short and mid-term planning in the Atrak Watershed

Current and Optimal Plans	Profit (10 billon Rls)	%	Employment (million man/days/y)	%	Erosion (0000C factor)	%
Current	6.17	-	3.33	-	2.10	-
Short-term	7.46	20.9	3.43	3.0	1.83	(12.9)
Medium-term	7.78	26.1	3.51	5.4	1.69	(19.5)

Table 5 shows the optimal cropping pattern for the medium-term planning. The availability resources were varied accordingly, but the level of technology was assumed to be fixed. The medium term results (Table 5) indicates that wheat occupied the number one spot in terms of the area allocation. Orchard was the second most important crop (10.5%) with 11,619 ha; while both alfalfa and grapes maintained their stable positions.

Table 6 shows the extent of changes to the various crops as compared with the baseline scenario. It reveals that the most notable changes that occurred between the short-term planning and medium-term planning were the increased acreage for orchards (grapes, walnut and other orchards), vegetables and wheat; while there were a decrease in the areas under cotton, rice and potato.

Table 7 compares the profits, labor requirements and soil erosions for the current cropping pattern as well as the optimal cropping patterns for the short-term and medium-term planning periods. Using the fuzzy model framework, the results reveal that there were substantial improvements in all the three objectives; both profits and labor requirements increased, while the extent of soil erosions decreased.

The results show that profits could be increased by almost 21% in the short term and subsequently by 26% in the medium term if the optimal cropping pattern as proposed by the fuzzy models were adopted. At the same time, employment would be increased by 3% and 5.4% in the short-term and in the medium-term respectively. The fuzzy modeling framework also suggests that the optimal cropping patterns could readily decrease the extent of soil erosions in the region. In the short-term, it could be reduced by 12.9% and a reduction by about 19.5% could be achieved in the medium-term.

CONCLUSION

Agricultural production planning and their environmental and social context are viewed within this study as a single complex system with interdependent sub-systems. The agro-ecosystem of the Atrak watershed has come under increasing pressure not only to provide food and fiber but also to generate jobs for the rapidly growing population. Some environmental effects such as erosion, however, have not been managed in a sustainable way. This study presents a framework for sustainable agricultural development as an integrated planning at the Atrak watershed.This study has affirmed that the present fuzzy multi objective model is an effective tool for generating a set of more realistic and flexible optimal solutions in dealing with and attempting to solve the complex real world land development issues particularly in the context of sustainable agricultural development. This model is able to achieve an integrated agricultural production planning with considerations for the economic, social and environmental targets.

From the overall analysis, it is clear that the cropping pattern in the Atrak watershed is skewed towards wheat, orchards (grape and other orchard) and alfalfa, which happens to be the three most important crops, not only in the short and medium-terms, but also in the existing cropping patterns, albeit in the different ratios. Therefore, these results indicate that making minor changes to the existing cropping pattern as suggested by the fuzzy models will still be able to increase the farmers' profit and employment while, at the same time, fulfilling and observing the environmental objectives; thus enabling the region to achieve a more sustainable agricultural development in the longer term.

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