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OPTIMIZATION OF CROPPING PATTERN AND WATER RESOURCES USING LINEAR AND NONLINEAR PROGRAMMING IN THE WEST OF IRAN

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Abstract

In this research, to save water resources and increasing net income, a linear and nonlinear programming model for optimizing three scenarios including existing cropping pattern, agriculture ministry policies and suggested pattern was used for the irrigation levels of 100%, 90%, 80%, 70%, 60% and 50% in the downstream lands of Doyraj Dehloran reservoir, Ilam province in Iran. Net profit changes for the nonlinear programming model related to the linear model for the ministry of agriculture policies and suggested scenarios decreased 0.86% and 2.83%, respectively at full irrigation and 80% irrigation as the optimal treatment, Increased 3.3% and 5.77%, respectively. Water saving changes from nonlinear programming model compared with linear model at all low irrigation treatment in the suggested scenario was increased with at least 0.8% and 1.55% for 90% low and 60% low irrigation, respectively. Generally, in this research nonlinear programming model relative to the linear model at suggested and agriculture ministry policies scenario related to existing crop pattern had increased both the net profit and water saving.

***Keywords*:** Low irrigation, Net profit, Water consumption

Introduction

The most important challenge for the agricultural division in the current situation is to produce more food using less water. This target will only be realized if suitable solutions are used for more efficient use of water resources in the agricultural sector. With the scarcity of water, the need to use more appropriate mechanisms to allocate and exploit water resources is felt more (Dehestani *et al.*, 2011).

Full irrigation can be used to obtain the maximum production per unit area that is related to the plant's genetic capacity in areas where adequate water is available. Different models and methods have been presented to optimize the pattern of cultivation in a plain or region. Researchers have been using linear and nonlinear programming methods to optimize cropping patterns to save water and maximize net profit from agricultural land (Birhanu *et al.*, 2015).

Schreedhar (2015) used linear programming to optimize the cultivation pattern in the Marandia region of India, taking into account the constraints on cropping land, seed, water availability, chemical fertilizers, labor force and pesticide to maximize net profit.

Safavi and Falsafioun (2016) Using a combination of surface water and underground water under low irrigation conditions for wheat, barley, onion, and alfalfa products in the Nokobad area under the Zayandehrud region of Isfahan using multi-objective genetic algorithm, reducing water consumption and maximizing profit net check.

Osama *et al.* (2017) In optimizing the cropping pattern using linear programming, they could achieve a net annual profit for 28 products in five years (taking into account the spatial variation of the products) need for water, products yield and food requirements to maximize.

Banihabib *et al.* (2012) Used a nonlinear programming approach to optimize water allocation and cropping pattern under low irrigation conditions in Tehran and Alborz provinces, the results showed that by changing the pattern of cropping of the products and using the low irrigation technique, the economic benefits of the agricultural sector of Tehran province increased 23.5% in comparison with the current conditions of cropping and irrigation patterns.

Garga and Dadhich (2014) Used low irrigation and nonlinear programming to optimize the pattern of cropping and surface water and groundwater resources in the Indus area of India. Their results showed that the net profit of the optimal cropping pattern compared to the existing pattern 92.5% increase.

Parhizkari *et al.* (2015) considered low irrigation with available water reduction and nonlinear programming for optimizing water resources and cropping patterns under the scenarios 10, 20, 30 and 40 percent on the existing cropping pattern. The results showed that the use of a low irrigation method with reducing irrigation water available, although it leads to a reduction in farmers' Gross profit, helps to maintain the surface water resources of the Qazvin plain of Iran.

Darani *et al*. (2017) used an integrated optimization-simulation model (PMP and WEAP) for investigating the effect of the network marketing reform on cropping pattern and groundwater resource in Neyshabur plain and the results of this research revealed that the cultivated area of crops with high marketing margin was increased. The results of the hydrological model simulations (WEAP model) showed that the change in cropping pattern (due to marketing network reform) made increase water use in the Neyshabur basin and increase pressure on groundwater.

Dehloran plains are located in warm and dry regions of Iran and have both fertile lands and a high potential for agricultural production. In this research, due to the lack of water resources and appropriate cropping pattern for Doyraj Dehloran region in the province of Ilam, located in the southwest of Iran, in the dry region, a linear and nonlinear programming model comparing the results of the models in order to optimize water allocation and increased net profit for optimal cropping pattern was used under low irrigation scenarios to help reduce water consumption and increase revenues to maintain surface water and underground water resources. Also, in this research investigated the effect of different cropping pattern on water resources simulated with MODSIM model. In This research has been resulted from Ph.D. Dissertation in some plain of Dehloran of Ilam province in the west of Iran at 2017-2018 years.

Materials and Methods

The study area is located in the southwest of Iran in Dehloran city of Ilam province. The elevation of the studied area is 230 meters. The annual rainfall of the region is 262.5 mm, the average temperature is 46.6 ºC in July and the minimum temperature is 8.3°C in January. The climate of the region is dry based on the method of the Demartonne method. Doyraj irrigation network located in Ilam province, Dehloran, with a geographical position of 47 degrees and 17 minutes to 22 minutes' east latitude and 32 degrees and 32 minutes to 37 minutes' north latitude. The net area of the irrigation network is 10,680 hectares and the annual water allocation is 123.6 million cubic meters per year, of which 102 million cubic meters is from the water of Doyraj Dam and 21.6 million cubic meters from 61 agricultural water wells. (Ministry of Energy, Ilam Regional Water Authority, 2006). To calculate the water requirement of the cropping pattern by extracting the initial values of growth coefficients from the 56th World Food Code (Allen *et al.*, 1998) for each product and using 23-year statistical data (1972-1953) from the Dehloran Meteorological Station, the climate parameters of wind speed at 2 meters' height and relative humidity and plant height, the coefficients of the middle and final stages of growth were calibrated for the products of the study area. For irrigation sensitivity coefficients of the products mentioned in the cultivar patterns, Use of data from Journal No. 66 World Food Organization (FAO) (Steduto *et al.*, 2012) and the length of different stages of growth were used of data from the Agricultural Research Center of Ilam province (Ministry of Jihad-Agriculture, 2015). According to data of vaporization and transpiration reference plant and the results of field soil experiments, which are often in the sandy loam soil texture class. As well as modified vegetation coefficients and agronomic calendars were correlated with the values of the FAO publication 56 for a dry climate. Also modified Vegetarian coefficients and developing the agricultural calendar with FAO publication number 56 has been adapted to the dry climate And by measuring the irrigation efficiency during the growing season in 2017-2018 in 8 farms, Which was carried out by the inlet and outlet method In the area covered by the irrigation network reservoir was located at a level of 10,600 hectares, which was often irrigated by border method and application efficiency parameters, water requirement efficiency, irrigation adequacy, runoff rate, amount of deep penetration losses was obtained. According to the data of evapotranspiration of the reference plant, the results of field experiments, modified plant factor and crop calendaring, calendar compilation in consultation with the researchers at the agriculture research center and its compliance with the values outlined in the 56th FAO, for hot and dry climates, according to the measured values of the water application efficiency of tested farms and synoptic climatic statistics with 30 years, the water requirement of the cropping pattern of the using the CropWat software Version 8 by the FAO Penman-Monteith method is shown in Table1. In this research, a linear and nonlinear linear programming model was used for optimization. Optimization was carried out in three scenarios for the existing cropping pattern, the Ministry of Agricultural (Policies) and suggested cultivar with a low irrigation level of 50%, 60%, 70%, 80 %, 90% and 100% water requirement and the LINGO software version 14 was used. To obtain the yield of each product for different irrigation amounts, (Jensen, 1968) equations (1) and (2) were used.

$$1-\frac{Y_a}{Y_m}=K_y\left(1-\frac{ET_a}{ET_m}\right) \quad ...(1)$$

Where Y_a: the actual yield of the product (kg/ha), Ym: maximum yield (kg/ha), ETa: actual evapotranspiration (mm), ETm: maximum evapotranspiration (mm), Ky: coefficient the plant's sensitivity to dehydration. To calculate the sensitivity of the plant to dehydration throughout the growth period, the relation 2 has been used (Jensen, 1968).

$$\frac{Y_a}{Y_m}=\prod_{i=1}^{N}\left[1-K_{y,i}\left(1-\frac{ET_{a,i}}{ET_{m,i}}\right)\right] \quad ...(2)$$

Where K_y, i: the sensitivity of the plant to dehydration at different stages of growth and N: the number of stages of plant growth. Production costs, growth period and planting date and harvesting of cropping pattern were obtained through interviews with research center researchers, expert experts of the Department of Plant Production, and the Department of Statistics and Information of the Agriculture Organization of Ilam province, and were used in the calculations of this study. The net profit is the difference between the gross profit and the cost of production institutions, for the irrigation water level and the resulting yield from equation 3 for each crop (Najarchi, 2017).

$$N_r=Y_a\times C_p-\left(T_{ve}\times\frac{Y_a}{Y_m}+L_e\times N_i+F_e+W_C\times G_V+E_W\times G_V\right) \quad ...(3)$$

Where N_r: net profit for each product (Rials per hectare), Y_a: actual product yield (Kilogram per hectare), C_p: price Product (Rials per Kilogram), T_{ve}: Total variable costs to achieve the highest yield (Rials per hectare), Y_a/Y_m The ratio of the product's actual yield to the maximum yield, Le: Labor cost per irrigation (Rials per hectare), N_i: number of irrigation for each product, Fe: fixed costs of each product (Rials per hectare), W_c: irrigation water cost (Rials per cubic meter), G_v: gross irrigation volume, and E_w: cost Transfer and Distribution and Application of Irrigation Water (Rials per hectare). Using the above equation, net profit was calculated for each product for 50%, 60%, 70%, 80%, 90% and 100% water requirement. According to the economic studies of the reservoir dam and Doyraj Dehloran irrigation network, the cost of each cubic meter of water up to the farm's head for the studied area is 1,054 Rials (Ministry of Energy, Ilam Regional Water Authority 2006).

Profit function of irrigation water

The relationship between net profit and consumed water for each product was obtained through linear and nonlinear regression. Based on this, the function of the relative performance of the products is calculated and shown in Table

2. Net profit was derived from equation 4 for the linear programming model and equation 5 for the nonlinear programming model (Najarchi, 2017).

$$N_{ri} = a_0 + a_1 w_i \quad ...(4)$$

$$N_{ri} = a_0 + a_1 W_i + a_2 W_i^2 \quad ...(5)$$

Where N_{ri}: the net profit or profit function for (i) product in per thousand Rials per hectare a_2, a_1, a_0: fixed coefficients, and W_i: the water used for (i) product. The objective function of the model is to maximize the net profit from the cultivation of different products as follows:

$$MaX{:}\,Z = \sum_{i=1}^{n} N_{ri} \times A_i$$

In this equation Z: Net profit, Ai is the cropping area of (i) product per hectare.

Constraint in available water

$$\sum_{i=1}^{n} w_i \times A_i \leq NIW$$

Where: W_i Water requirement for the product (i) per hectare and NIW: Available net volume of water. The total amount of available water from reservoir dam and agricultural water wells was 123.6 million cubic meters per year as a limit to the model, which is changed due to different levels of irrigation in optimizing the cropping pattern.

Land constraint

$$\sum_{i=1}^{n} A_i \leq A_t$$

At: Total available land for cultivation. The limits of agricultural land are included in the model concerning the total area of the network and the surface area that is considered as a fallow each year. The highest value for a condition that does not include any level of fallow for the model is equal to 10,680 hectares.

Constraints on the suggested cultivation pattern of the Ministry of Agricultural

To determine the levels of the Ministry of Agriculture cropping pattern by interviewing the plant production manager of the Ministry of Agriculture Organization of Ilam province and by adopting upstream policies for the study area, the following constraints were considered in the Ministry of Agriculture cropping pattern. Ministry of Agriculture cropping pattern has now been implemented in the region.

Constraints on autumn cultivation for full irrigation

A_1: Wheat cultivar up to 50% of the total area $A_1 \leq 0.50 \times A_t$

A_2: The surface area of the barley cultivar with a maximum of 5% of the total area

$A_2 \leq 0.05 \times A_t$

A_3: Rapeseed cultivars up to 17% of the total Area.

$A_3 \leq 0.17 \times A_t$

A_4: Sugar beet cultivar with a maximum of 20% of the total area

$A_4 \leq 0.20 \times A_t$

A_5: Bean cultivar with a maximum of 5% of the total area

$A_5 \leq 0.05 \times A_t$

A_6: Potato cultivar with a maximum of 1.5% of the total area

$A_6 \leq 0.015 \times A_t$

A_7: Onion cultivar with a maximum of 1.5% of the total area

$A_7 \leq 0.015 \times A_t$

The water needed for the autumn cropping pattern of the Ministry of Agriculture was optimized concerning the Constraints of 82.1 million cubic meters.

Constraints Ministry of Agriculture pattern in summer cultivation for full irrigation

The remaining water resources of the reservoir dam and agricultural wells were 41.4 million cubic meters optimized for summer cultivation, taking into account the constraints, 70% corn and 30% sorghum. In summer planting, two products of corn and forage sorghum have been considered. A_{10}: corn, equivalent to 70% of the total cultivated area

$A_{10} = 0.7 \times (A_{10} + A_{11})$

A_{11}: Forage sorghum, equivalent to 30% of the total cultivated area

$A_{11} = 0.3 \times (A_{10} + A_{11})$

Constraints suggested cropping pattern

Regarding the potential of mechanization of the agricultural sector and the start of construction of sugar production factories in the study area and the effect of crop rotation, the following level of cultivation restrictions in the suggested model was considered for optimizing net profit compared to the cropping pattern. Also, concerning, this pattern implements by the production cooperation, therefore farmer have not role in the selection of cropping patterns

Constraints on winter cultivation for full irrigation

The remaining water resources from the reservoir dam and agricultural water wells were allocated to a strategic corn product with the following fixed surface percentage. A_1: Wheat is at least 20% of the total cultivated area

$A_1 \geq 0.2 \times A_t$

A_2: Rapeseed is at least 30% of the total cultivated area

$A_2 \geq 0.3 \times A_t$

A_3: Autumn sugar beet up to 50% of the total surface area

$A_3 \leq 0.5 \times A_t$

Maximum cultivated surface $A_1 + A_2 + A_3 = 10680$

According to supplements of inputs especially water availability, also suitable lands, fallow has not considered for the winter cropping pattern.

Suggested model constraints in summer cultivation for full irrigation

Corn with a constant level of 17% of the total $A_4 = 0.17 \times A_t$

In summer pattern, due to the shortage of water resources, just content of 17% of total available lands allocated to maize cultivation and remains of land considered as the fallow. In the process of optimizing the net profit resulting from water requirement scenarios, this study was considered to be 10,680 hectares for the cultivated area and saving water saved from the optimization of irrigation scenarios in reservoirs and wells.

Optimizing water resources

Using MODSIM software version 8, the optimization and simulation of the amount of water in the reservoir dam and agricultural water wells were used to provide the required monthly water supply of the cultivar scenario products.

Results and Discussion

Results Net profit of cropping patterns

The net profit of the products the cultivation patterns for Full irrigation are shown in Figure 2. The minimum and maximum net profits of products in the cultivar pattern for the studied area were 9160 and 100, 470 thousand Rials per hectare, respectively, for barley and sugar beet production in autumn. The amount of water is 430% of the net profit of wheat and therefore, in the Ministry of Agricultural plan and the suggested model, with an optimal level of 20% and 50% added and was reduced to 70% in comparison to the cultivated area under the Ministry of Agriculture cropping pattern and the suggested cropping pattern compared to the existing cropping pattern. Although the barley product was added to the Ministry of Agriculture cropping pattern as a forage product, it was removed due to the low net profit in the suggested cropping pattern.

Crop density in existing cropping pattern

The results of Table 2 show that in the scenario 100% irrigation for the existing cropping pattern, wheat with cultivar 90.3%, and corn in the second crop with 48.6%, respectively, has the highest values in crop density. Rapeseed production is 5.9%, and other products each with a minimum of 0. 93%. Crops cultivation of 15,968 hectares of cropping pattern with the density 148.5 percent was achieved.

Optimization of cultivar patterns in full irrigation scenario

The results of Table 3 show that in the Ministry of Agriculture (policies), the optimum level of 5,340 hectares of wheat cultivation is equivalent to 50% of the total land area and 40.3% have decreased relative to the existing cropping pattern. The barley product of 534 hectares, equivalent to 5 percent, has increased compared to the existing cropping pattern. The area under cultivation of rapeseed increased by 11.1% and the total area reached 1815.6 hectares. Autumn beets with an optimum level of 2136 hectares increased by 20% compared to the existing pattern. Bean grew by 5%, equivalent to 534 hectares and the cultivation of corn decreased by 29.6 percent compared to the existing cropping pattern and reached 203.3 hectares. Autumnal watermelon and tomato were eliminated from the cropping pattern and potato and onion products loss by 57%. Based on previous research at the studied area; all of the crops have a moderate to high suitable, therefore; the proposed cropping pattern is not restricted in terms of land suitability. The cultivars in this pattern reached 13583 hectares and cultivation density was determined 127.2% less than the density of the existing cropping pattern. In the suggested cropping pattern, barley, bean, potato, sorghum and other crops were excluded. In this model, the cultivated area of wheat is 2136 hectares, which is reduced by 3.70 and 30 percent, respectively, to the existing cropping pattern and the Ministry of Agriculture cultivation pattern. Rapeseed has increased by 3204 hectares, 24.1 percent compared to the existing pattern and 13 percent compared to the Ministry of Agriculture. The area under cultivation of autumn sugar beet in this pattern reached 5339.9 hectares, which increased by 50% and 30%, respectively, compared to the existing cropping pattern and Ministry of Agriculture pattern. The rotation period for suggested cropping pattern for the sugar beet crop was biennially considered and for the wheat and rapeseed as a four year at winter cultivation based on the research of (Koch *et al.*, 2018) the sugar beet can be considered in rotation period of 2, 3 years with other suitable crops without loss of yield. The corn yield decreased by 31.4% to the existing cropping pattern and fell 1.8% to the Ministry of Agriculture cropping pattern. Other crops of the suggested cropping pattern were removed due to low profitability. The density in the Ministry of Agriculture cropping pattern and the suggested cropping pattern were decreased by 14.3% and 20.1%.

Results of optimizing net profit and saving water consumption

The results of net profit and water savings obtained from the optimization of cultivars in tables 4 and 5 show that the net profit of the existing cropping pattern with the level of irrigation is 100% with the total volume of water resources (123.6 million cubic meters) equal to 383, 204, 500 thousand Iranian Rials in the linear programming model and it is equal to 37, 790, 510 thousand Iranian Rials for the nonlinear programming model. The net profit of the Ministry of Agriculture (policies) in the linear programming model for irrigation levels of 100, 90 and 80 percent, respectively, increased by 33.44, 16.08 and 15.1 percent, compared to the current cropping pattern and in irrigation levels of 70, 60 and 50 percent, irrigation requirements were reduced by 11.64, 22.6 and 31.94 percent, respectively. In this scenario, in the nonlinear programming model, net profit at irrigation levels of 100, 90 and 80% was increased by 32.58%, 18.55%, 45.4%, compared to the existing pattern, and at irrigation levels of 70, 60 and 50%, the irrigation required the order of 9.09, 21.73, and 26.23 percent respectively decreased. The net profit from the linear programming model in suggested cropping pattern for all irrigation levels of 100, 90, 80, 70, 60 and 50% of irrigation requirement was 99.86, 73.11, 50.38, 31.15, 14.91, 26.1% increased relative to the existing cropping pattern. The net profit from the nonlinear programming model in this scenario for the levels of 100.90, 80, 70, and 60% of irrigation requirements was increased by 97.03%, 77.13%, 56.15%, 35.5%, and 16%, respectively, and for irrigation levels, 50% decreased by 0.81% compared to the existing pattern. Water-saving in the Ministry of Agriculture cropping pattern for all irrigation levels of 90, 80, 70, 60 and 50 percent for both linear and nonlinear models were 18.1, 33.8, 47.2, 58.8, and 68.7 percentage is obtained. Saving water in the suggested cropping pattern for linear programming for irrigation levels of 90, 80, 70, 60 and 50 percent is 18.1, 33.8, 47.2, 58.8 and 68.7, respectively, such as the Ministry of Agriculture cropping pattern. In this scenario, water-saving for nonlinear models is 18.9, 35, 48.7, 60.4, 70.2%, respectively. The results of Table 6 and Figure 3 show that the minimum and maximum net profit changes in the nonlinear programming model compared to the linear model for the Ministry of Agriculture cropping pattern are -

1.32% and 3.3% at irrigation levels of 50% and 80% respectively, and for the suggested cropping pattern -3.11 and 5.77% respectively, are obtained at irrigation levels of 50 and 80% respectively. Water use changes in two linear and nonlinear models were not obtained in the Ministry of Agriculture cropping pattern. However, in the suggested cropping pattern, the nonlinear programming model obtained a decrease in the amount of water needed for all irrigation levels in comparison with the linear model. The maximum of these changes is -1.55% at irrigation levels of 80%. One of the reasons for the changes in the two models is the optimization of the area allocated to the Suggested Cropping Pattern products, use of products with low sensitivity to low irrigation (Ky) and also increasing the correlation coefficient in the Water Consumption Functions for Non-linear programming model Non-linear relation to the linear model.

Results of water resources simulation

The results of water resource optimization for the suggested cropping pattern are shown in Table 7. The highest volume of water required for the suggested cropping pattern in April was achieved for sugar beet and wheat, amounting to 28,216,560 cubic meters, of which 23,285,510 cubic meters is from the reservoir dam and 4,931,049 cubic meters of agricultural water wells. The minimum volume of water required in December was 4,015,679 cubic meters for rapeseed, of which 3,313,910 cubic meters is from the reservoir dam and 701,769 cubic meters of agricultural water wells. Also, the results of simulation of dam water and wells indicate that the supply of water to the suggested cropping pattern, Except for the treatment of 100% irrigation with 3.4% deficit, other treatments is not limited by water shortages.

Conclusions and Suggestions

The results of optimization of the cropping pattern using linear and nonlinear programming models showed that for a steady cultivation, the existing cropping pattern is not suitable for profitability and water saving for a warm and dry area. The results of optimization of cropping pattern and water resources in two Ministry of Agriculture cropping patterns and suggested in this study showed that the linear programming model in the suggested cropping pattern with low irrigation until Water requirements 50 percent, and nonlinear programming model with low irrigation until Water requirements 60 percent, Net profit is still greater than the profit from the conditions of the existing cropping pattern, In this situation, a large amount of water resources are saved and Stored. The results also show that the changes in profit from 60, 70, 80 and 90 percent of the need for water in the suggested cropping pattern have increased in the nonlinear programming model compared to the linear model and at all these levels of irrigation, the water changes required for the product of the cropping pattern is reduced to the linear model. The maximum of these changes was achieved at the level of 60% of water requirement and in the amount of 1.55%. The reasons for making changes in the results of the profit and water consumption in both linear and nonlinear programming models can be the effect of the sensitivity coefficient of the products to water stress during the growth period for the nonlinear programming model, which has a second degree power, as well as optimized levels in the suggested cropping pattern. Therefore, it is recommended to use a nonlinear programming model that is proportional to the water production Function used to optimize the cropping pattern and water resources.

Table 1 : Estimation of Water Requirement of cropping pattern in Irrigation and Drainage Surface Networks of Dehloran Plain

Crops	Net irrigation water (m^3. ha^{-1})	gross irrigation water (m^3. ha^{-1})	Net Irrigation frequencies (mm)	gross Irrigation frequencies (mm)	Irrigation frequencies (n)	Max Hydro module (L.S^{-1}. ha^{-1})
Wheat	4512	6847	60	109	7	1.12
Barely	2903	3934	60	109	5	1.03
Corn	5158	10074	50	91	9	1.64
Green Been	3403	5203	35	64	7	1.09
Onion	4012	6524	35	64	8	0.81
Sugar beet	6052	14042	60	109	8	1.50
Sorghum	1555	24099	80	145	14	3.04
Potato	4057	6630	35	64	8	1.06
Rapeseed	3317	4732	55	100	6	0.8
Tomato	3927	6070	45	82	7	1
Watermelon	2514	3407	55	100	4	0.9

Table 2 : The function of the net profit of products, relative to irrigation water

The correlation coefficient	Relative operation function	crops	The correlation coefficient	Relative operation function	crops
Nonlinear functions					
$R^2 = 0.997$	$N_r = -6E - 05W^2 + 5.3265 w + 10207$	Potato	$R^2 = 0.9959$	$N_r = -3E - 05W^2 + 2.8918 w + 5081$	wheat
$R^2 = 0.9978$	$N_r = -0.0002 W^2 + 7.2849 w + 5389$	Onion	$R^2 = 0.9933$	$N_r = -0.0006 W^2 + 7.5404 w + 14547$	Rapeseed
$R^2 = 0.9968$		Green Been	$R^2 = 0.9853$		Barely
$R^2 = 0.9954$	$N_r = -0.0008 W^2 + 11.802 w + 900.68$	Fall watermelon	$R^2 = 0.9904$	$N_r = -4E - 05W^2 + 2.5051 w + 740.5$	Corn
$R^2 = 0.9926$	$N_r = -8E - 05 W^2 + 5.1235 w + 4828.6$	Tomato	$R^2 = 0.9992$	$N_r = -4E - 05W^2 + 2.2588w + 4059.7$	Sorghum
			$R^2 = 0.9973$	$N_r = -0.0002 W^2 + 8.8783 w + 15066$	Sugar beet

	linear functions				
$R^2 = 0.9968$	$N_r = 4.8249w + 11182$	Potato	$R^2 = 0.9957$	$N_r = 2.5923w + 5681.3$	wheat
$R^2 = 0.9963$	$N_r = 5.7474w + 8334.2$	Onion	$R^2 = 0.977$	$N_r = 3.8934w + 19779$	Rapeseed
$R^2 = 0.9924$	$N_r = 3.6733w + 1119.4$	Green Been	$R^2 = 0.9757$	$N_r = 2.6064w – 835.47$	Barely
$R^2 = 0.9917$	$N_r = 8.0851w + 4843$	Fall watermelon	$R^2 = 0.9892$	$N_r = 2.0461w + 2037.3$	Corn
$R^2 = 0.9921$	$N_r = 4.450w + 6039.4$	Tomato	$R^2 = 0.9334$	$N_r = 0.2337w + 16710$	Sorghum
	-	-	$R^2 = 0.9853$	$N_r = 5.3173w + 285535$	Sugar beet

Table 3 : Area and Percentage of cropping patterns in scenario 100% need for water

Crops	Cultivation Surface (ha)			Cultivation (%)		
	Existing	**Policies**	**Suggested**	**Existing**	**Policies**	**Suggested**
Wheat	9648	5340	2136	90.3	50	20
Barely	-	534	-	-	5	-
Rapeseed	632	1815.6	3204	5.9	17	30
Sugar beet	-	2136	5339.9	-	20	50
Been	-	534	-	-	5	-
Corn	5189.9	2032.3	1869	48.6	19	17.2
Sorghum	-	871	-	-	8.2	-
Potato	100	160.2	-	0.93	1.5	-
Onion	100	160.2	-	0.93	1.5	-
Watermelon	100	-	-	0.93	-	-
Tomato	100	-	-	0.93	-	-
Cultivation Comparison	-	-	-	148.5	127.2	117.5
Total	15869	13583	12548	-	-	-

Table 4 : Comparison of Net profit outcomes from linear optimization, water consumption and saving three scenarios of existing cropping pattern, policies and Suggested

Cropping patterns	**Irrigation Level (%)**	**Net Profit (1000 of Rials)**	**Water consumption (m^3)**	**water Saving* (m^3)**	**water Saving* (%)**	**Increase profits (1000 of Rials)***	**Increase profits* (%)**
existing	100	383204500	123600000	0	0	0	0
Politics	100	511342900	123600000	0	0	128138400	33.44
	90	444838000	101221500	22378490	18	61633500	16.08
	80	387617700	81881860	41718140	34	4413200	1.15
	70	338585200	65234530	58365470	47	-44619300	-11.64
	60	296591900	50916060	72683940	59	-86612600	-22.60
	50	260799400	38657590	84942410	69	-122405100	-31.94
Suggested	100	765889400	123600000	0	0	382684900	99.86
	90	663372500	100250000	23349990	18.9	280168000	73.11
	80	576268900	80320250	43279750	35	193064400	50.38
	70	502582100	63381470	60218530	48.7	119377600	31.15
	60	440339700	49002880	74597120	60	57135200	14.91
	50	388031500	36857720	86742280	68.72	4827000	1.26

*Relative to the existing cropping pattern

Table 5 : Comparison of Net profit outcomes from nonlinear optimization, water consumption and saving three scenarios of existing cropping pattern, policies and Suggested

Water saving changes *(%)	**Net profit changes* (%)**	**Irrigation requirements scenarios (%)**	**Cropping Patterns**
0	-0.86	100	Politics
0.001901	2.47	90	
0.001504	3.3	80	
0.001373	2.55	70	
0.000898	0.87	60	
0.000664	-1.32	50	
0	-2.83	100	Suggested
- 0.786004	4.02	90	
- 0.263439	5.77	80	
- 1.499240	4.35	70	
-1. 547880	1.09	60	
-1.456205	-3.11	50	

*Relative to the existing cropping pattern

Table 6 : Comparison of Net profit and water consumption changes in Linear and nonlinear programming models

Cropping patterns	Irrigation Level (%)	Net Profit (1000 of Rials)	Water consumption (m^3)	water Saving* (m^3)	water Saving * (%)	Increase profits (1000 of Rials)*	Increase profits* (%)
Existing	100	377905100	123600000	0	0	0	0
Politics	100	501013700	123600000	0	0	123108600	32.58
	90	447993800	101223900	22376140	18	70088700	18.55
	80	394714400	81883720	41716280	34	16809300	4.46
	70	343549900	65235980	58364020	47	-34355200	-9.1
	60	295774900	50917170	72682830	59	-82130200	-21.7
	50	252231500	38658410	84941590	69	-125673600	-33.3
Suggested	100	744590300	123600000	0	0.00	361385800	97.03
	90	669388000	100250000	23349990	19	286183500	77.13
	80	590111300	80320250	43279750	35	206906800	56.15
	70	512080000	63381470	60218530	49	128875500	35.50
	60	438373200	49002880	74597120	60	55168700	16
	50	370927300	36857720	86742280	70	-12277200	-1.85

Table 7 : The volume of Water Required Monthly Scenario of suggested cropping pattern for 100% needs to irrigate through the dam and wells

Month	Need to irrigated Wheat (m^3)	Wheat Area (ha)	Need to irrigated Rapeseed (m^3)	Rapeseed Area (ha)	Need to irrigated Sugar beet (m^3)	Sugar beet Area (ha)	Need to irrigated Corn (m^3)	Corn Area (ha)	Dam Water (m^3)	Wells Wate (m^3)	dam and wells (m^3)
January	0	3204	0	2136	958	5340	0	3791.62	4221710	894009	5115720
February	740	3204	1880	2136	1017	5340	0	3791.62	9752239	2065180	11817420
March	2540	3204	1880	2136	2060	5340	0	3791.62	19107867	4046372	23154240
April	3720	3204	0	2136	3052	5340	0	3791.62	23285510	4931049	28216560
May	0	3204	0	2136	2090	5340	0	3791.62	9210203	1950396	11160600
June	0	3204	0	2136	0	5340	0	3791.62	0	0	0
July	0	3204	0	2136	0	5340	0	3791.62	0	0	0
August	0	3204	0	2136	0	5340	3439	3791.62	10760654	2278727	13039381
September	0	3204	0	2136	0	5340	3540	3791.62	11076684	2345651	13422334
October	0	3204	0	2136	975	5340	2229	3791.62	11271182	2386839	13658020
November	0	3204	0	2136	0	5340	0	3791.62	0	0	0
December	0	3204	1880	2136	0	5340	0	3791.62	3313910	701769	4015679
total									**101999959**	**21599992**	**123599955**

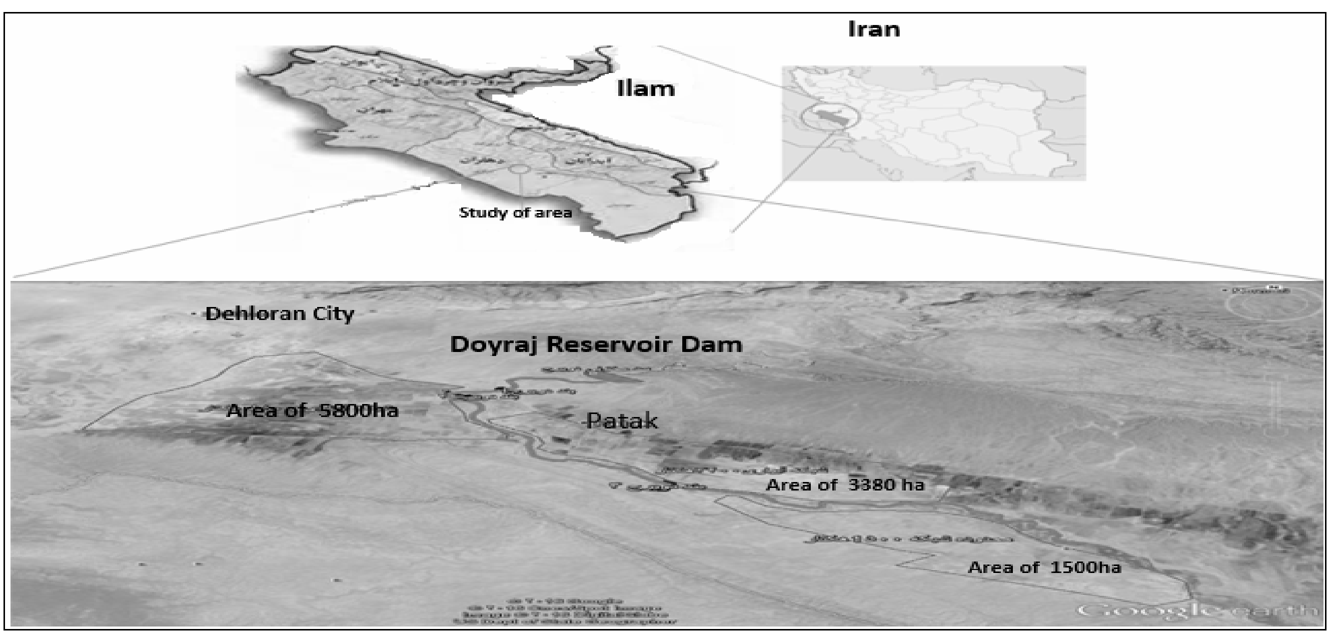

Fig. 1 : Location of the region in Iran, Ilam province and the distribution of the studied plains along with the location of Dam and Doyraj River on the satellite images of Google Earth

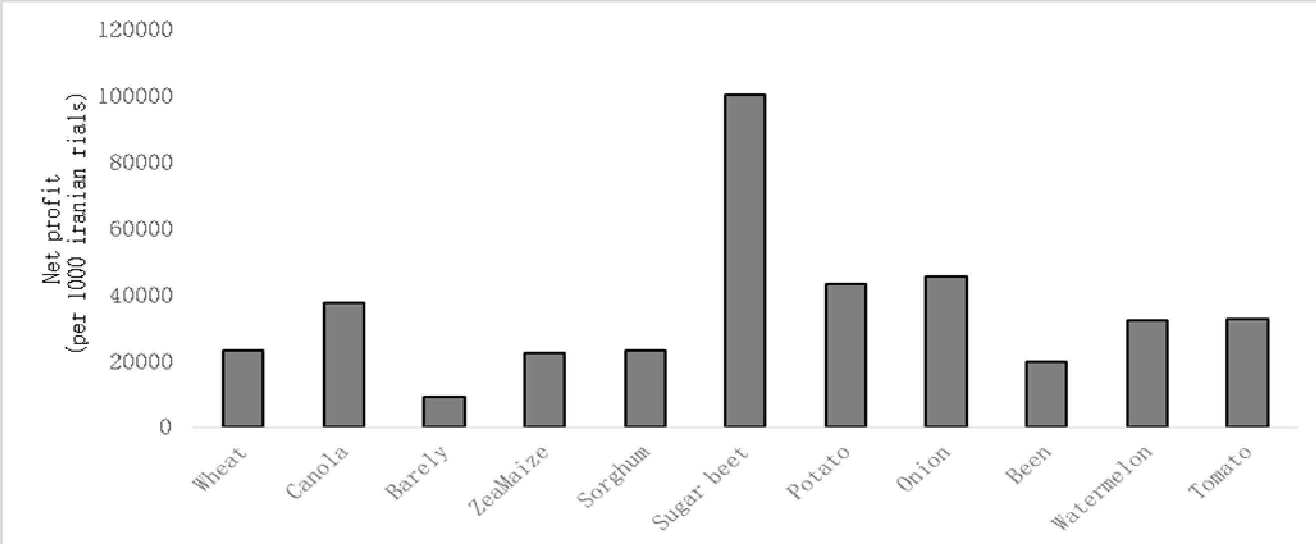

Fig. 2 : Net profit calculated (per thousand Iranian Rials) per hectare of cropping pattern Crops

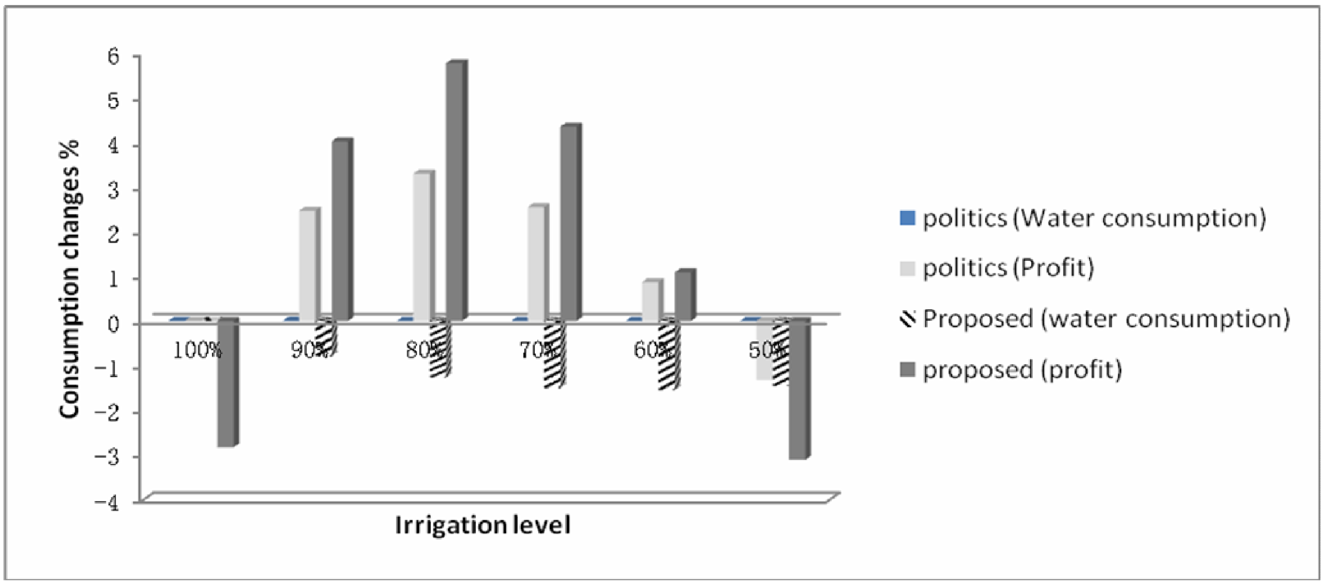

Fig. 3 : Changes in net profit and consumption of water nonlinear programming model, relative to linear

Disclosure Statement

No potential conflict of interest was reported by the authors

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