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Determination of the optimum cultivation pattern for increasing energy efficiency and reducing bioenvironmental contaminants (case study: Goharbaran Region, Sari)

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Abstract

Response to the need for healthy food for the growing population, given the limited supply of energy in crop production, and considering sustainable development in production, it is necessary to plan and model a production in a region. This study was conducted with the priority of environmental protection in order to achieve sustainable cultivation of crops in the southeastern margin of the Caspian Sea between the two rivers of Nakh river and Tajan. The results of this research indicate that the current cropping pattern in the region is different with the optimal patterns in terms of cultivars, use of pesticides and fertilizers, and the volume of use of agricultural water. To optimize, each cultivar must be modified to reduce the pollution of agricultural waste that passes through the canal to the Caspian Sea. Reducing rice cultivation from 1.7 to 0.214 hectares for sustainability of production in the environmental model, increasing the cultivation of garlic in the pattern of water reduction from the results of this study. Also, by reducing the available water for agriculture by 30% of the current conditions, the rapeseed and garlic cultivation pattern is reduced by 4.5% and 26.4%, respectively.

Keywords: cultivation pattern, energy efficiency, bioenvironmental contaminants, environmental protection, pollution of agricultural

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INTRODUCTION

Sustainable production of agricultural products has been realized as one of the most primary challenges in the face of the mankind during the recent century. The amount of energy used and the rate of net income are of great importance and particular superiority as two important sustainability components of the agricultural systems. Although optimization of them enables sufficient supply of food for the currently growing communities, the bioenvironmental problems arising from the increase in immethodical use of agricultural inputs cannot be avoided. Therefore, in order to achieve sustainable development while preserving the ecosystem and the environment, the social and economic factors should be taken into account and the correct use of the agricultural and ecological inputs should be underlined in local, national and global levels. It is based on this same issue that the satisfaction of the healthy food needs of the growing population, considering the scarcity of the energy resources in producing agricultural products and paying attention to sustainable development in production, should be carried out based on a production plan and model even in regional scale (Lewandowski et al. 1999).

Water is one of the important resources in the production of agricultural products. Water is a rare natural resource that is also vital and renewable and plays an important role in the economic development of the countries. The demands for water are increased with the growth in global population. Therefore, having a

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paradigmatic plan based on the specified objectives can enable positively responding to the demand and supply of water (Abdullahi Ezzatabadi and Jvanshah 2000, Mollaqasem et al. 2014). Moreover, a great many of the existent challenges arise out of the allocation of this vital liquid to various sectors (Savenkova et al. 2018, Shirzad and Sabohi 2008).

Singh et al. (2001) utilized linear planning model to estimate the optimum cultivation pattern aiming at maximizing the net incomes in a region in Pakistan. In their model, the amount of land and minimum wheat and rice cropping to serve the food needs of the farmers were considered as the model constraints. Based on their results, the region wherein wheat had been grown was found the most profitable.

Tanpakan et al. (2006) performed a study in a region in northeast India using ideal planning to determine the products that consume the highest amount of energy available in the village and at the same time are followed by the highest cash revenue. The results indicated that if the emphasis is on the maximization of products the consumable energy of which is vastly produced in the village, those products should be cropped the inputs of which are available in the immediate periphery. Furthermore, manures produced in the village should also be used in lieu of the chemical fertilizers (Laughlin Mc et al. 1997).

Alam et al. (2005) conducted a study in Bangladesh in a time span from 1980 to 2000. The obtained results indicated that the energy efficiency during these years has gone down from 11.28 to 8.1 and Cruse (2004), as well, figured out the relationships between the energy policy-making in agriculture sector.

Sink et al. (2004) showed in a study that the use of highly fruitful varieties, compact systems, increase in fertilizer use and chemicals and high levels of agricultural mechanization bring about an increase in energy consumption in modern agriculture.

As a closed basin, Caspian Sea is drastically influenced by processes taking place in its watershed. Population growth in the cities in the margins of Caspian Sea, development of industries and use of fertilizers and agricultural chemicals on farms have caused the discarding of a large volume of sewage and wastewaters into the sea hence being followed by bioenvironmental pollution (Mora Stephen de 2004).

The researches by the others are also suggestive of the idea that Caspian Sea has been inflicted with bioenvironmental crises, including pollution by agricultural chemicals, oil and so forth. The existence of chemicals and minerals and heavy metals, enclosed nature of Caspian Sea and the entry of water from the shorelines pouring therein are amongst the important factors giving rise to the pollution of this sea (Karpinsky 1992, Soundararajan and Thankappan 2015).

The present study has been conducted with the objective of determining the sustainable cultivation pattern for the preservation of the environment in the studied region and the evaluation of the effects of these production resources on the sustainability of Caspian Sea ecosystem.

MATERIALS AND METHODS

The studied region, Goharbaran, is situated in Mazandaran Province, Sari County, and it is geographically positioned between the southeast coast of Caspian Sea and eastern side of Alborz Mountain Range. The selected region is auspicious for substantial cultivation of such products as rice, Soya, canola, wheat and clover. To determine the cropping system, a 2.8-hectare farm was chosen for the performing of a selected type of research in large scale and cultivation variables on this farm are X1=Rapeseed, X2=Wheat, X3=Clover, X4=Garlic, X5=Soya, X6=Rice.

The cultivation density coefficient in one agricultural year per every hectare of land in the region was in a range between 1.8 and 2.8 times the surface area available.

The mathematical functions used in the present study are of the ideal multipurpose optimization functions type. The method has also been used by others for solving the equations (Akoz et al. 2018, Bagheryan et al. 2005, Pal et al. 2008). Optimization is carried out in a systematic form on a collection of goals and it is called multi-target optimization or vector optimization (Marler and Arora 2004). The overview of the multipurpose planning pattern is as shown below (Francisco and Mubarik 2006):

$$\begin{gathered}\mathrm{Max:}\, Z(x) = (Z_1(x), Z_2(x), \ldots Z_h(x), \ldots Z_k(x), \\ Z_1(x) = Z1(x_1, x_2, \ldots, x_n) \\ Z_2(x) = Z2(x_1, x_2, \ldots, x_n) \\ . \\ Z_h(x) = Zh(x_1, x_2, \ldots, x_n) \\ . \\ Z_k(x) = Zk(x_1, x_2, \ldots, x_n) \\ \text{Subject to: } X \in F, X \geq 0\end{gathered}$$

where, Z is the objective function vector; Z_i is the individual objective functions of X_i with i=1, 2,…, n, and n is the number of products selected and X_i is the surface area under the cultivation of product i-th. Various methods are applied in different fields of study for solving a multipurpose optimization pattern.

Haimes et al. (1971) introduced a method named bound method that can be considered as an extension to constrained objective function. In this method, an objective function is optimized at each time and the other functions are added to the model as constraints. The change in the amounts of the constraints on the right side enables obtainment of a collection of Pareto optimization responses (Huanga et al. 2006). Therefore, the following formula shows the general form of a multipurpose model in a state where h-th objective is

Table 1. Estimate the amount of land for cultivation using minimum water consumption, minimum chemical fertilizer and chemicals pesticide use (bioenvironmental pattern) and energy use efficiency amongst the large-scale

Products	The current pattern (ha)	bioenvironmental pattern			
		optimum pattern minimum water consumption (ha)	optimum pattern minimum pesticide consumption (ha)	optimum pattern minimum chemical fertilizer (ha)	Pattern maximize energy efficiency
Rapeseed	0.6	0.341	0.35	0.364	0
Wheat	0.5	0	0	0	0
Clover	0.7	0.286	0.162	0.192	0.88
Garlic	0.3	0.48	0.395	0.42	0
Soya	0.8	0.789	0.795	0.805	1
Rice(ha)	1.7	0.263	0.26	0.214	0

Table 2. Minimum water consumption, minimum chemical fertilizer and chemicals pesticide use (bioenvironmental pattern) and energy use efficiency amongst the large-scale

Patterns reviewed	The current pattern	bioenvironmental pattern			
		optimum pattern minimum water consumption	optimum pattern minimum pesticide consumption	optimum pattern minimum chemical fertilizer	Pattern maximize energy efficiency
gross output (million rial)	42668597.77	44154187	42714523	44490550	38018070
Variance (Risk)	8275391	8212444	8118024	7960657	8192146
water consumption M³	53200	17997	44991	44991	48325
Chemical fertilizer use (kg)	3210	2767.6	1317.03	2767.5	2965
Chemical pesticides use (lit)	46	36.04	36.02	15.8	44
energy efficiency	4	2.46	2.07	2.65	10.87

optimized out of k objectives and k-1 remaining objectives are considered as constraints:

$$\begin{gathered}
\text{Max: } Z_{(h)} = (x_1, x_2, \dots, x_n), \\
Z_1(x_1, x_2, \dots, x_n) \geq b_1 \\
Z_2(x_1, x_2, \dots, x_n) \geq b_2 \\
. \\
. \\
Z_{h-1}(x_1, x_2, \dots, x_n) \geq b_{(h-1)} \\
Z_{h+1}(x_1, x_2, \dots, x_n) \geq b_{(h+1)} \\
. \\
. \\
Z_k(x_1, x_2, \dots, x_n) \geq b_{(k)} \\
x \in F \\
x \geq 0
\end{gathered}$$

where, b_h is the right-hand side constraint of i-th objective function. In case of finding an identical response to the multi-objective problem, it would be the very Pareto optimum (Mitnine 1999: 386). But, no single answer is found in the majority of the cases and a set of optimal responses are achieved rendering it necessary to make use of supplementary methods for selecting an objective. The present study has been conducted using the data collected from the region that were analyzed in Excel and LINGO software packages.

RESULTS AND DISCUSSIONS

The vast spectrum of the optimization functions allows each researcher readily and easily to work with his or her decision on each of the intended objectives under different conditions of patterns so that the objective can be eventually accomplished.

Tables 1 & **2** summarizes the results of the optimum patterns for each of the objectives. The differences in the patterns' conditions are attributed to the optimum answers found for the three bioenvironmental patterns. The variations trends in using the inputs linearly change with the fluctuations in water use. The current pattern is reflective of the idea that the farmers are making an overly large use of fertilizers and chemicals on their farms and the specified pattern should be used for reducing these inputs, as the primary causes of bioenvironmental destruction, so that the surface area under cultivation can be changed. In this pattern, the agricultural water use amounts to 53200 cubic meters per hectare.

In optimization of using production resources, or the very bioenvironmental patterns, and investigating the energy efficiency maximization pattern, wheat cultivation is eliminated for the reason that its cropping takes a long period of time and also because its guaranteed purchase rates are very low. In maximizing the energy efficiency, the present study results indicated that canola, wheat and garlic cultivation are completely put away and only soya and clover cultivation were taken into consideration respectively for one hectare and 0.88 hectare.

Although garlic cultivation is followed by a higher rate of income, especially during the recent years, based on the study results, the product should be assigned with a larger surface area under cultivation under any circumstances in consideration of the current statuses. All of the products mentioned in the aforesaid table should undergo changes in cultivation area in various optimal patterns but the gross output in the optimum pattern indicating the minimum agricultural chemicals' use is more than the other patterns. When our objectives are determining the best bioenvironmental patterns for reducing the agricultural wastewater, the table makes it clear for us that revisions should be brought about in the cultivation of products featuring the highest wastewater

Table 3. The surface area under cultivation and output rates of the current patterns, optimum pattern of maximum output, minimum risk and energy efficiency amongst the exploiters owning large-scale lands in various levels of water consumption

Products	Current pattern of available water conditions	The first model is reduced to 30% of water resources	The first model is reduced to 40% of water resources
Rapeseed	0.6	0	0
Wheat	0.5	0	0
Clover	0.7	0.329	0.357
Garlic	0.3	0.451	0.45
Soya	0.8	0.818	0.82
Rice	1.7	0.247	0.24
gross output (million rial)	0.1449	0.15391	0.1541
Variance (Risk)	8275391	7458462	7407934

production and fertilizer, chemicals and water application or, in other words, the conditions should be changed so that the least use be made of the inputs damaging the environment. As it has been demonstrated in the other researches, agricultural wastewater is the primary factor contributing to the environment destruction and increase in Caspian Sea pollution in this region. Based thereupon, it was determined in this cultivation pattern that cropping rice, canola and clover should be decreased and, in opposite, garlic and soya cultivation should be increased to some extent so that the gross output could be maintained. The best conditions of environment conservation are obtained using the cropping pattern prescribing the reduction in chemicals and chemical fertilizers' use following which the bioenvironmental goals are best served.

Water resources available for agriculture in the region are the primary causes of leaching of the minerals in chemicals and fertilizers as a result of which these minerals are carried to the Caspian Sea in the wastewater streams and/or drainage channels the result of which is the destruction of the Caspian Sea ecosystem and its bioenvironmental jeopardy. In the present study, water was considered as the most important variable factor. We are faced with water shortage in which case and for such a reason as the reduction in water use, the experts and farmers should make use of optimum water use patterns along with devising of plans so that all the factors of production stability as well as the social, economic, cultural and bioenvironmental factors could be optimally observed. To do so, two patterns of reduction in agriculture water use were suggested herein for the region. The two 30% and 40% agriculture water use reduction patterns have been given in **Table 3**. The results indicate that the cultivation surface areas under the status quo of the conditions will be accompanied by reductions in water use upon the exercising of each of the water reduction patterns in such a way that the highest descending trends have been documented for rice cultivation. Canola and wheat are discarded from the cultivation course and garlic cultivation is only increased by 1.5 times. The reason for increase in garlic cultivation is that the plant is in need of less water and the reason for canola elimination from cultivation course, as well, can be reasoned on the idea that the plant needs the highest amount of water during spring and, as it is known, water shortages peak during spring.

It can be inferred from the table that the cultivation of garlic and clover have been increased and decreased by 4.4% and 26.8%, respectively. The stability of rice cropping in the studied region is not apparently changed in terms of surface area under cultivation but the results are indicative of the idea that because environment preservation has also been taken into account, water use reductions in the region would surely cause reductions in surface runoffs, drainage and agricultural wastewater hence lowering of the Caspian Sea water pollution.

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