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Environmental approach to determining optimal cropping pattern

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Abstract

In a majority of agricultural economics analyses, farmers' economic welfare is highlighted while the environmental issues are largely ignored. Therefore, the purpose of the present study was to determine the optimal cropping pattern through an environmental approach in a case study in Kazeroun County, Fars, Iran. Data was collected from production costs statistics provided by the Statistics and Information Technology Bureau of Agriculture-Jahad Organization. The optimal cropping pattern was determined through the goal programming model with four goals of maximizing farmers' net return, minimizing the amount of used water, chemical fertilizers, and pesticides under three scenarios. The results indicated that the third scenario which involved the environmental goals specified by the Islamic Republic of Iran's 5th Development Plan, was the optimal one. In this scenario, the use of water, chemical fertilizers and pesticides decreased by 4.4%, 4.72%, and 8.33% respectively while the net return increased by 10%. According to the results of the study, it is possible to increase the profit and productivity of resources with regard to environmental issues.

***Keywords*: Chemical Fertilizer, Cropping Pattern, Environment, Goal Programming, Pesticide, Water**

Introduction

Farming has been one of the most important financial resources throughout the history of civilization (Gouda et al., 2018). Increased use of water, chemical fertilizers and pesticides along with the application of modern technology have created considerable improvements in the modern agriculture over the past century. Yield of agricultural crops has increased, which in turn has led to population and economic growth (Zhang et al., 2015; Chen et al., 2018). Modern farming systems have been criticized due to their negative environmental impacts and people all over the world are searching for solutions to resolve these problems and achieve sustainable farming systems (Molaie Emamzadeh et al., 2016). In this context, one of the environmental issues is the reduction of groundwater levels and their pollution. Water is the most important source to sustain agriculture. Increasing demand by the industry sector for water and challenges such as global warming will increase water resource constraints for the agricultural sector in the future (Li et al., 2020).

Cropping pattern planning is one of the most critical decisions made by agricultural managers which can lead to either the improvement or destruction of the environment. Due to the complex nature of the agricultural systems, managers have multiple objectives (Xevi and Khan, 2005; Zeng et al., 2010). The Goal Programming model (GP) is one of the instruments widely adopted in decision making to achieve multiple objectives (e.g. Rollan et al., 2018; Zografidou et al., 2017; Mosleh et al., 2017; Panigrahi et al., 2010).

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In Iran, the agricultural sector is one of the most important economic sectors. In 2016 nearly 18 percent of the Iranian working population worked in the agricultural sector (Statistical Center of Iran, 2016) and about 9 percent of the country's GDP came from the agricultural sector. A majority of Iran's national food is provided by the agricultural sector and agricultural products accounted for 16.9 percent of the country's non-oil exports in 2016 (Central Bank of the Islamic Republic of Iran, 2016). However, the overuse of groundwater resources by farmers and, consequently, depletion of these resources, along with the widespread use of fertilizers and chemical pesticides have created numerous environmental problems in Iran. In the Islamic Republic of Iran's 5^{th} Development Plan it is stated that a suitable cropping pattern planning must be put in place so that the use of water, fertilizers, and pesticides decreases by 0.93%, 7%, and 1% respectively. The farmers' objectives, constraints, types of crops, social and economic conditions vary depending on the region. Therefore, planning for cropping also depends on the region. Several studies have addressed optimal cropping patterns based on different environmental conditions, goals, restrictions, and crops in different regions. Mardani Najafabadi et al. (2019) studied the optimization of regional cropping patterns in Isfahan Province focusing on account economic, social, and environmental objectives. Their results indicated that the crop area could be decreased by 16 percent in Isfahan Province to achieve the set goals. Quite surprisingly, this reduction will lead to a decrease in irrigation water by 17%, an increase in profit by 58%, and an increase in production by 11%. Golabi et al. (2019) determined the optimal cropping pattern in Kermanshah Province and showed that among the studied crops, watermelon, grazing corn, and sugar beet were optimal crops, and sesame, beans, and sunflower were non-optimal crops for farming. Furthermore, they found that for gardening purposes, cherry and sour cherry were optimal while almond was non-optimal. Mirkarimi et al. (2016) adopted the GP model to determine the optimal cropping pattern in the city of Amol. Their objectives were to reduce chemical fertilizers consumption by 7 percent, pesticides by 1 percent, and water consumption by 0.93 to preserve rare water resources and encourage sustainable development in the agricultural sector. The results showed that in the optimal pattern, high-yielding long-grain rice, rainfed barley, clover, irrigated lentil, rainfed rapeseed, and irrigated alfalfa have to be omitted, and parsley and irrigated potato's crop area should increase. Parhizkari et al. (2015) used the GP model to determine the optimal cropping pattern in west of Alamut, a small town east of Qazvin. The goal was to preserve and sustain the environment. The results indicated that the current cropping pattern is not optimal, and inputs are not used efficiently. Pitakpongjaroen and Wiboonpongse (2015) determined the best cropping pattern in Chiang Mai. They adopted the multi-objective planning model and set four goals. Their results indicated that considering environmental issues, the current cropping pattern should be changed while the amount and cost of fertilizer will reduce. No studies have addressed the issue of determining the optimal cropping patterns in Kazeroun, a county in Fars Province, which is suffering from water scarcity. Therefore, this study seeks to determine the optimal cropping pattern in the Kazeroun County in the southwestern part of Iran using the GP model and through various scenarios in order to resolve the environmental problems and to maximize the farmers' net return.

Materials and Methods

Study Area

Kazeroun is one of the biggest counties in Fars Province with geographical coordinates of 29°37'6" North and 51°39'30" East (Figure 1). With an average annual precipitation of 380 mm, the county's economy is based on agriculture. In 2016, about 51066 hectares of the county's land area was allocated to farming. The farming lands capable of irrigated agriculture make up a total of 24368 hectares. The irrigated crops planted there include wheat, barley, tomatoes, maize, vegetables, watermelon, and onions with respective total cultivated area of 4551, 2625, 1351, 2759, 956, and 782 hectares.

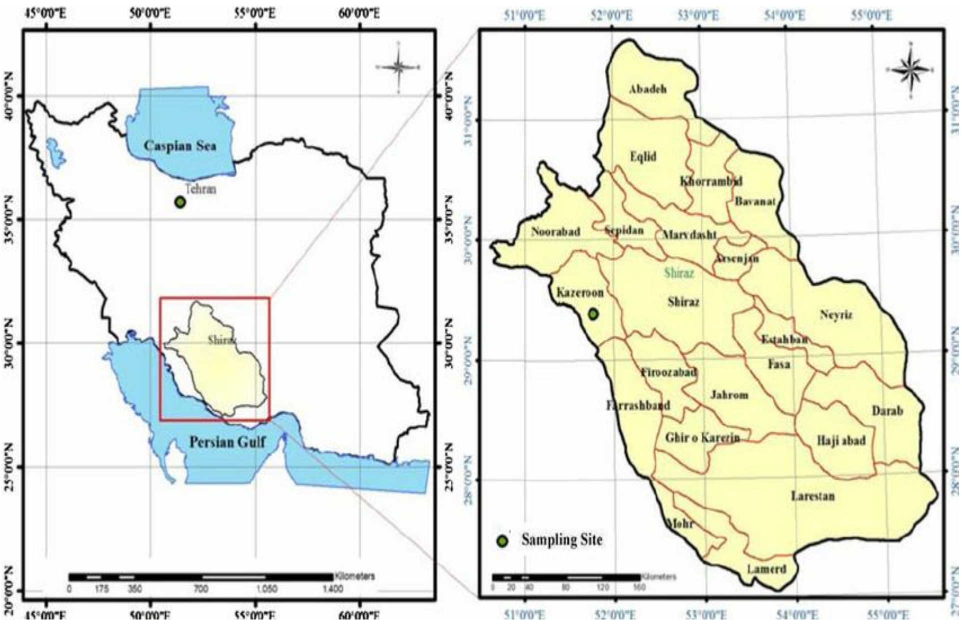

Figure 1. Location of the Area under Study

Database

The statistics and data used in this study were gathered from the production costs statistics provided by the Statistics and Information Technology Bureau of Agriculture-Jahad Organization in 2016. Table 1 summarizes the statistics used in this study.

Table 1. Coefficients matrix of objectives and constraints

Objectives and constraints	Crops						
	Wheat X_1	Barley X_2	Tomato X_3	Maize X	Vegetables X_5	Watermelon X_6	Onion X_7
Net Return (Thousand Rial/ha)	30815.89	20458.92	121462	83237.5	206655.2	102894.15	250816.21
Water (m^3/ha)	4742	3570	11874	7997	7105	7665	6212
Chemical Fertilizers (kg/ha)	650	640	790	800	450	770	870
Chemical pesticides (Liter/ha)	2.9	1.4	4	0.4	1.5	2.7	3.2
Machinery (Hour/ha)	12.4	15.8	8.1	13.3	7.2	10.8	11.1
Land (ha)	1	1	1	1	1	1	1
Labor use (man-day/ha)	18.3	16.5	96.25	23.47	19.65	49.7	165.4

Model Description

Goal Programming Approach

Like any form of planning, planning for farmers involves various criteria and objectives which have to be taken into account (Bibao-Terol et al., 2012). Practically, farmer's objectives are diverse depending on climate, availability of labor, water, energy, etc. Planning in agricultural systems with diverse objectives can make use of the Goal Programming model developed from the Linear Programming model (Dave, 2015). The GP model can help achieve multiple objectives simultaneously (Molaie Emamzadeh et al., 2016). This model was first proposed by Charnes and Cooper (1961) (Bilbao-Terol et al., 2012) and further expanded by Lee (1972), Ignizio (1985), and Romero (1990). This model has been extensively adopted due to its applicability (Bilbao-Terol et al., 2012), flexibility, and the possibility to include a wide range of social, economic, environmental, and other objectives simultaneously (Petridis and Dey, 2016).

The general shape of the GP model is as follows, where it is assumed that there are k conflicting objectives while objectives are a linear combination of n decision variables, in which m resources are used.

Min D = $\sum_{j=1}^{k} h_j(d_j^- + d_j^+)$

s.t:

$g_i(X) \leq b_i$

i=1,2,……,m

$\sum_{j=1}^{n} c_{ij}X_{ij} + d_j^- + d_j^+ = b_j$

j=1,2,……,n

$X, d_j^+, d_j^- \geq 0$

$d_j^+ . d_j^- = 0$

Where,

h_j: the indicator of j^th goal

$h_j(d_j^- + d_j^+)$: the deviation function from the j^th goal

$g_i(x)$: the constraint function of the i^th resource for various activities of X

b_i: the available amount of the i^th resource

c_{ij}: the amount of i^th resource used per unit of the j^th activity

d_j^+: the surplus variable

d_j^-: the slack variable

In this study, a GP model has been developed to determine an optimal cropping pattern. The Win QSB software package was used to solve the developed GP models.

Objectives and Scenarios

In order to determine the optimal cropping pattern, we considered four goals including maximizing the farmers' net return and minimizing the use of water, chemical fertilizers, and pesticides. Three scenarios were tested, i.e. an environmental approach (giving environmental objectives priority), involving a decrease in water use by 10%, and achieving the environmental objectives of the Islamic Republic of Iran's 5^th Development Plan.

Constraints

Since all planners face constraints in achieving their objectives, the present study suffered from the following constraints:

Land constraints

The total land area allocated to different crops should be less than or equal to the total cultivable lands (Mosleh *et al*., 2017; Amini Fasakhodi *et al*., 2010). The cropping pattern of the region under study during the past 8 years was investigated and the change coefficient percentage for the cultivated area was calculated (dividing the standard deviation by the average of data and multiplying the result by 100). The results indicated that there is a capability of change in the cropping pattern by 25%. Therefore, the following constraints were considered:

$3413 \leq X_1 \leq 5689$

$1969 \leq X_2 \leq 3281$

$2185 \leq X_3 \leq 3641$

$1013 \leq X_4 \leq 1689$

$2069 \leq X_5 \leq 3281$

$717 \leq X_6 \leq 1195$

$586 \leq X_7 \leq 977$

Water Constraints

The amount of water used for different crops cannot exceed the amount of available water (Aminin Fasakhodi et al., 2010; Molaie Emamzadeh et al., 2016).

Labor Constraint

The labor used for production of various crops should not be more than the available labor.

Machinery Constraints

This constraint was considered due to the mechanized farming in Kazeroun. The number of machinery work hours for different crops needs to be smaller than or equal to the available number of machinery working hours.

Chemical Fertilizers Constraint

Phosphate, nitrogen, and potash fertilizers are used for cropping in Kazeroun. The amount of chemical fertilizer used for all crops needs to be less than or equal to the available amount of chemical fertilizers.

Chemical Pesticides Constraints

The chemical pesticides used in agriculture in Kazeroun include herbicides, insecticides, and fungicides. The amount of chemical pesticides used for all crops need to be less than or equal to the available amount of chemical pesticides.

GP Model of the Case Study

In the present study, three scenarios have been considered. The GP model for the first scenario is presented as an example below, where the constraints are net return, water, labor, machinery, fertilizer, pesticide, and land respectively. The last constraint is related to the minimum area under cultivation.

$$\text{Min } Z = P_1 d_2^+ \; P_2 d_3^+ \; P_3 d_4^+ \; P_4 d_1^-$$

$$30815.89X_1+20458.92X_2+121462X_3+83237.5X_4+206655.2X_5+102894.15X_6+250816.21X_7+d_1^- - d_1^+ = 1681734000$$

$$4742X_1+3570X_2+11874X_3+7997X_4+7105X_5+7665X_6+6212X_7+d_2^- - d_2^+ = 108133200$$

$$18.3X_1+16.5X_2+96.25X_3+23.47X_4+19.65X_5+49.7X_6+165.4X_7 \leq 669750.4$$

$$12.4X_1+15.8X_2+8.1X_3+13.3X_4+7.2X_5+10.8X_6+11.1X_7 \leq 178340.8$$

$$650X_1+640X_2+790X_3+800X_4+450X_5+770X_6+870X_7+d_3^- - d_3^+ = 10678230$$

$$2.9X_1+1.4X_2+4X_3+0.4X_4+1.5X_5+2.7X_6+3.2X_7+d_4^- - d_4^+ = 38287.40$$

$$X_1+X_2+X_3+X_4+X_5+X_6+X_7 \leq 15937$$

$$3413 \leq X_1 \leq 5689$$

$$1969 \leq X_2 \leq 3281$$

$$2185 \leq X_3 \leq 3641$$

$$1013 \leq X_4 \leq 1689$$

$$2069 \leq X_5 \leq 3281$$

$$717 \leq X_6 \leq 1195$$

$$586 \leq X_7 \leq 977$$

$$X, d_i^+, d_i^- \geq 0$$

$$d_i^- . d_i^+ = 0$$

Results

First Scenario

In the first scenario, the environmental objectives of minimizing the use of water, chemical fertilizers and pesticides are of higher priority compared to the economic objective (i.e. increasing net return). In this scenario, compared to the existing pattern, the areas under wheat, barley and tomato cultivation decrease while for maize, vegetables, watermelon, and onion, the cultivated areas increase (Table 2). The areas under wheat and barley cultivation show a decrease due to the low net return and the area under tomato cultivation decreased as a result of high water consumption. The net return increased by 10.29 %. Due to the surplus values for fertilizer and pesticide inputs, their consumption can be decreased by 2.30% and 5.45% respectively.

Table 2. Cultivated areas for existing pattern and different scenarios

Crops	Existing Pattern	Scenario 1	Scenario 2	Scenario 3
Wheat	4551	3928	3413	3413
Barley	2625	1969	1969	1969
Tomato	2913	2462	3205	2560
Maize	1351	1689	1013	1689
Vegetables	2759	6449	2305	3449
Watermelon	956	1195	717	1195
Onion	782	977	977	977

Second Scenario: decreasing water consumption by 10 percent

In this scenario, due to continuous drought and excessive use of groundwater in the area, the amount of water consumption was decreased by 10%. The results indicate that compared to the existing pattern, in order to avoid further decreases in net return, the areas under tomato and onion cultivation which have higher returns compared to other crops increase while for other crops, the cultivated areas decrease (Table 2). This change in the model led to an increase in net return by 7.26%. Moreover, by decreasing water consumption, the amount of chemical fertilizer and pesticide outputs can be decreased by 13.27% and 10.15%, which in turn leads to an increase in environmental pollution.

Third Scenario: determining a cropping pattern in line with the environmental objectives specified by the Islamic Republic of Iran's 5th Development Plan

In the third scenario, in order to achieve the environmental objectives of the Islamic Republic of Iran's 5th Development Plan, water consumption, chemical fertilizer use, and pesticide use decreased by 0.93%, 7%, and 1% respectively. The results revealed that decreasing the use of pesticides by 7% is not viable; however, it is possible to decrease the use of pesticides by 4.72%. In this scenario, the areas under wheat, barley, and tomato cultivation were decreased and the ones for other crops were increased (Table 2). The use of chemical fertilizers and water can be decreased by 7.33% and 3.47% respectively, which is more than the planned amount. In this scenario, the net return increased by 10%.

Discussion

While agriculture plays a crucial role in the nations' economy, careless agriculture can be environmentally destructive and threaten the health of human beings and other creatures. Therefore, a farmer needs to consider environmental issues as well as economic goals. For managers to achieve optimal results, purposeful planning is required. Among various planning models, the Goal Programming model is one of the most robust and flexible ones capable of incorporating various and sometimes conflicting objectives in one single system. The present study determined the optimal cropping pattern for Kazeroun County by considering three scenarios and adopting the GP model to achieve the economic and environmental objectives simultaneously.

The results of the GP model revealed that it is feasible to increase farmers' net return and decrease environmental problems at the same time.

The areas under wheat and barley cultivation in all three scenarios are less than the existing pattern, which indicates in order to resolve environmental problems in this region the cultivated areas for these crops need to be decreased. The area under onion cultivation in all three scenarios is bigger than the existing pattern. Therefore, it is proposed that in order to improve the environmental conditions of the region, the cultivated area for this crop should increase. The areas under watermelon, vegetables, and maize cultivation decreased in the second scenario (decreasing water consumption by 10%) due to their high water requirements, while in the other two scenarios they increased (Figure 2).

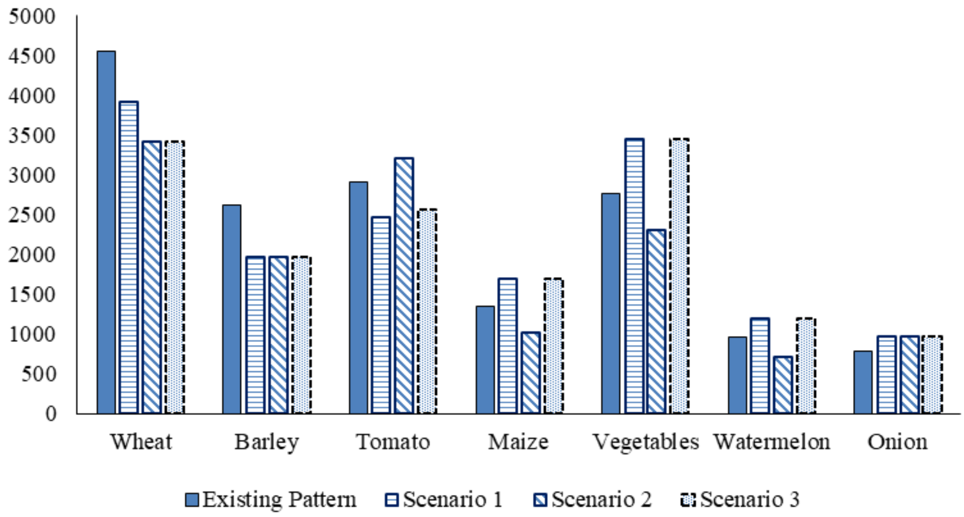

Figure 2. Comparison of crop area under cultivation in difference scenarios

Generally, the results of the three scenarios can be compared economically and environmentally. From an economic point of view, the first scenario is the optimal one. In this scenario, the net return increases by 10.29%, which is the highest among all scenarios. Environmentally, the second scenario, which aims at decreasing water consumption by 10%, is optimal. In this scenario, while water consumption is decreased by 10%, the use of chemical fertilizers and pesticides decrease by 13.27% and 10.15%, respectively. However, in this scenario the net return decreases by 7.26%. In terms of environmental and economic considerations, the third scenario is the best since it causes 4.72%, 8.33%, and 4.4% decrease in the use of chemical fertilizers, pesticides, and water respectively while net return tend to increase by 10%.

About 90 percent of Iran falls into arid and semi-arid climates including the study area, making the region vulnerable in terms of water due to a lack of enough resources. This fact has further led to an excessive extraction of underground water resources in Kazeroun plains and a considerable reduction and negative balance in these water levels. Planners and policy-makers are looking into solutions to stop this excessive extraction. Reducing water consumption in agriculture sector can have a significant influence on underground water resource extraction. One way to reduce water consumption is to change cropping patterns. If the goal of changing the cropping patterns is to reduce water consumption, the second scenario is still more viable.

In almost all the studies conducted on determining the optimal cropping pattern using the GP model, like the current study, the optimal and current cropping patterns have been found to be different. In some cases, the farmers' gross profit decreased after optimizing the cropping patterns (Kohansal and Firooz Zare, 2009, Hosseinzad et al., 2014). However, the results of this study and some others (Mirkarimi et al., 2016; Nematollahi et al., 2017; El-Gafy et al., 2013) indicated that optimizing cropping patterns in terms of environmental considerations can lead to increased gross profits for farmers as well.

Conclusion

Changing the cropping pattern is perhaps the most suitable way to prevent the underground waters from becoming depleted and to decrease water and soil pollution. Convincing farmers to follow the proposed cultivation model is hard. Therefore, by a gradual and logical decrease of the area under cultivation for crops such as watermelons, vegetables, and corn, which require high levels of water, we can save water resources. By conducting scientific research to boost the productivity of crops with lower monetizing power smaller harmful effects on the environment, and also by subsidizing these crops, farmers could be convinced to cultivate these crops. Also, to change the cropping patterns, promotional work has to be implemented. When farmers realize that a scientific cropping pattern guarantees sustainable agriculture and food safety and increases the productivity and viability of natural resources, they are more willing to adopt the proposed cropping patterns.

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