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Determining Farm Program In Line With Sustainable Agriculture (Case Study: Coastal Lands on the Right Side of Nekuabad Irrigation System)

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ABSTRACT

One of the challenges in developing sustainable agriculture is too much and non-optimal use of sustainable agriculture disruptive inputs. In the present study, current cropping pattern of the lands on the right side of Nekuabad derivation dam irrigation system with cropping pattern of fractional linear programming and linear programming with multiple objectives under uncertainty was compared. To implement uncertainty in these two types of the programming, robust optimization was used. The findings showed that in optimal cropping pattern of fractional linear programming with multiple objectives under certainty, sustainability index of the fertilizer proportion (poison) for all inputs (except fungicide input) was less than sustainability index of the current cropping pattern and linear programming under uncertainty. According to the findings, the use of optimal cropping pattern presented by fractional linear programming with multiple objectives under uncertainty is proposed. Also, to compensate the decrease in gross profit of the optimal cropping pattern, use of a variety of pricing policies (reasonable pricing for organic products) and credit policies (allocation of low-interest loans) are recommend.

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INTRODUCTION

Over the past five decades, agricultural development policies in line with the use of disruptive sustainable agricultural inputs such as pesticides, chemical fertilizers, and agricultural machinery has increased agricultural production. These factors gradually took the place of existing processes and resources within the farmland [18]. Over the past decades, the topic of sustainable agriculture (especially organic farming) has been highlighted by various international organizations and has led to positive environmental, economical and social impacts [6]. Economically, emphasis on organic farming increases productivity of using agricultural production inputs as well as improvement and creation of various opportunities in the market for these products [1]. Sustainable agriculture is defined as, first, to improve the quality of the environment related to agricultural issues in long term, second, to satisfy food needs of the human, third, to be economically long lasting and, finally, to improve the quality of the lives of farmers and society [14]. One way to achieve optimal use of external and disruptive inputs of organic farming process is the application of mathematical programming for the efficient use of these inputs. In order to study the relative performance in the field of sustainable agriculture, fractional programming is much more efficient than other methods [4]. Fractional programming is the most common type of mathematical programming with ratio objectives [20]. Multi-objective linear fractional programming (MOLFP) can be used to consider multiple objectives in a problem. Numerous studies have been done in several economic, social, and environmental fields of sustainable farming [9,11,17]. Mousavi and Qrqany [16] calculated sustainability indices of agricultural water use with fractional programming model in Marvdasht city. The results showed that with cultivation pattern of tomato, rice, sunflower, and alfalfa, gross income index to water use is 3/06 and the employment index to water use is 0/265 in Marvdasht. Environmental goal to reduce nitrogen entering the soil and in other words reduction of the amount of chemical fertilizer in agricultural production were regarded in the studies of [23]. Gutzler *et al.* [7] conducted integrated impact assessments for agricultural intensification scenarios in the federal state of Brandenburg, Germany, for 2025. They applied nine indicators to analyze the economic, social and environmental effects at the regional, in this case district scale,

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which is the smallest administrative unit in Brandenburg. Assessment results discussed in a stakeholder workshop involving 16 experts from the state government. Mohamed *et al*. [15] focused on assessment of sustainability factors for agricultural utilization through integrated biophysical, economic viability and social acceptability in the North Sinai area. They developed Sustainable agricultural spatial model (SASM) using Arc GIS 10 to identify and classify the area, according to sustainability degree of agricultural utilization, where the factors of productivity, security, protection, economic viability, and social acceptability in the different mapping units assessed. However, these studies did not address the important issue of uncertainty in the data used. Considering uncertainty in optimization models often alters the optimal solutions to this problem. Fractional linear programming methods are not exceptional to this rule and disregarding uncertainty in them leads to deviation in decision-making process. Some Studies have also been conducted in this area in Iran. Rastgaripoor and Sabouhi [19] in a study entitled "Grey fractional programming, a new experimental approach to sustainable farming, case study: Ghochan city" determined an optimal cropping pattern consistent with sustainable agriculture. The results showed that sustainability index to nitrogen fertilizer in fractional programming mode is in grey fractional programming period and is improved compared to the current cropping pattern. In addition, the average efficiency of the calculated program showed 17% decrease from the current cropping pattern state. The main disadvantage of using caustic models is difficulty of evaluation and interpretation of the upper and lower limits of optimal solutions. Kohansal and Zare [10] conducted a study to determine the optimal cropping patterns in North Khorasan Province using fractional fuzzy programming with multiple objectives. The results showed that the pattern obtained from simple linear programming is very close to the current cropping pattern of the area; however, the pattern obtained from fractional fuzzy programming has a drastic difference with pattern obtained from the simple linear programming and the current cropping pattern of the area to obtain sustainability. Profit decline in the sustainable optimal cropping pattern to the current cropping pattern is noteworthy in this study. Zamani *et al* [25] performed a study to determine the cropping pattern of Piranshahr city using fuzzy fractional programming with multiple objectives. The results of their study indicated that the optimal cropping pattern obtained from fuzzy fractional programming is very different from the current cropping pattern. However, the gross profit obtained from optimal cropping pattern is equal to current cropping pattern. The problem of using fuzzy methods in these studies is that part of the information on uncertainty coefficient should be ignored [2]. This study aimed at determining the optimal cropping pattern of coastal area of irrigation network on the right side of Nekuabad diversion dam using MOLFP. The dam was constructed in Nekuabad village at a distance of 45 kilometers from Isfahan city. A major canal is constructed on the right side of this dam to take water at most 15 m^3/s, which provides the water needed for the area of 15000 ha located on the right side of Zayanderud river [8]. To apply uncertainty, robust optimization was used. This model will eliminate the problems mentioned in other methods[2]. Studies using this formidable model to determine the optimal cropping pattern are totally limited to [13] and [23]. The results of these two studies suggest that with increasing the protection level of the model against uncertain data, gross profit obtained from determining the optimal cropping pattern decreases. However, to our knowledge, no studies exist that applies robust optimization to the sustainable agriculture. This method, unlike stochastic and fuzzy models, does not assume that uncertain parameters are random variables with known distributions. Unlike the interval approach, in the robust optimization, the relative solutions have no lower or upper bounds.in addition we used The Monte Carlo simulation to test the quality of the model.

MATERIALS AND METHODS

In different types of fractional programming optimization problems, objective function is expressed as a ratio of ($\frac{f(x)}{g(x)}$). Except that the numerator and denominator of the objective function in it is among Affine Functions (AF) and possible set in it is a polyhedron convex. A multi-objective linear fractional programming is presented as follows [3]:

$$\begin{aligned} Max \quad & \left\{ \varphi_1(x) = \frac{c_1^t x + \alpha_1}{d_1^t x + \beta_1}, \ldots .. \varphi_p(x) = \frac{c_p^t x + \alpha_p}{d_p^t x + \beta_p} \right\} \\ s.t \quad & Ax \le b, \\ x \ge 0, & \end{aligned} \tag{1}$$

Where, $c, d \in \Re^n$, $\alpha_i, \beta_i \in \Re$, $A \in M_{m \times n}(\Re)$ and $b \in \Re^m$. To find the optimal solution in multi-objective optimization problems, CONNISE method which is a combination of restriction method and Non-inferior Set can be used [24]. This method is also used for multi-objective linear fractional programming with a brief change [5]. Suppose that E is an introducer of an efficient set and E^w is an introducer of a low-efficient set in the multi-objective programming. CONNISE method is defined based on finding low-efficient boundaries estimate in objective space ($\varphi(E^w)$) including some points from sets of possible area. The distance between these points should not violate the previously considered ones. This method is useful for finding efficient solutions. However, solutions lose their convergence in problems with more than two objectives and finding the final solution can be very difficult. This problem is resolved by controlling the considered distance for the predetermined error. This problem can be controlled using the Controlled Estimation Method (CEM). In the following, description of the algorithm related to CEM, which was proposed by Caballero and Hernandez in 2004, will be discussed. First phase is to find the ideal and non-ideal points or in other way to get pay-off matrix [20]. The gap between the ideal values (D_{i-}) and non-ideal ones (D_i^*) constitute the spatial boundaries of the objective. Second phase is calculation the of $\xi = \underset{i=1,\ldots,p}{Max}\left|\varphi_i^* - \varphi_{i-}\right|$ Where φ_i^* and φ_{i-} are ideal and non-ideal points values in objective space, respectively. At this stage, the tolerance for the distance between possible points is considered (d) and $\delta = \frac{1}{d}$ is calculated. Then, two sets of $S \neq \phi$ and $A \neq \phi$ are defined in which S is called points of current estimation and A is known as loose points. Third step is to calculate $m = E(\frac{1}{d})$ where $E(\frac{1}{d})$ is the correct component of $\frac{1}{d}$. Using the parametric constraints method (PCM) and the number of m , the occurrences of S set is obtained. The fourth phase is calculation of $\theta = \alpha\delta$ in which $\alpha \in [0,1]$. Suppose that $S = \{x^1,\ldots,x^k\}$, $k = 1,\ldots N$ and $k \neq J$. If for each $i = 1,\ldots, p$, the inequality of $\left|\varphi_i(x^j) - \varphi_i(x^k)\right| < \theta \big/ \left|\varphi_i^* - \varphi_{i-}\right|$ is true, x^k point is removed from S set. This process continues until there are not many points in S set. This stage is known as the filtering step. In fifth stage suppose $S = \{x^i,\ldots,x^N\}$. For each ($J = 1,\ldots,N$) x^j , end point of (x^k) is found corresponding to the objective space. If $\underset{i=1,\ldots,p}{Max}\left|\varphi_i(x^j) - \varphi_i(x^k\right| > d\xi$, x^j is an unsustainable point. So, x^j is put in A set. This step is repeated for each x^j. In the sixth step, if A is empty, this process will be finished. Otherwise, m obtained from the third step is considered as $m+1$. Suppose $A = \{x^1,\ldots,x^m\}$. For each x^j from A , the x^k point which is closer to x^j (stage four) is considered. This step is achieved for each point of A set. Finally, in seventh stage, $A \neq \phi$ is achieved and it is referred to the third stage. Different methods have been expressed to consider uncertainty in optimization problems. Consider the following optimization problem (Bertsimas and Sim, 2004):

$$\begin{aligned} &Maximize \quad cx \\ &subject \quad to \quad \sum_{j=1}^{n} \tilde{a}_{\cdot j} x_j \leq b_i, \qquad \forall i, j \in J_i \\ &l \leq X \leq u. \end{aligned} \tag{2}$$

J_i is a subset of indexes associated with uncertain parameter which is given for each constraint of i . Here, robust optimization model (2) is rewritten that improves system reliability under uncertainty [2]:

$$\begin{aligned} &Maximize \quad cx \\ &subject \ to \ \sum_i \bar{a}_{ij} x_j + \\ &\max_{\{S_i \cup \{t_i\} | S_i \subseteq J_i, |S_i| = [\Gamma_i], t_i \in J_i \setminus S_i\}} \left\{ \sum_{j \in S_i} \hat{a}_{ij} y_j + (\Gamma_i - [\Gamma_i]) \hat{a}_{it_i} y_t \right\} \leq b_i, \qquad \forall i \\ &-y_j \leq x_j \leq y_j, \qquad \forall j \in J_j \\ &l \leq X \leq u, \\ &y \geq 0 \end{aligned} \tag{3}$$

Where for each j , $y_j = \left|x_j^*\right|$. $\hat{a}_{ij}$ is the nominal value of the uncertain parameter and $\bar{a}_{ij}$ is obtained from multiplying nominal value of variable ($\bar{a}_{ij}$) by specific uncertainty level of (ε). Thus, the variable $\tilde{a}_{ij}$ has a symmetric and bounded distribution in the constraint $[\bar{a}_{ij} - \hat{a}_{ij}, \bar{a}_{ij} + \hat{a}_{ij}]$. To control the degree of conservation, Γ_i parameter is defined that a real number in the range of [0, J_i] can be attributed to it. In model (3), $\sum \bar{a}_{ij} x_j \leq b_i$ is the introducer of the constraint i under certainty. The certainty level of the model against uncertainty depends on Γ_i parameters. There are different values for Γ_i parameters and it depends on the probability of the constraint i violation from its bound (*p*) and the number of uncertain parameters in that constraint. With insertion of x^* in the equation (3) as the optimal solution, the probability of the constraint i violation from its bound is defined as follows [2]:

(4) To calculate Γ_i , an optimal level of constrain i violation from its bound is considered and equation (4) is used to calculate it [2]. The objective functions in this study are defined as follows:

Objective functions of φ_1 and φ_3 are related to sustainability to three types of chemical fertilizers of nitrogenous, phosphate and potash. In these functions, x_j represents product j cultivated area, a_j represents the gross income from a hectare of j crop production and f_{tj} represents the amount of fertilizer needed to produce each hectare of crop j. Functions φ_4 to φ_6 are related to sustainability to the three types of pesticides including, herbicides, fungicides and insecticides. pe_{zj} functions represent the amount of pesticide z needed to produce each hectare of crop j. Ten products which are usually cultivated in the area under study are considered. These products and their related symptoms include x_1: wheat, x_2: barley, x_3: corn, x_4: onion, x_5: potato, x_6: tomato, x_7: sunflower, x_8: sugar beet, x_9: rapeseed, x_{10}: cucumber. There are many uncertain parameters in a model of optimal cropping pattern. In this study, only available water in season s is considered part of the uncertain parameters. Therefore, by defining parameter Γ, water constraint with degree of conservation control parameters (model (3)) is as follows

$$Max \left\{ \begin{array}{l} \varphi_{1-3} = \dfrac{\sum_{j=1}^{J} a_j x_j}{\sum_{j=1}^{J} f_{tj} x_j} \Big| t = 1,2,3; \\ \varphi_{4-6} = \dfrac{\sum_{j=1}^{J} a_j x_j}{\sum_{j=1}^{J} pe_{zj} x_j} \Big| z = 1,2,3 \end{array} \right\} \quad (5)$$

$$\sum_{j=1}^{J} w_j x_j - \overline{W}_s + (\Gamma_s - 1)\left| -\hat{W}_s \right| \le 0 \qquad \forall s \quad (6)$$

in constraint 6 , w_j represents the amount of water needed to produce one hectare of crop j, $\overline{W}_s$ represents the amount of available water in season s. Value $\hat{W}_s$ is obtained by multiplying $\overline{W}_s$ to the level of the given uncertainty (ε). Other constraints used in this study are as follows:

$$\sum_{j=1}^{J} l_j x_j \le L \quad (7)$$

$$\sum_{j=1}^{J} m_j x_j \le M \quad (8)$$

$$\sum_{j=1}^{J} f_{tj} x_j \le F_t \qquad \forall t \quad (9)$$

$$\sum_{j=1}^{J} pe_{zj} x_j \le P\overline{E}_z \qquad \forall z \quad (10)$$

$$\sum_{j=1}^{J} x_j \le A \quad (11)$$

Constraint (7) is related to workforce. In this constraint, l_j represents the amount of labor required to produce one hectare of crop j and L represents the available workforce. Constraint (8) is related to the agricultural machinery work hours. In this constraint, m_j represents the agricultural machinery work hours needed to produce one hectare of the product j and M represents the amount of hours that agricultural machineries are available. Constraints (9) and (10) are related to chemical fertilizer and pesticide, respectively. In these constraints, F_t is the index of total amount of available t type fertilizer and PE_z represents the amount of available t type pesticide. Constraint (11) is related to the available land. A represents the amount of land available for all products under study. To evaluate the amount of the sustainability of optimal cropping pattern provided by the mentioned model, a measure known as sustainability index can be used. Sustainability index of fertilizer ratio (poison) can be written as follows:

$$\text{Sustainability index of fertilizer(poison) ratio} = \frac{\text{Amount of fertilizer (poison)}}{\text{Cultivated area}}$$

The more the ratio of fertilizer use (poison) per unit area in a period is declined, the more farmers do sustainable operations. Thus, the sustainability index decrease means more sustainability.

It is worth mentioning that the amount of fertilizer or poison used for fractional linear and linear programming models with multiple objectives are obtained from final values of using this inputs. Finally, Monte Carlo simulation method is used to evaluate the proposed model. To do this, 100 random numbers with normal distribution and 99/99 convergence for available water (uncertain parameter) are provided and robust optimization for each level of probability of constraint violation from its bound and every level of specific uncertainty is resolved. In the next stage, infeasible solution percentage generated by the model is recorded as model infeasibility. In the present study, all the required data of the problem are obtained from the Agricultural

Organization, Regional Water Company and Mirab Zayanderud Company of Isfahan Province for the cropping year of 2009-2010.

Results:

Table (1) shows the results related to determining optimal cropping pattern for simple linear programming and linear fractional programming with multiple objectives under certainty and uncertainty. To implement uncertainty in the model, probability of constraint violation level of water from its bound on the probability of ten percent (p=0/1) and specific uncertainty level of five percent (ε= 0/05) were considered. The highest and lowest total acreage in the current cropping patterns are related to wheat (55% of the total acreage) and sunflower (1% of total acreage). The results obtained from estimation of simple linear programming model show that the total gross profit obtained from the current cropping pattern of the region is not very different from the cropping pattern determined by simple linear programming (a decrease of 9%). This shows the utilitarian behavior of the farmers of the area under study. In addition, reduction of the total gross profit of 317 billion Rials in the current cropping pattern to 186 billion Rials (41 percent decrease) in the fractional programming cropping pattern with multiple objectives under certainty indicates lack of farmers' attention to environmental issues. Gross profit decrease in optimal pattern of sustainable cropping in the present study confirms the results of [10] and contradicts the results of Moreover, the results show that the percentage of current cropping pattern changes has a considerable difference with sustainable optimal cropping pattern under certainty for all crops, which indicates lack of the attention of the farmers under study on sustainable agriculture. Comparing fractional linear programming with multiple objectives under certainty and uncertainty indicates that there is a slight difference in the optimal cropping pattern between these two groups. Decrease in gross profit is very slight and it is approximately 3 percent.

Table 1: Results related to simple linear programming models in terms of certainty and uncertainty.

Product	Acreage (ha)					
	Curren t	Simple linear	Fractional linear with multiple objectives under certainty (p =1)	Change percentage compared to the current cropping pattern	Fractional linear with multiple objectives under uncertainty (ε =0.05, p =0.1)	Change percentage compared to the current cropping pattern
Wheat (x_1)	8161	2116	2092	-74	2034	-75
Barley (x_2)	3288	1893	1898	-42	1826	-44
Corn (x_3)	283	344	-	-100	-	-100
Onion (x_4)	403	2789	315	-22	315	-22
Potato (x_5)	1590	594	1360	-14	1319	-17
Tomato (x_6)	140	-	513	73	498	72
Sunflower (x_7)	67	1677	-	-100	-	-100
Sugar beet (x_8)	495	-	-	-100	-	-100
Rapeseed (x_9)	178	-	-	-100	-	-100
Cucumber (x_{10})	171	-	541	68	541	68
Total gross profit (billion Rials)	317	288	186	-41	181	-43

Findings of the study

Graph (1) shows the sensitivity analysis of the total gross profit in fractional linear programming with multiple objectives under uncertainty. It is seen that in fixed given uncertainty levels (e.g. ε= 0/05), the total amount of gross profit increases with the probability of constraint violation increase from its bound (conservation reduction) and, in other words, with uncertainty reduction. Furthermore, in the fixed levels of p probability, the total gross profit decreases with increasing levels of the given uncertainty. Therefore, results of [10] and [19] in which they used grey and fuzzy fractional programming are also confirmed by robust optimization. In addition, results of the present study correspond exactly to the study of [13,22] in optimization of gross profit (regardless of the pattern sustainability of the optimal cropping in the present study). Results of the study of [25] are inconsistent with the findings of the mentioned studies.

In table (2), sustainability index related to important inputs in sustainable agriculture for the current cropping pattern, linear programming, and fractional linear programming under both certainty and uncertainty is shown. It is seen that this index in all cases in optimal cropping pattern for simple linear programming has outshined the current cropping pattern (except fungicide input).

This indicates the inability of simple linear programming model to estimate the sustainable cropping pattern for the study area. In contrast, the sustainability index related to all organic farming disturbing inputs in optimal cropping pattern of fractional linear programming has declined (except for the inputs of fungicide which had a small increase of 4%). For example, sustainability index of herbicide consumption from 1240 in the current cropping pattern decreased to 689 in the optimal cropping pattern by fractional linear programming (a decrease

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of 44 percent) which indicates more sustainability of the cropping pattern in this case. This result confirms the results of the study of [10]. Notable in this table is the equality of the calculated sustainability index for disturbing organic farming inputs in terms of certainty and uncertainty. Due to the reduction of the consumption of these inputs and the optimized acreage, this issue is the same in both patterns.

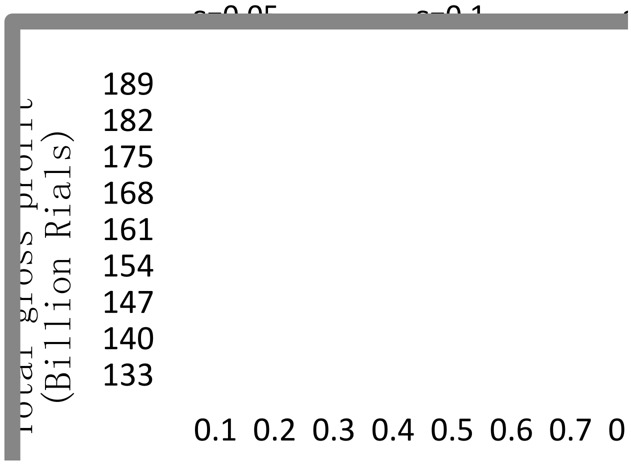

Fig. 1: Total gross profit in fractional linear programming with multiple objectives under uncertainty with different levels of p and ε.

Table 2: Sustainability index of production inputs considered in in sustainable agricultural in various optimal cropping patterns.

Input	Sustainability index					
	current	Simple linear	fractional linear with multiple objectives under certainty (*p* =1)	change percentage compared to the current cropping pattern	fractional linear with multiple objectives under uncertainty (ε =0/05, p =0/1)	change percentage compared to the current cropping pattern
Phosphate fertilizers	199	213	176	-11	176	-11
Nitrogenous fertilizers	393	437	315	-20	315	-20
Potash	21	22	17	-23	17	-23
Herbicide	1240	1508	689	-44	689	-44
insecticide	877	957	725	-17	725	-17
Fungicide	147	124	141	4	141	4

Research Findings

Table 3 shows the results of the evaluation of the model under study by using Monte Carlo simulation. We can see that with increase of the probability of constraint violation from its bounds (at fixed levels of given uncertainty), the amount of infeasible solutions has increased. Results of the evaluation of the model correspond exactly to the study of [22]. In other words, by reducing the amount of model conservation against uncertainty, the percentage of infeasible solutions increases. With increasing levels of given uncertainty, this value is increased. For example, in the given uncertainty level of 5% (ε =0/05) and probability of p =0/1, only 7 times infeasible solutions were obtained out of one hundred times model solutions generated by random numbers. In other words, in 93% of cases the optimal solution model was correct. By increasing the probability p to one (one hundred percent violation from the constraint) and increasing the given uncertainty level to 20%, this rate increases to 81 percent. In other words, only 19% of the cases provided feasible solutions. This method is more efficient than scenario-based assessment that Gutzler *et al*. [7] applied to assessing the robustness of their model.

Table 3: percentage of infeasible solutions for random numbers generated at different levels of p and ε.

	Probability level of each constraint violation from its bound (*p*)									
Given uncertainty level (**ε**)	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
0/05	68	54	43	37	29	20	16	12	9	7
0/1	78	78	67	55	43	35	28	20	14	11
0/2	81	81	75	68	60	53	41	34	27	19

Research Findings

Discussion:

The present study dealt with the optimal allocation of irrigation network of coastal lands on the right side of Nekuabad diversion dam taking into account factors of sustainable agriculture and uncertainty. Three types of simple linear programming (with respect to the maximum gross profit in the objective function), fractional linear programming with multiple objectives in terms of certainty and uncertainty were estimated. For solving fractional linear programming, six objectives were considered as proportional for the sustainability in the optimal cropping pattern. Using CONNISE method, 512 sub-spaces were created in the space of the objective that with the use of CE method, analysis, and elimination of these sub-spaces with various numbers of ideal and non-ideal points, optimal solutions were attained. To impose conditions of uncertainty, robust optimization with different levels of the probability of ach constraint violation from its bound (p) and certain uncertainty (ε) were used. Due to the reduction of sustainability index in all disturbing inputs of sustainable agriculture (except fungicide inputs) as well as the current uncertain situation in the coastal area of Zayanderud river, use of optimal cropping pattern of fractional linear programming with multiple objectives under uncertainty is proposed for coastal lands of the irrigation network on the right side of Nekuabad diversion dam. Moreover, to compensate the gross profit reduction which is due to the implementation of this type of cropping pattern, a variety of pricing policies (acceptable pricing for organic crops) and credit policies (allocation of low-interest loans for this kind of cropping) can be used.

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