OPTIMUM CROP CULTIVATION AT DIFFERENT LEVELS OF IRRIGATION WATER ALLOCATION (CASE STUDY: QAZVIN PLAIN)

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Abstract. Designing and implementing a crop pattern is necessary not only to cope with water deficit, but also to control the limiting factors and optimal utilization of available facilities, which have been addressed in many countries of the world. The current study was conducted at five levels of irrigation including I_1, I_2, I_3, I_4 and I_5 (100, 90, 80, 70 and 65% of crop evapotranspiration) and at three different levels of cultivation including S_1, S_2 and S_3 (current cultivated area, 10% increase in cultivated area and 10% decrease in cultivated area compared to current conditions). Optimum crop levels were estimated for each crops of crop pattern. The results show that the model in S_2 allocates a higher level to strategic crops, and in S_3 it allocates a higher level to higher-yielding crops. The S_3I_1 has the highest income among all scenarios. I_2 increased economic productivity at an average level of 7.5% while maintaining income. Therefore, it is possible to allocate a lower amount of area and a lower amount of water, and to earn more income. Also, I_4 and I_5 levels are not recommended due to reduced income and yield. If there is a decrease in available water and I_5 is reached, cropping tomato, beet and alfalfa are not recommended considering economic level**.**
Keywords: *cropping pattern, drought, linear programming, productivity, water deficit*

Introduction

Regarding world statistic, the greatest water consumption in countries can be found in the agriculture section (Kang et al., 2016; Programme, 2012; Mancosu et al., 2015). Consumed water in agriculture sector guarantees food security of the countries (Daiand Li, 2013). Therefore, optimal usage of water and maintaining the existing water resources are necessary (Garg and Dadhich, 2014). Cultivation pattern has a key role in water management and it can be determined that what level of cultivation and how much water could be allocated to what crops in order to receive more profit, water storage and providing food security (Niu et al., 2016; Zeng et al., 2010).

Amount of cultivation of agricultural products must be determine regarding the existing resources, price of products, cost of production, yield of production, demand of the country and correct policies. Also, in order to supply countries fundamental

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demands, choosing agronomical and horticultural productions must be based on the existing infrastructures, social-economic issues and level of technologies maintaining basic resources of production.

Jiang et al. (2016) have developed PBREOP model in west north of China. Results of optimization through this model led to 15% increase in profit. In addition, analyzing scenarios including five level of water allocation has shown that allocation of water could be decreased to 23% without declining profit. Mushtaq and Moghaddasi (2011) have investigated the effect of deficit irrigation to respond climate changes and environmental water demands in Murray-Darling basin of Australia. Three scenarios have been compared in this research: Optimization with full irrigation, optimization with deficit irrigation and deficit irrigation without optimization. Results have shown that deficit irrigation is effective to maximize gross yield and increase water consumption efficiency.

About four decades ago, Qazvin plain was one of the five fertile plains of Iran. Agriculture in this plain has supposed to become one of the industrial poles of the country, but it has become the main occupation of people living in the region. Exactly for this reason and while some of the surface waters of the area are transported through the construction of the Taleghan Dam to supply Tehran's drinking water. The utilization of Qazvin plain surface water and groundwater resources has been expanded to the extent. According to the existing reports, it is far beyond the capacity of the water system. The aquifers are progressing towards irreversible degradation. At present, usage of groundwater in the whole consuming sectors is estimated to be 1.8 billion cubic meters, while the authentic limit to use the water resources of Qazvin province is 880 million cubic meters (Shokoohi et al., 2014). In order to resolve the water crisis in Qazvin plain, revise of crop pattern and water management is required especially in the agricultural sector (Shokoohi, 2012; RamezaniEtedali et al., 2015).

Using a single-objective mathematical model, Shirdeli and Dastavar (2014) have dealt with optimization of crop patterns of the lands in the down part of BoiinZahra (Qazvin, Iran) dam. The aim of this study had been to maximize the income of farmers in this area and they developed four 5-year programs for future analysis. The results of their study showed that there is a possibility for a significant increase in farmers' income in this area. Also, farmers' income increases during the second to fourth 5-year program will be 20, 44.7 and 50.3% respectively in compare with the first 5-year period. Upon completion of the last five-year program, water productivity will increase from 50 to 77%.

Yousefdost et al. (2016) turned to optimization for managing the water resources of the Taleghan dam and determining the maximum yield of crop production in Qazvin Plain under different climate conditions. One of the most important results of the research is to determine the new cultivar pattern, so that both objectives which are providing the farmer's profit and allocation of water resources to the other needs by its saving, become available. According to the presented results, 2.81, 2.62, 1.34 and 1.355% profit have obtained for farmers with the new culture pattern in hot and dry, dry, normal, and wet weather situation, respectively.

Parhizkari et al. (2016) have considered three methods of irrigation including full irrigation, 5% deficit irrigation and 10% deficit irrigation for studying the effect of deficit irrigation on crop pattern and farmers profit in Qazvin. The results of using deficit irrigation method have showed that by applying this strategy under different scenarios, it is possible to reduce the area under cultivation of products that are less

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economic (wheat and water barley) and increase the area under cultivation of those products with more gross profit through the saved volume of water.

The plan of water allocation in irrigation and drainage networks is one of the main issues of optimal management of economic efficiency of water. Therefore, a model that could assess the plan of water allocation in the constraints and ruled conditions in the network, would enjoy of a great importance. Mathematical models and planning methods can help planners and managers in decision making. In previous studies, deficit irrigation has been dealt with, but deficit irrigation and decreasing or increasing the area under cultivation has not been studied at the same time. The purpose of current study is to manage the pattern of cultivation to achieve higher income with less water consumption in Qazvin plain.

Materials and methods

The case study

The area of Qazvin province is 15820 km^2 and is in central sphere of Iran between 48°44' to 50°51' E length and 35°24' to 36° to 36°48' N latitude (QPG, 2016). Qazvin plain is belonging the Central Salt Lake basin. This area has the highest level of cropping of various types of products in the plains of this basin (Shokoohi et al., 2014). Qazvin Plain with an area of 440 thousand ha is in the central plateau of Iran and has semi-arid climates and hot summer and relatively cold winters. The main aim of constructing Taleghan dam is to provide agricultural water in Qazvin Plain, to provide drinking water to Tehran and Karaj, to artificially recharge Qazvin aquifer and to control the seasonal floods of the Taleghan River. *Figure 1* shows the location of the studied area (Yousefdost et al., 2016).

The required statistics were obtained from statistics of the Ministry of Agricultural Jihad or from the Organization of Agricultural Jihad of Qazvin province. *Table 1* shows the current level of cultivation area, income, maximum yield, sensitivity coefficients (K_y), Crop Evapotranspiration (Et_c), water requirement and proportion of areas under cultivation of important products in the studied area in the crop year 2015. The K_y and ET_c in the study area suggested by Tafteh et al. (2014) were used. Monthly weather data for three years (2012–2015), including maximal and minimal temperature and monthly average rainfall were collected from Feizabad (36°8' N, 50°15' E, 1240 m) station in this study area and they are shown in *Figure 2*.

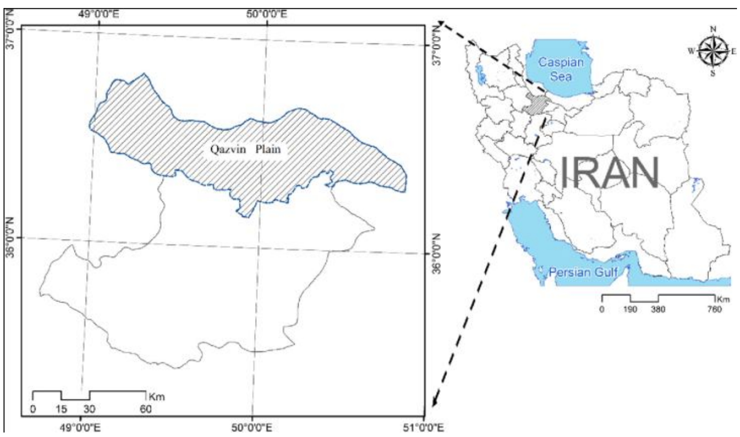

Figure 1. *Location of the study area in Iran map*

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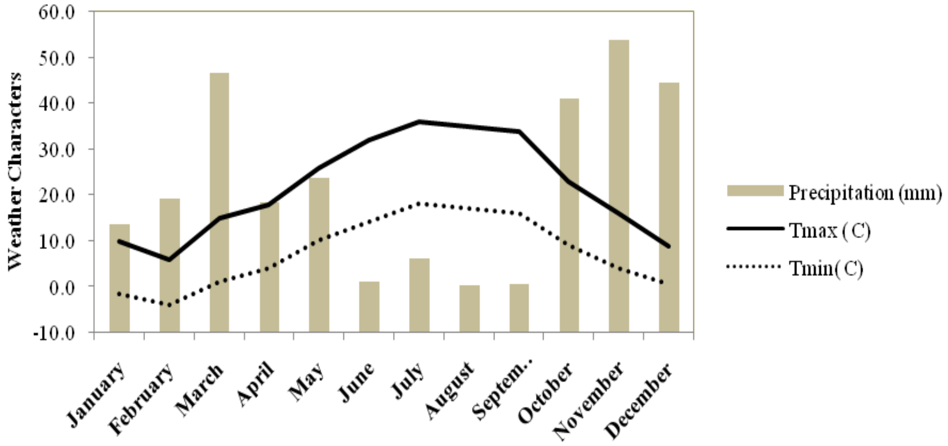

Figure 2. *Distribution of monthly temperatures and monthly average rainfall in the Qazvin District over 3 years (2012–2015)*

Table 1. *Basic data used in optimization model based on the year 2015*

Crop	Area ha	Yield kg/ha	Marketing price USD/Kg	Income USD	K_y	ET_c mm	Water requirement MCM	Area under cultivation ratio
Wheat	18118	5069	0.32	828	0.79	542.0	9.82	0.42
Barely	9170	4417	0.30	573	0.79	400.7	3.67	0.21
Seed corn	892.9	9604	0.36	1560	0.92	760.0	0.68	0.02
Sugar beet	1650	54109	0.61	1307	0.94	1038.4	1.71	0.04
Tomato	630	48317	0.91	1330	0.88	1092.1	0.69	0.01
Alfalfa	5094	17672	0.19	1826	1.00	1336	6.81	0.12
Maize	7850	51443	0.05	1077	0.96	696	5.46	0.18
Total	43404.9			8502			28.84	

Defining the model and its dependent variables

The method of linear programming modeling which involves the parameters of crop pattern designing including crop water requirement, cultivation frequency and etc., requires designing a model that initially consists of three principles, i.e. objective or objectives, variables, constraints, and limitations, also the relationship between these principles must be defined in a matrix called the planning matrix. In the framework of the program's objective function and by using a linear planning approach, a designer can follow many lateral objectives within the framework of variables and constraints, in addition to what is considered as the ultimate objective.

In current study, the maximum income in thousand USD was considered as the objective function (*Eq. 1*). The objective function was the most economic benefit with considering the decline in yield caused by water shortage, which is presented in the following relation (*Eqs. 1-2*):

$$Max\ Z : \sum_{i=1}^{n} \alpha_i . A_i (P_i . Y_i - C_i - Q.C_w) \quad \text{(Eq.1)}$$

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$$Y_i = Y_i^{\max} . \left[1 - k_y \left(1 - \frac{W_i}{ET_i} \right) \right] \quad \text{(Eq.2)}$$

where Z: the objective function, α_i: the percentage of the surface area under cultivation for each product, i: the product, A_t: the total area of the lands (Ha), P_i: marketing price of each kg of product (USD), Y_i: the product yield function (Eq. 2), Y_{imax}: Maximum product yield (kg), K_y: Coefficient of the crop yield response to water deficit, W_i: the amount of water entered into the earth (mm), ET_i: the water demand of the product (mm), Q: water used (liter), C_w: Cost of each litre of water (USD), C_i: Cost of production per product (USD). Applying the constraints was done with the following assumptions:

1. Wheat is a strategic product and the least supposed culture is 30%.
2. Products which are below 5% in the current state are determined at least 1% and utmost 15%. The basis for selection 15% is based on the capability to crop yields in the region.
3. Products whose cultivation in the region is less than 20% and are cultivated after strategic crops, their minimum cultivation is as the same as the current cultivation and their maximum area under cultivation is selected 2 times more than the current cultivation.
4. Percent of the present area under cultivation of barely is 21%. Considering the importance of this crop, it is chosen at least 15% and utmost 30%.
5. Total cultivation area was considered as a limitation in different scenarios.
6. The allocated water was considered as water constraint in the five water scenarios.

The crop production function is a function of the relative yield of the product according to the evapotranspiration of the crop. The researchers have presented the Ky of the products in general after analyzing experimental data. In current research, *Equation 3,* which is based on the relative reduction of the product and the relative lack of evapotranspiration, was used to investigate the effect of the reduced water allocated to the crop yield (Doorenbos and Kassam, 1979).

$$1 - \frac{y_i}{y_{i\max}} = k_y (1 - \frac{ET_a}{ET_m}) \quad \text{(Eq.3)}$$

where Y_i: the product yield function, Y_{imax}: Maximum product yield (kg), $\frac{y_i}{y_{i\max}}$: Actual yield ratio to maximum yield (relative yield), $\frac{ET_a}{ET_m}$: Actual evapotranspiration to the maximum evapotranspiration of the crop (mm), k_y : Coefficient of the crop yield response to water deficit.

The current study was optimized considering five irrigation scenarios including I_1, I_2, I_3, I_4 and I_5 (regarding water allocation of 100, 90, 80, 70 and 65% of crop water requirement, respectively) and three different levels of cultivation including S_1, S_2 and S_3 (respectively equivalent to the existing cultivated area, 10% increase in cultivated

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area and 10% decrease in cultivated area compared to the current situation) and the optimal amount of cropping levels were estimated for each crop pattern of the products. The total cultivation area and water used of fifteen defined scenarios are presented in *Figure 3*.

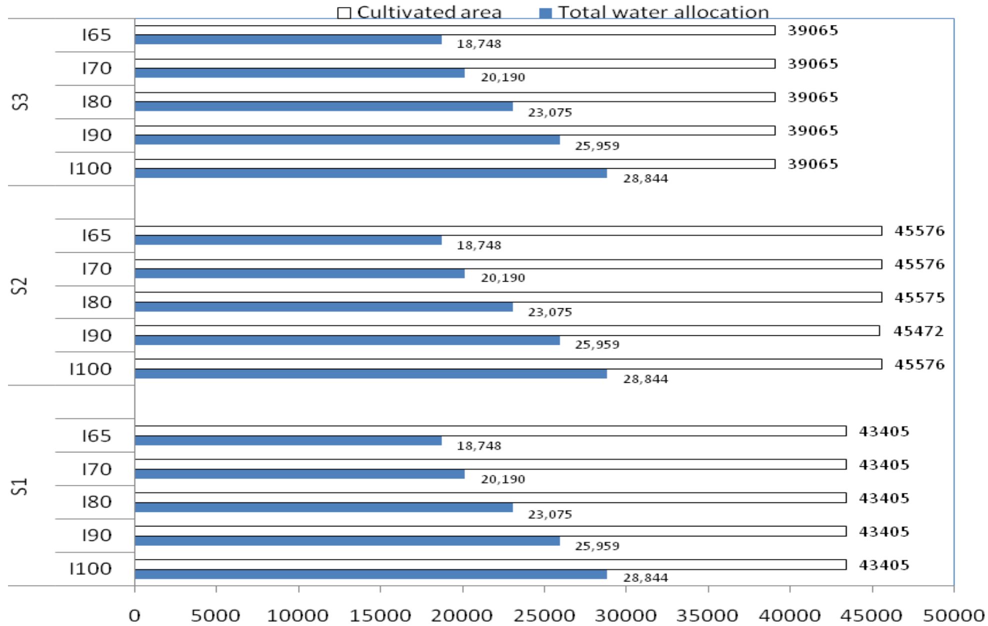

Figure 3. *Cultivated area and total water allocated to each scenario in Qazvin District (the amount of allocated water was calculated based on crop evapotranspiration*

Since farmers generally pay attention to the economic yield of crop cultivation, the economic productivity index ($WP_{\$}$) has also been studied and calculated in this research from different scenarios. The $WP_{\$}$ index was defined and calculated based on thousand USD per cubic meter of crop water requirement as follows (*Eq. 4*):

$$WP_{\$} = \frac{(\$\ kg^{-1})\ (kg\ ha^{-1})}{ET(m^3 ha^{-1})} \quad \text{(Eq.4)}$$

where $ has been considered equal to thousand USD.

Results

Relative yield of the products in different water allocations is the most important of water allocation modeling. In the case that the water allocated to the crop is equal to the maximum water requirement of the crop, the relative yield is equal to one. Also, if the water allocated is less than the crop water requirement, its relative yield will be less than one. In *Figure 4,* the relative yield of the products is shown in various water scenarios. The economic level of products yield is 0.7 (Papamichi et al., 2008); therefore, in I_5, the estimated yield for most products is at the level of 0.7, and for the tomato, alfalfa and sugar beet is 0.69, 0.68 and 0.69 respectively, these values are less than those of their economical level. This means that the cultivation of these products in these water conditions is not economic due to high water requirements and decrease in yield. The relative yield of different crops at all cultivation scenarios has been reduced by decreasing the amount of water allocated (*Fig. 5*). The main output of the model, which is related to the objective function of the model, is the income and the area under cultivation ratio for each product. Total income for different irrigation and cultivations scenarios as well as the optimal cultivation ratio is presented in *Table 2*. The income of I_1 at S_1 cultivation level was less than S_3 with income of 91 and 96 thousand USD respectively, while by increasing the level under cultivation (S_2) the amount of income (78 thousand USD) fell down.

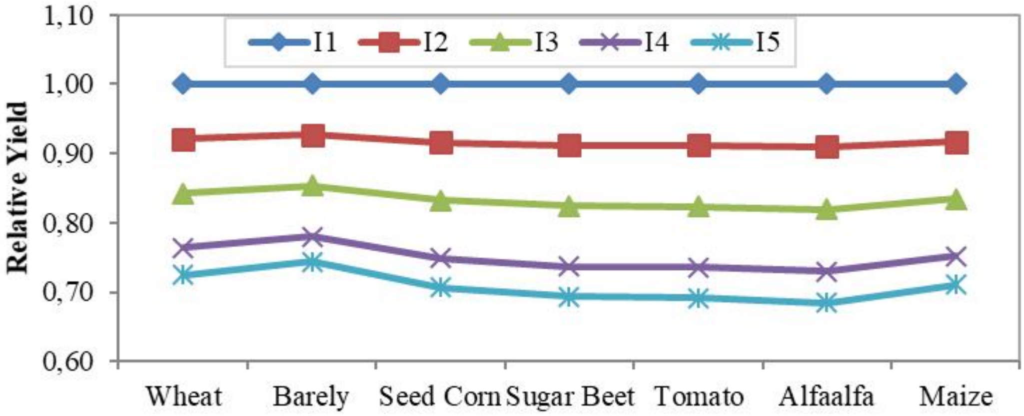

Figure 4. *Relative yield of crops in different water scenarios*

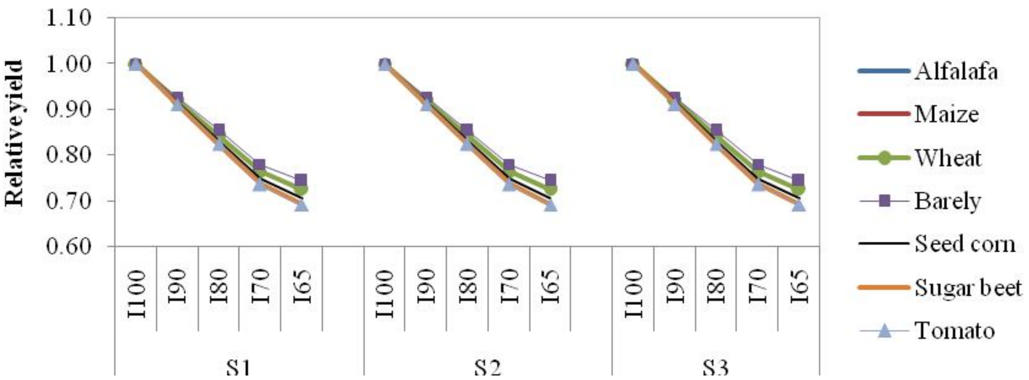

Figure 5. *Relative yield of crops in different water scenarios and cultivations*

The percentage of optimal cultivation area for products with higher incomes in the S_3 is in highest so far as the water allocated is not limited. The highest cultivation areas were for alfalfa, tomato and sugar beet cultivars that are 16.20, 4.70 and 2.40%, respectively in S_3 and the lowest in were 1_2, 1 in S_2. The highest ratio of optimum cultivation area for seed corn was found to be 7% in S_1 and the lowest was observed at S_2, i.e. 1%. However, in S_2, products with high water consumption are at the minimum of the specified constraint domain and strategic products such as wheat and barley are at the maximum specified range in the model. In wheat and barley, the highest culture percentage was observed in S_2, i.e. 47.00% and 30.00%, respectively.

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Table 2. *Comparison of the average total income for different irrigation and the cultivars scenarios and the optimal percentage of crop cultivation*

		Income USD*10^3	Optimized area under cultivation %						
			Wheat	**Barely**	**Seed corn**	**Sugar beet**	**Tomato**	**Alfalfa**	**Maize**
S_1	I_1	91**bc**	30.60	25.70	7.00	1.80	1.00	12.00	22.00
	I_2	90**c**	30.30	26.00	3.00	2.60	1.10	12.00	25.40
	I_3	75**e**	31.75	27.00	3.50	2.20	2.40	12.15	21.15
	I_4	66**hi**	35.70	24.10	2.70	3.00	1.30	12.10	21.10
	I_5	61**j**	30.70	29.00	2.75	3.20	1.90	12.75	19.80
S_2	I_1	78**e**	43.00	30.00	1.10	1.00	1.00	12.10	18.00
	I_2	75**e**	40.75	30.00	1.00	1.00	1.00	12.00	20.25
	I_3	63**ij**	44.00	30.00	1.00	1.00	1.00	12.20	21.00
	I_4	56**k**	43.50	28.50	1.00	1.00	1.00	12.00	18.00
	I_5	52**l**	42.70	29.00	1.10	1.00	1.00	12.50	18.30
S_3	I_1	96**a**	31.80	15.00	1.70	2.40	4.70	16.20	18.30
	I_2	93**ab**	30.40	15.00	1.00	5.30	3.60	15.00	19.70
	I_3	84**d**	27.65	16.20	2.20	3.70	4.60	15.10	20.60
	I_4	71**f**	29.60	15.75	2.00	3.20	4.35	15.80	19.35
	I_5	67**g**	30.70	15.00	1.00	2.90	4.50	15.80	20.10

The letters are used to determine the results of scenario adaptation

Figure 6a shows the final income per different levels of area under cultivation for each irrigation scenario and *Figure 6b* shows the final income per different levels of irrigation for each are as under cultivation. In Section A, we can see that the difference between income in I_1 and I_2 is insignificant subtle and income has fallen from I_1 to I_5 totally.

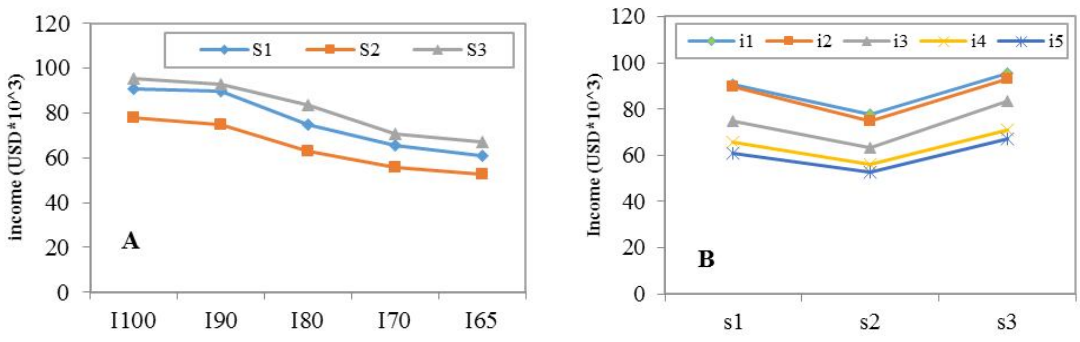

Figure 6. *The final income in (a) cultivar scenarios, (b) irrigation scenarios*

Table 3 shows binary comparison matrix in different products related to the total income. Studies showed that the total income (based on million Rials) has positive correlation with all products except barley (with coefficient equal to -0.072) and they were 0.011, 0.387, 0.449, 0.425, 0.885 and 0.829 for wheat, seed corn, beet, tomato, alfalfa, respectively. Total income has significant correlation with all products except wheat and barley. The highest correlation of total income was with alfalfa, i.e. 0.855.

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Table 3. *Binary comparison matrix in different scenarios of area under cultivation and water allocation*

	TR	MZ	AF	TO	SB	CR	BL	WT
WT: Wheat	0.011	0.214	0.129	-0.289	-0.400	-0.383	0.550	1
BL: Barely	-0.072	0.314	-0.246	-0.465	-0.473	0.267	1	
CR: Seed corn	0.387	0.583	0.060	-0.080	0.021	1		
SB: Sugar beet	0.449	0.136	0.433	0.065	1			
TO: Tomato	0.425	-0.130	0.423	1				
AF: Alfalfa	0.855	0.573	1					
MZ: Maize	0.829	1						
TR: Total income	1							

Figure 7 shows the required water for each crop and total income in a diagram. In I_1S_2 the required water for wheat, barley and alfalfa were increased in compare with I_1S_1 which shows allocating more area under cultivation for these three productions in this scenario. It can be observed that, in this section, income has decreased. This issue reminds two results: first that despite high importance of strategic products, they are not economic necessarily and second that more water consumption and high cultivation area necessarily do not lead to more income. In I_1S_3 water requirement has increased in tomato, beet and Alfalfa which shows allocating more area under cultivation to these three productions in compare with the conditions I_1S_1 and I_2S_2. Income increase has observed in this section.

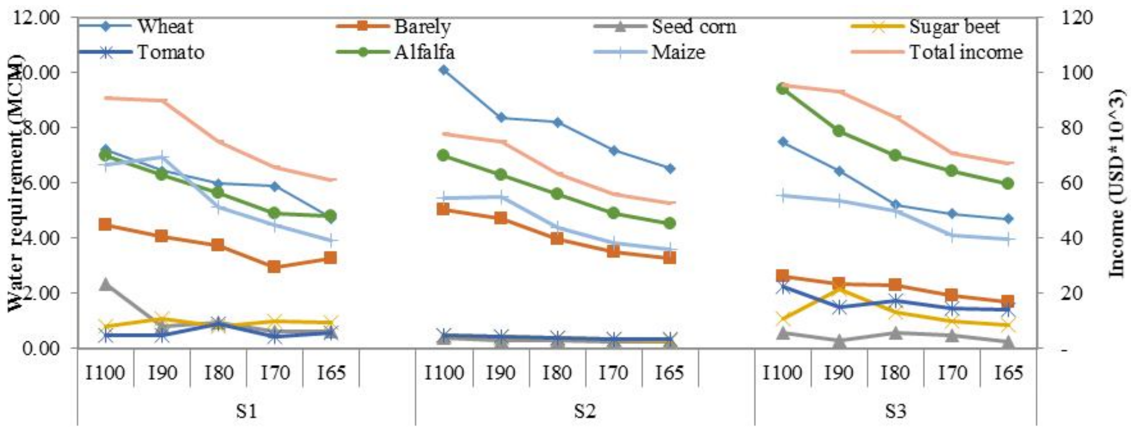

Figure 7. *Water requirement by crops and total income*

In *Figure 8,* economic productivity and total income has been presented in all scenarios. Economic productivity was calculated in different scenarios from 2.7 to 3.6 thousand USD in cubic meter. In addition of maintaining the income, I_2 has averagely increased economic productivity in different levels, i.e. 0.43 thousand USD per cubic meter water. Economic productivity is in the minimum level in S_2. S_3 obtained more income while its water consumption was equal to S_1 and S_2. Economic productivity was more observed in S_3. Generally, water allocation to products with high income in S3 has increased income.

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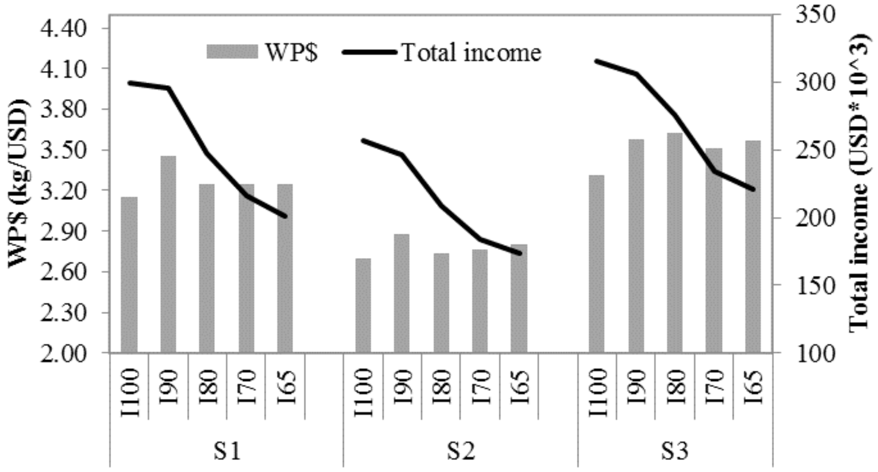

Figure 8. *Total income and economic productivity by scenarios*

Discussion

Using study results, we can now answer the question which of the strategies ‘increasing cultivated area’ or ‘reducing cultivated area’ will result in the highest WP or economic benefit. Reducing the cultivated area will result in higher water productivity. However, it is seen that even a decrease in the area under cultivation and the optimal use of water at a lower level have resulted in an increase of 5.3% of income. Lalezari et al. (2016) reported that the result of applying deficit irrigation plan and increasing economic profit plan at the same time for allocating water and land shows providing more water requirement and decreasing area under cultivation is a more proper strategy for managing water in agriculture in drought condition.

With increasing the cultivation area, since the allocation of water is constant or less than the existing conditions, the model has optimized the high water-consuming products such as tomato and beet at the minimum ratio of the defined area for scenario and developed cultivation area of strategic products such as wheat and barley toward higher bound of cultivation range. The results of this study are not in line with the results of the studies conducted by Jafarzadeh et al. (2016) and Alizadeh et al. (2012) as all concluded that optimization leads to high levels of cultivation for strategic products in the region. It is recommended that greenhouse products and products that can be cultivated in the greenhouse become transferred to the greenhouse and the stored water from removing these products become allocated to strategic products.

I_2, we can save 10% of water consumption with only 1.2% reduction in income. A study in the West of the Palestine Region revealed that optimal cultivation pattern reduces water consumption by as much as 10%, which contributes to the sustainability of water resources (Nazer et al., 2010). In addition, as compared to the previously published results (García-Vila and Fereres, 2012; Zhanget al., 2014), objective function could not only have a feasible computation, but also well consider the benefit coordination between different water conditions and the various cultivated area in the district.

Results showed that it is possible to have more income with lower area and even lower water allocation by managing the cultivation area.

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Conclusion

Crop pattern is supposed to be one the most important effective components in management of water resources. This study has determined an optimal Crop pattern in Qazvin plain in order to decrease water allocation and increase or decrease the area under cultivation. I_4 and I_5 are not recommended due to decrease in income and yield. In order of decrease in existing water and reaching to I_5 amount, with regard to economic limit, cultivating of high water consuming products such as tomato, beet and alfalfa is not recommended. According to the results if there were enough cultivation area, Model recommend higher area for strategic products. Also with regard to the higher cultivation area and decrease in water allocation related to the current situation and due to high water demand of crops such as beet, alfalfa and corn, the cultivation area of these products were decreased. Unlike, when the cultivation area is limited constrain, the model would increase area under cultivation of economic products with higher income and allocate water to them. So it has been observed that income in S_2 and S_3 has been decreased and increased in compare with S_1, respectively. In addition of retaining income, I_2 increased economic productivity in different levels, i.e. 0.82 million Rials per cubic meter water averagely. These results could decrease lots of tests and it could be used as a certain criterion for the future research works and management of crop pattern.

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