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Sustainable Cropping Pattern with the Tradeoff between Economic and Environmental Consideration in Shiraz Plain, Iran

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ABSTRACT

One of the most important decisions that farmers make is the allocation of resources in an optimal manner, which is often done by determining the optimal cropping pattern. The purpose of this study was to present a cultivation model compatible with the agricultural ecosystem of Shiraz Plain, Fars Province, Iran, by quantifying the environmental effects of agricultural production using the Life Cycle Assessment (LCA) approach. The results of LCA showed that cultivation of crops such as lentils, onions, and tomatoes had the most negative environmental effects. The ecosystem quality index for crops in this plain varied between 0.03 and 3.64 PT. The highest negative impact of crop cultivation on the quality of the ecosystem was attributed to onion, tomato, and rain-fed lentils. The results of multi-objective planning showed that farmers can achieve their economic objectives and policymakers' environmental goals through reducing the area under cultivation. By changing the cropping pattern towards the suggested pattern for Shiraz Plain, an average decrease of 5.60% in profit was expected. However, this change is an effective step in controlling consumption of water, chemical fertilizers, and pesticides. Achieving sustainable agriculture in terms of economic and environmental indicators is possible by reducing the cropland area and economic profit by 18.05% and 11.43%, respectively.

Keywords: Cultivation pattern, Life cycle assessment, Multi-objective programming, Sustainability.

INTRODUCTION

In recent decades, due to environmental concerns, the conventional agricultural systems have been severely criticized and sustainable agriculture has gained a significant importance (Harwood, 2020). To reduce the negative effects of agricultural activities on the environment and solve the issue of agricultural sustainability, several alternative methods have been presented based on reducing the use of natural resources, limiting inputs, and maintaining soil fertility and biodiversity (Gomiero *et al*., 2011). It is widely accepted that the adjustment of planting timing, crop variety, and crop re-allocation are among the effective measures to achieve sustainable agriculture and planned adaptation to climate change (IPCC, 2007).

Water restrictions and increased demand have created new water security issues and increased water tension both at the regional and international levels. Iran's water challenges are not limited only to surface water. Currently, Iran is among the top groundwater extractors in the world (Döll *et al*., 2014; Gleeson *et al*., 2012). It is estimated that Iranians have already used most of their underground water reserves. Different

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strategies for managing water resources in the world were considered. Iran has always suffered from seriously inefficient agriculture (Madani, 2014), which relies heavily on irrigation (Gohari *et al*., 2017; Layani *et al*., 2021) and consumes most of the country's limited water resources. Considering the high share of agriculture in the water demand, determining the cultivation pattern is one of the effective solutions in overcoming the water challenge. Optimizing crop patterns based on the potential of each region is a key to sustainable agriculture and water resource management (Najafabadi *et al*., 2019).

Single-objective planning models have been used in farming research, but multi-objective planning models have also emerged to account for conflicting goals like economic and ecological benefits (Mirzaei *et al*., 2019). The multi-objective programming model is crucial in real-world problems like resource management in agriculture (Pedro Monzonis *et al*., 2016; Najafabadi *et al*., 2019; Mirzaei *et al*., 2022). A large and growing body of literature has investigated optimal crop pattern in the world. Recently, Mirzaei *et al*. (2022) optimized crop patterns in Jiroft Plain, Iran, using a multi-objective programming model. Results showed that changing cultivation patterns can improve water resource management. Nikouei *et al*., (2022) showed that optimal cultivation patterns can reduce agricultural water consumption, pollution, and non-renewable energy usage by 1%, global warming potential by 14%, and nonrenewable energy use by 14%, with no change in farms' net profit compared to the current pattern in the region. Radmehr *et al*. (2021) used MCDM nonlinear programming to optimize the cropping pattern in Neishaboor Plain, Iran, and manage groundwater while improving economic profit for farmers by focusing on the water, energy, and food nexus.

Human activities have caused environmental challenges, leading to international agreements and policies to reduce their effects. Life Cycle Assessment (LCA) is a tool that measures the environmental impact caused by products along their entire life cycle (Finnveden *et al*., 2009). In fact, LCA helps with examining the production process from an environmental point of view along with the technical and economic dimensions (Wowra *et al*., 2021). Many LCA studies have investigated agricultural crop production systems for diverse products like food and feed, bio-based materials, or bioenergy (Khoshnevisan *et al*., 2015; Tricase *et al*., 2018). Wowra *et al*. (2021) presented a comprehensive evaluation of regionalization in LCA with a focus on nitrogen in agricultural crop production systems. By combining LCA with multi-objective programming, Marzban *et al*. (2021) used a multi-objective nonlinear programming model to maximize net profit and minimize the environmental effects on the ecosystem and determine the optimal cultivation pattern in Lorestan Province, Iran. Through the LCA, they determined the environmental effects of crop cultivation and entered into the model as a constraint. Recently, Layani *et al*. (2023) also recommended reducing crop area in Sari City, Iran, to meet environmental, economic and social goals. Changing the pattern predicts 12.97% decrease in profit, but it effectively reduces water, fertilizer, and pesticide consumption.

The studies cited provide proof that selecting the most effective crop pattern can have a positive impact on resource management within the agricultural sector. These researches emphasize the importance of two key themes: utilizing multi-objective programming models for decision-making and taking into account environmental factors when making decisions. In contrast to previous studies, this study focused on the concept of LCA for various environmental impacts of agricultural production, in addition to economic goals. Previous studies primarily aimed to minimize chemical fertilizer and water consumption as environmental goals. As such, this study aimed to determine the best cultivation pattern in Shiraz Plain, Fars Province, Iran, where crop management is particularly difficult due to periodic drought. The paper is structured as follows: the next section presents the case study and features of the multi-objective model, followed by a description of the data used. Finally, the results of the model and

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conclusions are presented in the last part of the paper.

MATERIALS AND METHODS

Methodology

This study was conducted to optimize the cropping pattern in Shiraz Plain, with a focus on economic and environmental considerations. The environmental effects of crop cultivation were determined, and a multi-objective planning approach was used to propose an optimal cultivation model. The life cycle assessment method was used to determine the environmental effects of agricultural production, and the multi-objective planning model was used to optimize the cultivation pattern.

The Study Area

This study was based on a cross-sectional survey with a statistical population of the farmers of Shiraz Plain in Fars Province. Shiraz Plain, in the southern part of Iran, is located at 53° 37 E longitude and 29° 57 N latitude with an area of 10,434 km^2. The mean annual precipitation is 330 mm and the mean annual temperature for the study area is about 18°C. The geographical location of the study region is shown in Figure 1. Among the cereal crops, the largest cultivated area is related to wheat (40,419 ha), followed by rice (17,104 ha), irrigated barley (7,691 ha), and rain-fed barley (1,227 ha). Canola, with an area of 638 ha, is one of the important crops in the current cropping pattern of Shiraz Plain, and the cultivation area has been growing in recent years (Jihad-e Agriculture Organization of Fars Province, 2020).

Multi-Objective Programing

Multi-objective planning is used in order to plan various activities, including agriculture, with multiple and conflicting goals. Mathematically, the equations of the MOO (Multi-Objective Optimization) problem can be written as follows (Ehrgott, 2005):

$$min/\max f_1(x).\, f_2(x) \dots f_n(x) \qquad (1)$$
$$subject\ to:$$
$$x \in U$$

Where, x is the decision variable, n is the number of objective functions, U is the feasible set, $f_n(x)$ is the nth objective function, and min/max is combined object operations. Since the objectives conflict with each other, a number of solutions are found to be Pareto optimal or efficient solutions space.

To determine the cropping pattern for a region, multiple distinct objectives may be considered. Different objectives include

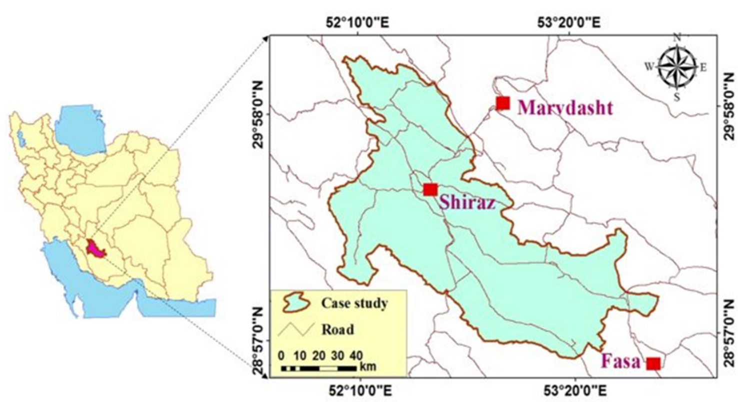

Figure 1. Regional map of Iran, Fars Province, and Shiraz Plain.

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economic objectives (for the farmer) and environmental objectives (for the policy maker). The algebraic form of these goals is explained in terms of their importance in Equations (2) – (5):

Economic Objective Function

Economic efficiency was measured as the level of productivity and total net output was used to measure the economic benefits.

$$Max\ f_1(x_j) = \sum_{j=1}^{n} n_j x_j \quad (2)$$

$$Min\ f_2(x_j) = \sum_{j=1}^{n} wr_j x_j \quad (3)$$

Where, n_j represents the gross margin per unit area of crops j, x_j represents the optimal cultivations of crops, and f_1 represents the total net output of crops.

Environmental Objective Function

Minimizing the consumption of water and chemical fertilizers in the production of crops was one of the environmental goals in this study.

$$Min\ f_3(x_j) = \sum_{j=1}^{n} fc_j x_j \quad (4)$$

$$Min\ f_4(x_j) = \sum_{j=1}^{n} hh_j x_j \quad (5)$$

Where wr_j and fc_j represent the water and fertilizer requirements per unit of area of crops j, respectively. Reducing the harmful effects of crop production on human health, ecosystem quality, and resource consumption was also considered as another environmental goal in this study.

$$Min\ f_5(x_j) = \sum_{j=1}^{n} eq_j x_j \quad (6)$$

$$Min\ f_6(x_j) = \sum_{j=1}^{n} rc_j x_j \quad (7)$$

Where hh_j, eq_j and rc_j are the effects of the production of each product on human health, ecosystem quality, and resource consumption, respectively. These coefficients were obtained using LCA.

The constraint of the model includes available land, water resources, chemical fertilizers and pesticides, and labor.

$$\sum_{j=1}^{n} x_j \leq RHS_{land} \quad (8)$$

$$\sum_{j=1}^{n} x_j \leq RHS_{land} \quad (9)$$

$$\sum_{j=1}^{n} fc_j x_j \leq RHS_{fertilizer} \quad (10)$$

$$\sum_{j=1}^{n} pc_j x_j \leq RHS_{Poison} \quad (11)$$

$$\sum_{j=1}^{n} lc_j x_j \leq RHS_{labour} \quad (12)$$

Where RHS_{LAND}, RHS_{water}, $RHS_{Fertilizer}$, $RHS_{pesticides}$, and RHS_{Labor} are available land, water, fertilizer, pesticides, and labor resources at the study area.

Our problem is multi-objective, and there are various methods such as ε-constraint (Haimes *et al*., 1971), LP-Metric (Pasandideh *et al*., 2015), goal programming (Sharma *et al*., 2003) and evolutionary algorithms (Che and Chiang, 2010) to solve these problems. Multi-objective mathematical programming involves several conflicting objectives that must be optimized simultaneously, and there is no single optimal solution that optimizes all objective functions simultaneously. These solutions are known as the Pareto optimal solutions and are obtained using scaling methods. In this research, the LP-Metric method, known as the most popular method, and the weighted min-max (also called the weighted Lp method) were used to obtain Pareto-optimal solutions. Therefore, the multi-objective problem with some parameters becomes a single-objective optimization problem. In these methods, objective functions are combined with appropriate weights. Determining the weight of functions is a challenge. Weights (w1, w2, ..., w6 in this case) are determined by the decision-makers through some methods such as AHP (Analytic Hierarchy Process).

Method of Weighted Metrics (L_P Method)

A brief discussion of L_P method is given in this section. L_P method, which is usually discussed in MOO literature (Asgharpour, 1998; Hwang and Masud, 2012), is among optimization techniques that combines multiple objectives into a single objective. The weighted L_p measures distance of any solution x from the ideal solution $f(x^{\max j})$, which can be minimized as follows:

$$L_P = \left\{\sum_{j=1}^{k} w_j \left(f_j\left(x^{\max j}\right) - f_j(x)\right)^p\right\}^{1/P} \quad (13)$$

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Where, w_j is the non-negative weight assigned to each objective function by the decision maker and P indicates the importance of each objective function deviation from its ideal value. When P=1, the resulting problem reduces to a weighted sum of the deviations, and when P=2, a weighted Euclidean distance of any point in the objective space from the ideal point is minimized. When p= ∞, the largest deviation $w_j(f_j(x^{\max j}) - f_j(x))$ is minimized, that is:

$$\underset{x}{Min}\left\{\underset{j}{Max}\ w_j(f_j(x^{\max j}) - f_j(x))\right\} \quad (14)$$

Which is equivalent to:

$$Min\ y$$
$$s.t:$$
$$y \geq w_j\left(f_j(x^{maxj}) - f_j(x)\right)\ \forall_j$$

(15)

Chankong and Haimes (1983) showed that all solutions corresponding to 1£ *p* £ ¥ and w>0 are efficient solutions when L_P method is used. On the other hand, with constrained L_P problems, according to Miettinen (1999), only L_∞ leads to Pareto optimal solutions. These are two characteristics of the L_P method.

In Equation (13), it is assumed that objective functions have the same scale. If $f_j(x)$s do not have the same scale, then, each objective function could be made scale-less using either of the following equations:

$$L_P = \left(\sum_{j=1}^{k} w_j\left[\frac{f_j(x^{\max}\ ) - f_j(x)}{f_j(x^{\max j})}\right]^p\right)^{1/p}$$

Or

$$L_P = \left(\sum_{j=1}^{k} w_j\left[\frac{f_j(x^{\max j}) - f_j(x)}{f_j(x^{\max}\ ) - f_j(x^{\min j})}\right]^p\right)^{1/p} \quad (16)$$

After determining the desired objectives, a questionnaire was developed with the help of 10 experts (the experts in this study include 4 Agricultural Jihad Experts, 4 University Professors, and 2 Experts from the General Directorate of Natural Resources and Watershed Management) and AHP method. In order to optimize the cultivation pattern based on the multi-objective programming model, GAMS software was used.

Life Cycle Assessment (LCA)

LCA, also known as ecological balance or cradle-to-grave analysis, is a technique for assessing the environmental impacts related to all stages of a product's life, from the input materials to the farm to the output. The purpose of LCA is to compare the full range of environmental impacts attributable to products and services by quantifying all inputs and outputs of material flows and assessing how these material flows affect the environment (Kaab *et al*., 2019).

According to this pattern, LCA consists of the following four sections: (1) Goal and scope definition, (2) Life Cycle Inventory (LCI), (3) Life Cycle Impact Assessment (LCIA), and (4) Life cycle interpretation (Mostashari-Rad *et al*., 2021). The definition of goal and scope is a significant key to constituting the overall framework that includes Functional Unit (FU), system boundaries, resource allocation, and sector selection effect (Nabavi-Pelesaraei *et al*., 2017). LCI analysis involves creating an inventory of flows from and to nature for a product system (Saber *et al*., 2021). Inventory flows include inputs, energy, raw materials, and pollution releases to air, land, and water (Taherzadeh-Shalmaei *et al*., 2021). The *Ecoinvent* database (https://ecoinvent.org/the-ecoinvent-database/) can also be used for calculations of the average emissions of each pollutant and its environmental effects. This database is used for many life cycle assessments, environmental design and product environmental information projects. This database is a compatible data source for studies and evaluations based on ISO 14040 and 14044. This database contains datasets for most industries and is updated as new data becomes available. The next stage is the LCIA where the importance of possible

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environmental effects results according to the LCI is assessed (Cavalliere *et al*., 2018). LCIA is divided into three subsections: Characterization, Normalization, and Weighting (Grados and Schrevens, 2019). To evaluate environmental impact, a characterization index is calculated for each pollutant or source. Then, this is normalized to the region's total environmental effects, and weighted based on the level of harm caused.

There are many software designed and provided for life cycle assessment, and *SimaPro8.3* was used in this study. *SimaPro* quantifies environmental impact and enables your organization to improve products and systems, measure progress and report on sustainability efforts. To evaluate the effects in *SimaPro* software, there are different methods such as Environmental indicators 99, ReCiPe 2008, CML 2001, EDIP0 97, EDIP2003, EPS2000 method and EcoPoints. However, the IMPACT 2002+ method is usually used for life cycle analysis (Grados and Schrevens, 2019). Environmental effects are categorized as human health, ecosystem quality, and resource depletion. Factors that affect human health include toxicity, respiratory effects, ozone layer destruction, and ionizing radiation. Ecosystem quality can be diminished by land acidification, nutrition, toxicity, and land use change. Resource depletion is influenced by non-renewable energy and mineral extraction (De Schryver *et al*., 2010).

Data was collected through questionnaires, face-to-face interviews, and the Jihad-e Agriculture Organization. The extracted information includes data on costs, input consumption, yield, and cultivation areas in an Excel file. Random sampling and Cochran's formulas were used to collect 200 questionnaires to verify and correct input consumption and production cost.

RESULTS

Table 1 shows crop yield and cultivated area in the region for 2019-2020. Wheat had the largest cultivated area (40,419 ha), followed by rice (17,104 ha), irrigated barley (7,691 ha), and rain-fed barley (1227 ha) among the cereal group. Canola and corn are important crops in Shiraz Plain, with canola cultivation area increasing in recent years. Grain corn and fodder corn make up 7.85% of total cropland area. According to Table 1, the net water requirement of crops such as potatoes, alfalfa, and rice is more than other crops. Among the selected crops, rain-fed barley, rain-fed lentils, and beans have the lowest fertilizer requirements.

Environmental Impact Assessment

The effect of different crops on environmental indicators is presented in Figures 2 to 4. The human health index of different crops ranged between 1.001 to 81.30 PT (PT is a unit for measuring the annual environmental load of an average European person, represented as a dimensionless value) (eco-point) in Shiraz Plain. Sugar beet, fodder corn, and cucumber had the lowest human health impact and are the best crops for cultivation. On the other hand, onions, tomatoes, and irrigated lentils had the most harmful impacts on human health and are recognized as the most unsuitable products from an environmental point of view. The human health index of rice is equal to 13.19 PT; this index is equal to 11.19 PT for canola. Considering the high use of nitrogen fertilizer to increase rice yield in the rice and canola growing season, the effect of this fertilizer on human health index is quite evident. Direct emission from the farm due to diesel burning in the machines used in agricultural activities can also increase the risks of cancerous and non-cancerous diseases. The destruction of the ozone layer is caused by the use of diesel and electricity in crop growing, leading to climate change and global warming. UV radiation from the depleted ozone layer poses risks such as skin damage, weakened immune systems, and respiratory issues. Depreciated agricultural

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Table 1. Some observed data of Shiraz Plain in baseline (2019).

Crops	Cropland area (ha)	Yield (Kg)	Water requirement (m^3)	Fertilizer (Kg)	Pesticides (Kg)	Labor (person-days ha^{-1})
Wheat	40416	4185	8641	386	1.46	11.5
Irrigated barley	7691	2803	7358	255	0.72	14.4
Rain-fed barley	1227	649	0	104	0.08	14.4
Grain corn	176	9528	7811	682	3.45	21.8
Irrigated lentils	11	848	9547	272	0	18.7
Rain-fed lentils	245	214	0	129	0	10.5
Sugar beet	3572	51747	18056	516	4.57	55.1
Cucumber	90	30067	10528	604	5.78	83.1
Onion	319	53713	16245	646	5.23	98.5
Tomato	3369	54206	13358	655	7.76	77.7
Alfalfa	1824	7873	19509	235	0.51	28.1
Fodder corn	6354	54131	13358	596	1.99	21.5
Bean	25	1733	13264	219	4.32	28.1
Rice	17104	6000	16962	500	7.46	38.1
Canola	638	2530	7545	503	2.44	15
Potato	43	33712	20000	655	2.79	40

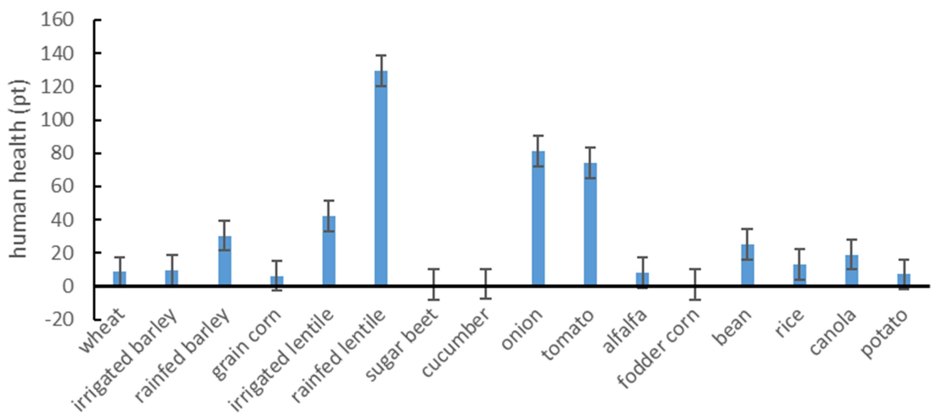

Figure 2. The effects of crops on human health index.

machines and butachlor herbicides contribute to this destruction.

The ecosystem quality index of different crops was between 0.03 and 3.64 PT obtained by alfalfa and onion, respectively. The average ecosystem quality index of crops in Shiraz Plain was equal to 0.978 PT. From the ecosystem quality viewpoint, alfalfa, sugar beet, and cucumber were the most suitable crops for this area. The ecosystem quality index of wheat, Irrigated barley, rain-fed barley, and rice was obtained equal to 0.337, 0.351, 0.777, and 0.544, respectively. Pesticides and chemical fertilizers are commonly used in agriculture, but they have negative effects on the environment by harming non-target organisms and reducing ecosystem quality.

Rain-fed lentils, tomatoes, and onions had the highest impact on resource depletion in

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this region, while the lowest value of the index was related to fodder corn. The effects of the agricultural production system on the resource consumption index varied between 0.031 and 3.040. In addition, the average resource depletion index of crops in Shiraz Plain was equal to 0.799. Agricultural machinery consumes a lot of non-renewable energy in planting, maintaining, and harvesting crops. Fertilizers like urea, potassium sulfate, and triple superphosphate also contribute to resource depletion.

Optimal Cropping Pattern

The weight of different economic-environmental objectives to solve the multi-objective planning model is presented in Table 2.

The economic model found that cropland areas of rice, irrigated lentils, and cucumbers are growing, while sugar beet, alfalfa, and onion are not suitable due to high input consumption and production costs. In other words, in an economic optimal model, the desired economic goal can be achieved by replacing the crops with higher prices and profitability with crops with lower gross margins. The proposed wheat crop area in Shiraz Plain is 6.28% less than the baseline. Barley crop areas decreased by 6.81% for irrigated and 6.67% for rain-fed. The rice cropland area increased to 23,369 hectares.

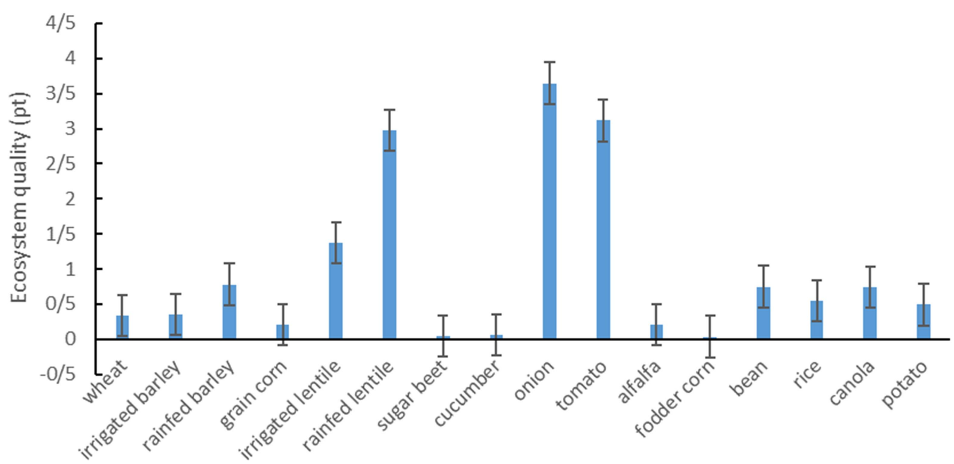

Figure 3. The effects of crops on the ecosystem quality index.

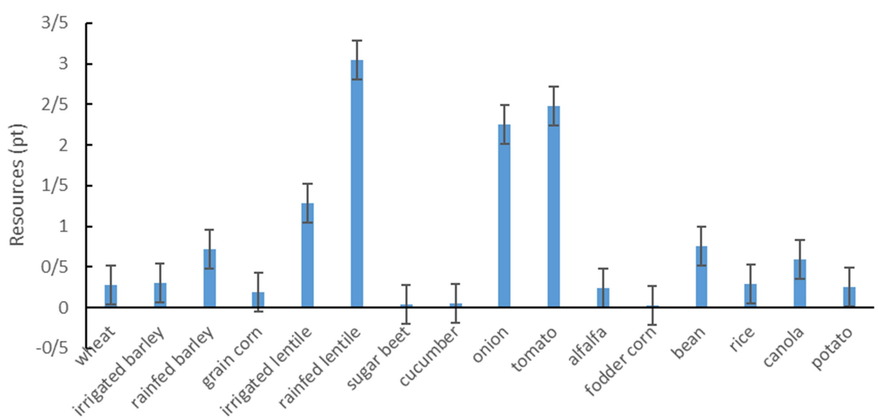

Figure 4. The effects of crops on resources index.

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Table 3. Optimized cropping pattern and the base year cropping pattern in Shiraz Plain (Hectare).

Crops	Baseline	Maximizing GM	Minimizing water	Minimizing Fertilizer	Human health model	Ecosystem quality model	Resources model	**Mixed model**
Wheat	40416	37881.1	35758.8	33738.2	40414.9	40414.9	36689.3	33116.6
Irrigated barley	7691	7166.5	6713.8	6937.7	7645.8	7645.8	6941.1	6265.1
Rain-fed barley	1227	1145.1	1459.5	0	1221.6	1221.6	1109.1	1001.1
Grain corn	176	164.3	1408.4	146.3	175.3	5244.3	159.1	143.6
Irrigated lentils	11	706.6	7.2	0	8.3	8.3	7.5	6.8
Rain-fed lentils	245	225.9	211.6	201.1	241.1	241.1	218.7	197.4
Sugar beet	3572	0	2919.1	0	0	0	0	0
Cucumber	90	389.4	78.8	74.9	89.7	89.7	81.4	340.4
Onion	319	0	0	0	318.3	247.9	0	0
Tomato	3369	272.6	3225.8	242.8	3355.2	3425.6	8343.7	238.3
Alfalfa	1824	0	0	2775.1	1356.7	448.3	0	1498.1
Fodder corn	6354	5920.1	5546.2	5272.6	8863.5	6316.13	5733.8	5175.5
Bean	25	23.4	36.4	34.6	0	25.1	22.7	20.4
Rice	17104	23369.1	15018.6	19390.5	18741.6	17103.4	15526.7	19542.5
Canola	638	592.1	554.6	524.2	631.6	631.6	573.3	517.5
Potato	43	40.2	37.7	35.8	42.9	42.9	39.1	35.2
Total	83107	77896.7 (%-6.26)	72977.1 (%-12.18)	69374.3 (%16.52)	83107 (%0.00)	83107 (%0.00)	75445.8 (%-9.21)	68099.1 (%-18.05)

Lentils were suggested to be cultivated in 706 hectares of irrigated land and 225 hectares of rain-fed land. Increasing the cucumber cropland area to 389 hectares can boost profits. Canola crop area decreased by 7.21% to 592 hectares. Potato and tomato crop areas were 40 and 272 hectares, respectively. Grain corn and fodder corn crop areas decreased by, respectively, 6.61 and 6.82%. Overall, the cropland area decreased by 6.26% due to economic considerations.

The minimizing water consumption model shows reduced cropland for most crops, except barley, beans, and grain corn. Wheat and rice areas decrease by 11.52 and 12.19%, respectively. Due to the importance of wheat in the public's diet, this product has always been of great importance in policies in the agricultural sector. Barley areas change by -12.70% (irrigated) and +18.95% (rain-fed). Sugar beet is a main crop in this model, while cucumber, tomato, and potato areas decrease. Beans experience 45% growth.

The total area under cultivation of crops in the third optimal pattern decreased by 16.58% compared to the current conditions. The cultivated area of most of the crops decreased, and rain-fed barley, irrigated lentils, sugar beet, and onion were not prioritized for cultivation. It is notable that the area under cultivation of alfalfa, beans, and rice had an increase compared to the baseline. Unlike other proposed models, in this model, the alfalfa crop had an increase in the cultivated area. As well as, the cultivated area of potato, tomato, grain corn, and fodder corn in the optimal cultivation model ensures minimization of the consumption of chemical fertilizers by 35, 242, 146, and 5272 hectares, respectively. All available agricultural land was used in the optimal model that reduces harmful effects on human health and ecosystem quality. Sugar beet was removed from the cultivation pattern, and the area under cultivation of grain corn, tomato, fodder corn, beans, and rice were increased. In the sixth optimal cropping pattern, the cultivated area of most crops, except tomatoes, was reduced, and sugar beet, onion, and alfalfa were not suggested for Shiraz Plain. The total cultivated area in this model had 9.21% decrease compared to the base conditions. Finally, in mixed model, sugar beet and onion were removed, while rice and cucumber cultivation increased. Wheat cropland decreased by 18.06%, while rice cultivation increased by 14.25%. Canola cultivation decreased by 18.87%. The total cultivated area decreased from 83,107 to 68,009 hectares through economic and environmental optimization (Table3).

According Table 4, the economic model shows 6.26% reduction in crop area, leading to 6.66% less water consumption and 6.86% less chemical fertilizer usage. Meanwhile, the net economic benefit increases by 4.19%. Despite the increase in farmers' profits, the proposed cultivation pattern with an emphasis on economic considerations can also reduce the consumption of water and chemical fertilizers. Another important finding is that the greatest saving in water,

Table 4. The effects of cropping pattern on economic-environmental indicators.

	Crop pattern	GM (Million $)	Water (Million m^3)	Fertilizer (tons)	Pesticides (1000 Liter)	Cropland area (ha)
	Baseline	11.284	905.31	35307.14	253.29	83107
% Change	Economic model	+4.19	-6.66	-6.86	+0.15	-6.26
	Minimizing water	-12.10	-14.12	-10.85	-10.81	-12.18
	Minimizing fertilizer	-11.43	-14.06	-18.06	-14.90	-16.52
	Human health	-0.75	-3.01	-0.70	-0.04	0.00
	Ecosystem quality	-3.15	-2.73	-1.42	-0.37	0.00
	Resources	-4.53	-12.05	-5.89	-0.31	-9.21
	Combined model	-11.43	-17.48	-19.31	-14.75	-18.05

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fertilizer, and pesticide consumption is reflected in the combined optimal crop pattern. Under these circumstances, with 18.05% reduction in cropland area, the amount of agricultural water consumption decreases by 17.48%. One of the main ways to manage water consumption in the country is to change the cropping pattern, given the water resources potential in each region and optimizing the productivity of water used in the agriculture sector. Economic and environmental cropping patterns can be effective in this regard. However, the cost of saving water in the study area is 11.43% reduction in the net economic benefit. To pursue environmental objectives, policymakers must take into account that the main incentive for farmers is economic incentive. Therefore, policymakers must propose appropriate solutions to compensate for the economic losses of farmers.

DISCUSSION

The purpose of the current study was to determine optimal cropping patterns based on economic and environmental concerns in Shiraz Plain, where managing crop patterns is very critical due to periodic drought and deterioration of water and soil resources. Among the various proposed patterns, rice, wheat, barley, and corn are regarded as the primary products of the region. Based on the results, paying attention only to economic goals in the design of the cropping pattern will increase the consumption of pesticides, which The results of the farmers' profit maximization model showed that the optimal model has increased the consumption of pesticides in addition to increasing the farmers' profit.

This finding was also reported by Najafabadi *et al*. (2019) and Acosta Alba *et al*. (2019). In comparison with the economic cropping pattern, the environmental cropping pattern can significantly reduce the consumption of water resources and chemical fertilizers. By following the recommended cropping patterns, we can reduce resource consumption by 14.12% for water, 18.06% for chemical fertilizers, and 14.90% for chemical pesticides, leading to more sustainable and efficient agriculture. A comparison of the findings with those of other studies (Layani *et al*., 2023; Mirzaei *et al*., 2022) confirms the impact of changing cropping patterns on agricultural resource management.

In the optimal environmental model, the opportunity of strengthening the cultivation area of rain-fed barley, grain corn, rice, bean, and tomato crops in comparison with the current model was the most important change in the cultivation area. According to combined optimal objectives, given the reduction in wheat and canola cultivated area, it seems that increasing the yield per unit area of this crop to achieve self-sufficiency goals is essential. This study supports evidence from previous observations (Marzban *et al*., 2021).

The current cropping pattern has more crop diversity than the optimal pattern (due to the result that some crops were not prioritized in the optimal cropping pattern). This diversity itself is a solution to control or reduce risk in agriculture. The results also showed that a more specialized cultivation model could be used in the optimal economic model, while reducing the risk. The specialized cultivation model will also provide benefits such as specialized cultivation and economies of scale. The findings showed that changing the cropping pattern based on economic and environmental considerations can help reduce the consumption of water inputs, fertilizers, and chemical pesticides. Chen *et al*. (2022) demonstrated that achieving improvement in economic, social, and environmental indicators was possible by reducing the cultivated area. Although environmental goals such as reducing water consumption may not be considered as an immediate goal of farmers, in the long run, farmers can be convinced to reduce water consumption. Because of the drought conditions in Iran, it is not possible to support any increasing pattern of water consumption. It is notable that achieving the

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aim of reducing water consumption or similar aims that are important off-farm (for policymakers, for instance) decreases the potential for improvement in on-farm aims (maximizing net benefit). Therefore, policymakers must provide appropriate solutions to compensate farmers for economic losses. One of these solutions is to guide farmers to off-farm activities.

CONCLUSIONS

The main goal of the current study was to determine optimal cropping pattern by considering environmental and economic aspects. Based on the results, to promote sustainability in agriculture, it is advisable to decrease the cropland area. While the current pattern offers a greater range of crops, adopting the optimal pattern can lead to environmental sustainability in the long run by managing the use of agricultural water, chemical fertilizers, and pesticides. The results of this study can be a good guide for policymakers in regional planning for the agricultural sector. However, this study did not address whether social indicators influence farmers' decisions to alter their cropping patterns. Hence, it is recommended that future researches incorporate social objectives along with the economic and environmental objectives while modeling the optimization of cropping patterns.

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الگوی کشت پایدار با توجه به ملاحظات اقتصادی و زیست محیطی در دشت شیراز در استان فارس، ایران

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چکیده

یکی از مهم ترین تصمیمات کشاورزان، تخصیص منابع به صورت بهینه است که اغلب با تعیین الگوی بهینه کشت انجام می¬شود. هدف از این پژوهش، ارائه مدل الگوی کشت سازگار با اکوسیستم کشاورزی دشت شیراز استان فارس با کمی‌سازی اثرات زیست‌محیطی تولید محصولات کشاورزی با استفاده از رویکرد ارزیابی

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چرخه حیات است. نتایج LCA نشان داد که کشت محصولاتی مانند عدس، پیاز و گوجه فرنگی بیشترین اثرات منفی زیست محیطی را به همراه داشته است. شاخص کیفیت اکوسیستم برای محصولات در این دشت بین ۰/۰۳ و ۳/۶۴ متغیر بود. بیشترین تأثیر منفی کشت محصول بر کیفیت اکوسیستم مربوط به پیاز، گوجه فرنگی و عدس دیم بود. نتایج برنامه ریزی چندهدفه نشان داد که کشاورزان با کاهش سطح زیر کشت می توانند به اهداف اقتصادی خود و اهداف زیست محیطی سیاست گذاران دست یابند. با تغییر الگوی کشت به سمت الگوی پیشنهادی برای دشت شیراز در استان فارس، میانگین کاهش ۵/۶۰ درصدی سود پیش بینی شد. اما این تغییر گامی موثر در کنترل مصرف آب، کودهای شیمیایی و سموم دفع آفات است. دستیابی به کشاورزی پایدار از نظر شاخص های اقتصادی و زیست محیطی با کاهش سطح زمین زراعی و کاهش سود اقتصادی به ترتیب به میزان ۱۸/۰۵ و ۱۱/۴۳ درصد نسبت به شرایط پایه امکان پذیر است.

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