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Optimum Water Allocation between Irrigated and Rainfed Lands in different Climatic Conditions

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ABSTRACT: In this study, water allocation managements between irrigation and rainfed lands were surveyed in different climate conditions. The optimization model results in the Qazvin Plain indicated net benefit increased under new management in case of water conveyance from 2000, 4000, 6000, 8000 and 10000 meters in a climatically normal year to be 11.1, 13.5, 19.2, 16.6 and 15.8 percent, respectively, while in a wet year 9.0, 10.9, 17.0, 15.9 and 13.4 and in a dry year 8.05, 12.5, 16.1, 19.1 and 19.9, respectively. Barley was the best choice for deficit irrigation in three climate conditions. Depths of deficit irrigation were 20, 25 and 30 mm in the first decade of November and 50, 50 and 60 mm in the second decade of May in normal, wet and dry conditions. Also lentil was the first choice for supplementary irrigation. The best treatments for supplementary irrigation in lentil rainfed fields were 75 mm in the third decade of May in normal years, 75 mm in the second decade of May in wet years and 100 in the second decade of May in dry years.

Keywords: Deficit Irrigation, Irrigated lands, Qazvin plain, rainfed lands, Supplementary Irrigation, Water Allocation Management.

INTRODUCTION

Many studies have been devoted to improve water and cropping pattern management in irrigated farming. Raju and Kumar (1999) and Singh *et al.* (2001) used linear programming (LP) to determine optimum cropping pattern for maximizing the goal function of total net income with a given volume of water. Mainuddin *et al.* (1997) developed a linear optimization model to determine optimum cropping pattern and used LINGO to solve it. Reca *et al.* (2001) developed a nonlinear programming model for optimum water allocation and changed the economic goal function into a linear problem using a discontinuous function. Carvallo *et al.* (1998) used MINOS to develop a nonlinear programming model and solved a similar problem.

Among the previous studies, many had focus on cropping pattern and optimum allocation of water and/or soil resources (Paudyal & Gupta 1990; Sethi *et al.,* 2002) and some paid attention to simultaneous optimization of groundwater management (Sethi *et al.*, 2006), surface water resources and integrated management of surface and groundwater resources besides total net income (Hallaji &Yazicigil 1996).

Nonetheless, optimum allocation of water between irrigated and rainfed lands had received little attention. Most studies have dealt with optimum water allocation and choosing the best cropping patter in irrigated lands. So, there are opportunities to extend this kind of studies and pay more attention to the management of water allocation to rainfed lands for supplementary irrigation.

In Iran, 7.8 and 6 million hectares of cultivated lands are irrigated and rainfed, respectively, indicating a 43 percent share for rainfed agriculture. Moreover, about 10% of raw agricultural products are being produced by rainfed agriculture (Tavakkoli 2010). It is obvious that the contribution of the country's rainfed products is much less than the global averages. The analysis of rainfed yields revealed that between 25 to 50% of potential yield is achievable under rainfed conditions, while this ratio is about 20% in Iran (Rockström *et al.*, 2010). Taking into consideration erratic spatial pattern of precipitation, especially in dry and semi-dry regions of the world, the management of water supply in these areas should receive the highest priority.

Although single irrigation and supplementary irrigation have been recently receiving more attention (Harmsen 1984; Zhang & Oweis 1999; Tavakkoli & Oweis 2004;Tavakkoli *et al.,* 2005, 2010), water supply challenges still exist in water sectors. Hence, taking benefit and cost criteria into consideration, optimum water allocation between irrigated and rainfed lands seems necessary. Furthermore, it is also necessary to assess and manage the reduction of allocated water to irrigated lands and decreased crop yields in these areas.

Therefore, the main objective of this study is to use saved water from irrigated lands to improve crop yields in rainfed areas by supplementary irrigation. Since irrigated lands are located in the neighborhood of rainfed lands in many regions of the world, the volume of supplementary irrigation in rainfed lands and its impacts on the total net income of these areas was assessed in this study.

MATERIAL AND METHOD

Study Area. The case study of this study is Qazvin Plain (35-30'N to 36-40'N; 39-10'E to 50-40'E), one of the most important agricultural poles in the northwestern Iran. This region includes vast irrigated and rainfed lands . Wheat, barley, corn and tomato are major irrigated crops and wheat, barley, lentil and chickpea are major rainfed crops in this region. According to the report by Tehran Regional Water Company (TRWC, 2006), total network area is about 85000 ha with 20-25% kept as fallow. Agricultural-Jihad Bureau of Qazvin Province (AJBQP) has recently reported the 5-year average cultivated areas of irrigated wheat, barley, corn and tomato 27200, 8500, 6800 and 4250 ha, respectively, and the 5-year average cultivated areas of rainfed wheat, barley, lentil and chickpea 50, 15, 5 and 30 percent of total rainfed lands.

Objective Function. In this research, total net benefit has been used as the objective function:

$$OF: Maximize\ NB=\sum_{i=1}^{n}\sum_{m=1}^{4}\left(B_{i,m}-C_{i,m}\right) \quad (1)$$

$$B_{i,m}=A_{i,m}\times Y_{i,m}\left(P_i+\alpha_i\times P_i'\right) \quad (2)$$

$$C_{i,m}=A_{i,m}\times CC_i+A_{i,m}\times Y_{i,m}\times CW_i+A_{i,m}\times D_{i,m}\times 10\times CW+A_{i,m}\times IN_{i,m}\times CI+A_{i,m}\times CT+A_{i,m}\times CP+A_{i,m}\times CS+A_{i,m}\times CE \quad (3)$$

where, i: crop index, m: management index (full irrigation, deficit irrigation, rainfed and supplementary irrigation), $B_{i,m}$: net income (Rials), $C_{i,m}$: costs (Rials), $A_{i,m}$: lands under different management conditions (ha), $Y_{i,m}$: crop yield under the same management condition as $A_{i,m}$ (kg/ha), P_i: main product price (Rials/kg), $\alpha_{i,\ m}$: the fraction of main products indicating by-product yield (kg /ha), P'_i: by-product price (Rials/kg).CC_i: constant costs (Rials/ha), CW_i: variable and delivery costs (Rials/kg), CW: water costs (Rials), CI: costs of each irrigation event (Rials), CT: costs of water conveyance with polyethylene pipes (Rials/ha), CP: pumping station costs (Rials/ha), CS: irrigation system costs (Rials/ha) and CE: costs of each supplementary irrigation events (Rials/ha). The values of α has been assumed 1 for wheat and barley and 0.5 for lentil (AJBQP). The costs related to delivery pipe lines, pumping station and irrigation systems were converted into uniform series of annual payments according to the lifetime (n') and interest rate (i'), using Equation (4):

$$A=P[(i'\left(1+i'\right)^{n'}/\left(1+i'\right)^{n'}-1]=P(A/P\ ,i',n') \quad (4)$$

Where, A: annual payments, and P: costs at the beginning of the period.

Constraints. *Land Constraints.* The lands allocated to irrigated cultivation (full + deficit irrigation, AFi) are constant for each crop and just the management conditions are going to be changed:

$$\sum_{i=1}^{n}\sum_{m=1}^{2}A_{i,m}=AF_i \quad (5)$$

The aggregated lands allocated to rainfed and supplementary-irrigated lands are equal to the average land areas allocated to that crop for rainfed cultivation (ARi):

$$\sum_{i=1}^{n}\sum_{m=3}^{4}A_{i,m}=AR_i \quad (6)$$

Water Constraints. The total volume of water which is allocated to full irrigation in a decade is now allocated between fully irrigated, deficit irrigated and supplementary irrigated cultivation in the same decade, or up to 4 decades later in rainfed lands for supplementary irrigated cultivation:

$$for\ j=1:72\ [\sum_{i=1}^{n}AF_i\times 10\times d_{j,i,1}/(E_i)]-\{[\sum_{i=1}^{n}\sum_{m=1}^{4}A_{i,m}\times 10\times d_{j,i,m}/(E_i)]+[\sum_{k=j+1}^{j+4}\sum_{i=1}^{n}A_{i,4}\times 10\times d_{k,i,4}/(E_i)]\}\geq 0 \quad (7)$$

Where *i*: crop index, *j*: decade index, *m*: management index, AF_i: irrigated lands of crop i (ha), dj,i,1: irrigation depth under full irrigation condition (m=1) (mm), 10: factor to convert mm into m^3/ha, dk,i,4: supplementary irrigation depth (m = 4) (mm), A_i, 4: lands allocated to supplementary irrigated cultivation (ha) and E_i: irrigation efficiency (%). In this equation, the first part indicates the available water from lands which are being already fully irrigated, the second part indicates allocated water to the whole irrigated (full + deficit + supplementary) lands and the third part indicates allocated water to supplementary irrigated lands up to 4 decades later.

In irrigated lands, decision variables include irrigation depth (i.e. deficit irrigation level) and areas allocated to full and deficit irrigation. In rainfed lands, decision variables include depth and time of supplementary irrigation and areas allocated to rainfed and supplementary irrigation. Maximum number of supplementary irrigation was set to 2 events.

LINGO was used for model programming. Crop yields and water requirements were simulated using Aqua Crop model (Raes *et al.,* 2009). This model was calibrated and validated using field data obtained from pilot farms (Ramezani Etedali 2012).

Costs and Incomes. Production cost of each crop includes constant and variable costs. Variable costs depend on water consumption, number of irrigation events and harvesting and delivery costs. Constant costs consist of land preparation and cultivation costs. Average production constant costs of each crop were obtained from AJBQP for the period 2009-2010 (Table 1).

Table 1: Constant costs of each crop.

Crop	Rainfed (Rials/ha)	Irrigated (Rials/ha)
Wheat	1950000	5400000
Barley	1950000	4400000
Corn	-	6300000
Tomato	-	35900000
Lentil	3100000	-
Chickpea	3300000	-

Some cultivated crops, like wheat and barley, have additional incomes related to their by-products. Crop prices were obtained from AJBQP for the period 2009-2010 (Table 2). Since there is no irrigation facility in the rainfed lands, it is necessary to consider additional costs to prepare required facilities for supplementary irrigation. These costs are converted into annual payments, taking the economic lifetime of these facilities into consideration. In this study, polyethylene pipes were considered for water conveyance because of their persistence, high conveyance efficiency and low water loss.

Also, travelling sprinkler irrigation system was suggested for supplementary irrigation in rainfed lands.

Table 2: Main and by-products prices of each crop.

Crop	Main Product (Rials/kg)	By-Product (Rials/kg)
Wheat	3300	1000
Barley	2600	1000
Corn	2700	-
Chickpea	10000	1300
Lentil	15000	1300
Tomato	3000	-

These systems have portable devices which have the advantages of fast transportation and wide coverage (Hlavek 1992). The costs related to pumping station and energy is another part of costs to be considered.

Implementation and purchase costs of the pipe line were obtained through inquiry from consulting engineering companies with experience in the study region. According to the distance between water resource and target farms, these costs can range 40 to 80 M-Rials per hectare (Table 3). Economic lifetime of polyethylene pipes and interest rate were considered 50 years and 7%, respectively. Travelling irrigation system is most consistent with supplementary irrigation (Hlavek 1992).The price of this irrigation system is about 400 M-Rials, making it possible to irrigate 80 ha each decade. Hence, system price per hectare is about 5 M-Rials with a 25-year lifetime. Purchasing required equipment and implementation of pumping station costs about 2.5 M-Rials/ha with a 25-year lifetime. Moreover, energy and operation costs of pumping station for each supplementary irrigation event are about 100 K-Rials/ha.

RESULTS AND DISCUSSION

Optimization model was used for three periods, representing wet (2002-2003), normal (2003-2004) and dry (2007-2008) climatic conditions. These periods were selected according to the SMDI drought index (Ramezani Etedali *et al.*, 2012).

Table 3: Total and annual uniform costs of water conveyance pipe line.

Delivery Distance (m)	Total Costs (Rials/ha)	Annual uniform Costs (Rials/ha)
2000-0	40,000,000	2,898,394
4000-2000	48,000,000	3,478,073
6000-4000	58,000,000	4,202,671
8000-6000	68,000,000	4,927,270
10000-8000	80,000,000	5,796,788

A. Objective Function

The developed model was run for different water conveyance distances (2000-10000m). The resulted values of objective function are presented in Tables 4, 5 and 6 for different climatic conditions. In these tables, both incomes from allocating saved water to neighboring rainfed lands (2nd column) and to the outside rainfed lands up to the distance of 10000m (3rd column) were considered. For conventional management scenario (no supplementary irrigation), total net benefit was estimated as the sum of the incomes from irrigated lands (within the irrigation and drainage network) and rainfed lands (without supplementary irrigation).

New management scenarios resulted in an increased total net income from irrigated and rainfed lands. The increased values are 11.2, 13.5, 19.2, 16.6 and 15.8% (as compared to the conventional management) in normal climatic condition; 9, 10.9, 17, 15.9 and 13.4% in wet climatic condition, and 8.1, 12.5, 16.1, 19.1 and 19.9% in dry climatic condition for the conveyance distances of 2000, 4000, 6000, 8000 and 10000m, respectively. These values confirm the results of Ramezani Etedali *et al.* (2013) which showed that the total income was increased 14.3%, if the saved water in irrigated lands is used for supplementary irrigation in rainfed lands in Kermanshah and Lorestan provinces in Iran.

It can be seen that in normal and wet climatic conditions, the highest objective function value is related to the distance of 6000m, while in dry condition, it is related to the conveyance distance of 10000m. The main reason is that in dry periods, crop yields in rainfed lands considerably decrease and supplementary irrigation has greater impacts which compensate for considerable implementation costs to convey water up to the distance of 10000m.

Table 4: The net benefits under different water allocation managements in the normal period.

Scenario	Total Net Benefit from Irrigated Lands (10^9Rials)	Total Net Benefit from Rainfed Lands (10^9Rials)	Total Net Benefit (10^9Rials)
Conventional	-	-	1386.1
Up to 2000 m	1366.2	175.2	1541.4
Up to 4000 m	1453.4	119.4	1572.7
Up to 6000 m	1586.3	66.0	1652.3
Up to 8000 m	1588.7	27.9	1616.6
Up to 10000 m	1604.9	0.0	1604.9

Table 5: The net benefits under different water allocation managements in the wet period.

Scenario	Total Net Benefit from Irrigated Lands (10^9Rials)	Total Net Benefit from Rainfed Lands (10^9Rials)	Total Net Benefit (10^9Rials)
Conventional	-	-	1482.1
Up to 2000 m	1378.1	237.7	1615.8
Up to 4000 m	1481.8	162.4	1644.2
Up to 6000 m	1659.0	75.3	1734.3
Up to 8000 m	1679.8	37.8	1717.5
Up to 10000 m	1681.5	0.0	1681.5

Table 6: The net benefits under different water allocation managements in the dry period.

Scenario	Total Net Benefit from Irrigated Lands (10^9Rials)	Total Net Benefit from Rainfed Lands (10^9Rials)	Total Net Benefit (10^9Rials)
Conventional	-	-	1111.1
Up to 2000 m	1210.6	-4.6	1206.0
Up to 4000 m	1253.0	-13.3	1249.9
Up to 6000 m	1292.1	-1.7	1290.4
Up to 8000 m	1324.4	-0.7	1323.7
Up to 10000 m	1332.7	0.0	1332.7

B. Normal Climatic Condition

The allocated areas to each crop under different irrigation treatments (full, deficit and supplementary) are presented in Tables 7 to 11 for different water conveyance distances in normal climatic condition. Up to 2000m conveyance distance, saved water volumes from barley lands (8500ha), resulted from a 20mm deficit irrigation in 1 November (the first decade of November) and 50mm deficit irrigation in 2 May (the second decade of May), and are used for supplementary irrigation in neighboring rainfed lands. For wheat and barley, the supplementary irrigation time is in 1 November and 2 May. For lentil and chickpea, this time is in 1 May and 3 May. These results reveal that no deficit irrigation in irrigated lands, except for barley, has any economic justification. This happens because of barley's considerable drought resistance and relatively lower price. Regarding supplementary irrigation, with increasing water conveyance distance and a given volume of saved water, supplementary irrigation is used for crops with higher economic values. For the distance of 4000m, supplementary irrigation is more commodious in lentil and chickpea lands, since the prices of lentil and chickpea are higher than wheat and barley. As the required water for supplementary irrigation of lentil and chickpea increases in spring (more areas allocated to these crops), the depths of spring supplementary irrigation of wheat decreases from 90mm to 50mm. Yet, autumn supplementary irrigation of wheat shows no reduction, since lentil and chickpea are not cultivated in autumn and there is no need for their supplementary irrigation.

Table 7: Yield and allocated areas to each crop in the normal period (up to 2000m).

Crop	Irrigation Treatments	Yield (kg/ha)	Area (ha)	Rainfed Lands Beyond the Network (ha)
Barley	Full	6400	0	-
	Deficit (20-mm in November_1, 50-mm in May_2)	6100	8500	-
	Rainfed	800	0	4036
	Supplementary (45-mm in November_1, 80-mm in May_2)	4000	1175	-
Wheat	Full	6100	27200	-
	Deficit	-	0	-
	Rainfed	900	0	13455
	Supplementary (50-mm in November_1, 90-mm in May_2)	3900	3915	-
Corn	Full	12400	6800	-
	Deficit	-	0	-
Tomato	Full	59300	4250	-
	Deficit	-	0	-
Chickpea	Rainfed	700	0	1345
	Supplementary (80-mm in June_1)	2000	392	-
Lentil	Rainfed	1000	0	6727
	Supplementary (75-mm in May_3)	3000	1958	-

Table 8: Yield and allocated areas to each crop in the normal period (up to 4000m).

Crop	Irrigation Treatments	Yield (kg/ha)	Area (ha)	Rainfed Lands Beyond the Network (ha)
Barley	Full	6400	0	-
	Deficit (20-mm in November_1, 50-mm in May_2)	6100	8500	-
	Rainfed	800	2462	2749
	Supplementary	-	0	-
Wheat	Full	6100	27200	-
	Deficit	-	0	-
	Rainfed	900	3249	9165
	Supplementary (50-mm in November_1, 50-mm in May_2)	3200	4956	-
Corn	Full	12400	6800	-
	Deficit	-	0	-
Tomato	Full	59300	4250	-
	Deficit	-	0	-
Chickpea	Rainfed	700	0	916
	Supplementary (80-mm in June_1)	2000	821	-
Lentil	Rainfed	1000	0	4582
	Supplementary (75-mm in May_3)	3000	4103	-

Up to this distance, barley lands receive no supplementary irrigation because of water shortage and its lower economic value. For the conveyance distance of 6000m, similar results were obtained, with just one difference, decreased spring supplementary irrigation of wheat from 50mm to 20mm. For the conveyance distances of 8000 and 10000m, total consumed water for spring supplementary irrigation is allocated to lentil and rainfed wheat lands are only irrigated in autumn.

Table 9: Yield and allocated areas to each crop in the normal period (up to 6000m).

Crop	Irrigation Treatments	Yield (kg/ha)	Area (ha)	Rainfed Lands Beyond the Network (ha)
Barley	Full	6400	0	-
	Deficit(20-mm in November_1, 50-mm in May_2)	6100	8500	-
	Rainfed	800	3707	2322
	Supplementary	-	0	-
Wheat	Full	6100	27200	-
	Deficit	-	0	-
	Rainfed	900	7399	5015
	Supplementary(50-mm in November_1, 50-mm in May_2)	2800	4956	-
Corn	Full	12400	6800	-
	Deficit	-	0	-
Tomato	Full	59300	4250	-
	Deficit	-	0	-
Chickpea	Rainfed	700	0	501
	Supplementary(80-mm in June_1)	2000	1236	-
Lentil	Rainfed	1000	0	2507
	Supplementary(75-mm in May_3)	3000	6178	-

Table 10: Yield and allocated areas to each crop in the normal period (up to 8000m).

Crop	Irrigation Treatments	Yield (kg/ha)	Area (ha)	Rainfed Lands Beyond the Network (ha)
Barley	Full	6400	0	-
	Deficit(20-mm in November_1, 50-mm in May_2)	6100	8500	-
	Rainfed	800	4569	642
	Supplementary	-	0	-
Wheat	Full	6100	27200	-
	Deficit	-	0	-
	Rainfed	900	10274	2140
	Supplementary(50-mm in November_1)	2100	4956	-
Corn	Full	12400	6800	-
	Deficit	-	0	-
Tomato	Full	59300	4250	-
	Deficit	-	0	-
Chickpea	Rainfed	700	735	214
	Supplementary(80-mm in June_1)	2000	788	-
Lentil	Rainfed	1000	0	1070
	Supplementary(75-mm in May_3)	3000	7615	-

C. Wet Climatic Condition

The allocated areas to each crop under different irrigation treatments are presented in Tables 12 to 16 in wet climatic condition. These results are very consistent with the results in normal condition. In wet period, the best crop for deficit irrigation is still barley (25mm in 1 November and 50mm in 2 May). The only difference between normal and wet conditions is higher levels of deficit irrigation in 1 November in wet condition. This happens because of higher quantities of precipitation in wet periods, especially in autumn which allow for higher levels of deficit irrigation without considerable yield decline. In wet periods, total barley lands were allocated to deficit irrigation, just like in normal climatic condition. Up to the distance of 2000m, it is possible to supply water to total rainfed lands because of small cultivated lands up to this distance. But with increasing water conveyance distance and a given volume of saved water, supplementary irrigation is used mostly for crops with higher economic values, i.e. lentil and chickpea. These two crops will be irrigated only up to the distance of 2000m from the irrigation network.

Table 11: Yield and allocated areas to each crop in the normal period (up to 10000m).

Crop	Irrigation Treatments	Yield (kg/ha)	Area (ha)	Rainfed Lands Beyond the Network (ha)
Barley	Full	6400	0	-
	Deficit (20-mm in November_1, 50-mm in May_2)	6100	8500	-
	Rainfed	800	5211	0
	Supplementary	-	0	-
Wheat	Full	6100	27200	-
	Deficit	-	0	-
	Rainfed	900	12414	0
	Supplementary (50-mm in November_1)	2100	4956	-
Corn	Full	12400	6800	-
	Deficit	-	0	-
Tomato	Full	59300	4250	-
	Deficit	-	0	-
Chickpea	Rainfed	700	1737	0
	Supplementary	-	0	-
Lentil	Rainfed	1000	300	0
	Supplementary (75-mm in May_3)	3000	8385	-

Table 12: Yield and allocated areas to each crop in the wet period (up to 2000m).

Crop	Irrigation Treatments	Yield (kg/ha)	Area (ha)	Rainfed Lands Beyond the Network (ha)
Barley	Full	6700	0	-
	Deficit(25-mm in November_1, 50-mm in May_2)	6400	8500	-
	Rainfed	1600	0	4036
	Supplementary	5500	1175	-
Wheat	Full	6400	27200	-
	Deficit	-	0	-
	Rainfed	1600	0	13455
	Supplementary(65-mm in November_1, 90-mm in May_2)	5400	3915	-
Corn	Full	12400	6800	-
	Deficit	-	0	-
Tomato	Full	61400	4250	-
	Deficit	-	0	-
Chickpea	Rainfed	1400	0	1345
	Supplementary(80-mm in May_3)	2200	392	-
Lentil	Rainfed	1300	0	6727
	Supplementary(75-mm in May_2)	3000	1958	-

Table 13: Yield and allocated areas to each crop in the wet period (up to 4000m).

Crop	Irrigation Treatments	Yield (kg/ha)	Area (ha)	Rainfed Lands Beyond the Network (ha)
Barley	Full	6700	0	-
	Deficit (25-mm in November_1, 50-mm in May_2)	6400	8500	-
	Rainfed	1600	2462	2749
	Supplementary	-	0	-
Wheat	Full	6400	27200	-
	Deficit	-	0	-
	Rainfed	1600	3300	9165
	Supplementary (65-mm in November_1, 65-mm in May_2)	5000	4905	-
Corn	Full	12400	6800	-
	Deficit	-	0	-
Tomato	Full	61400	4250	-
	Deficit	-	0	-
Chickpea	Rainfed	1400	821	916
	Supplementary	-	0	-
Lentil	Rainfed	1300	0	4582
	Supplementary (75-mm in May_2)	3000	4103	-

Table 14: Yield and allocated areas to each crop in the wet period (up to 6000m).

Crop	Irrigation Treatments	Yield (kg/ha)	Area (ha)	Rainfed Lands Beyond the Network (ha)
Barley	Full	6700	0	-
	Deficit (25-mm in November_1, 50-mm in May_2)	6400	8500	-
	Rainfed	1600	3707	2322
	Supplementary	-	0	-
Wheat	Full	6400	27200	-
	Deficit	-	0	-
	Rainfed	1600	7450	5015
	Supplementary (65-mm in November_1, 35-mm in May_2)	4200	4905	-
Corn	Full	12400	6800	-
	Deficit	-	0	-
Tomato	Full	61400	4250	-
	Deficit	-	0	-
Chickpea	Rainfed	1400	1236	501
	Supplementary	-	0	-
Lentil	Rainfed	1300	0	2507
	Supplementary (75-mm in May_2)	3000	6178	-

Table 15: Yield and allocated areas to each crop in the wet period (up to 8000m).

Crop	Irrigation Treatments	Yield (kg/ha)	Area (ha)	Rainfed Lands Beyond the Network (ha)
Barley	Full	6700	0	-
	Deficit (25-mm in November_1, 50-mm in May_2)	6400	8500	-
	Rainfed	1600	4569	642
	Supplementary	-	0	-
Wheat	Full	6400	27200	-
	Deficit	-	0	-
	Rainfed	1600	10325	2140
	Supplementary (65-mm in November_1, 10-mm in May_2)	3300	4905	-
Corn	Full	12400	6800	-
	Deficit	-	0	-
Tomato	Full	61400	4250	-
	Deficit	-	0	-
Chickpea	Rainfed	1400	1523	214
	Supplementary	-	0	-
Lentil	Rainfed	1300	0	1070
	Supplementary (75-mm in May_2)	3000	7615	-

Table 16: Yield and allocated areas to each crop in the wet period (up to 10000m).

Crop	Irrigation Treatments	Yield (kg/ha)	Area (ha)	Rainfed Lands Beyond the Network (ha)
Barley	Full	6700	0	-
	Deficit (25-mm in November_1, 50-mm in May_2)	6400	8500	-
	Rainfed	1600	5211	0
	Supplementary	-	0	-
Wheat	Full	6400	27200	-
	Deficit	-	0	-
	Rainfed	1600	12465	0
	Supplementary (65-mm in November_1)	2800	4905	-
Corn	Full	12400	6800	-
	Deficit	-	0	-
Tomato	Full	61400	4250	-
	Deficit	-	0	-
Chickpea	Rainfed	1400	1737	0
	Supplementary	-	0	-
Lentil	Rainfed	1300	307	0
	Supplementary (75-mm in May_2)	3000	8378	-

Table 17: Yield and allocated areas to each crop in the dry period (up to 2000m).

Crop	Irrigation Treatments	Yield (kg/ha)	Area (ha)	Rainfed Lands Beyond the Network (ha)
Barley	Full	6200	0	-
	Deficit (30-mm in November_1, 60-mm in May_2)	5800	8500	-
	Rainfed	0	0	4036
	Supplementary (80-mm in November_1, 100-mm in May_2)	3700	1175	-
Wheat	Full	5400	27200	-
	Deficit	-	0	-
	Rainfed	0	0	13455
	Supplementary (65-mm in November_1)	3600	3915	-
Corn	Full	11400	6800	-
	Deficit	-	0	-
Tomato	Full	58900	4250	-
	Deficit	-	0	-
Chickpea	Rainfed	0	0	1345
	Supplementary (100-mm in May_2)	1800	392	-
Lentil	Rainfed	0	0	6727
	Supplementary (100-mm in May_2)	2000	1958	-

Table 18: Yield and allocated areas to each crop in the dry period (up to 4000m).

Crop	Irrigation Treatments	Yield (kg/ha)	Area (ha)	Rainfed Lands Beyond the Network (ha)
Barley	Full	6200	0	-
	Deficit (30-mm in November_1, 60-mm in May_2)	5800	8500	-
	Rainfed	0	2462	2749
	Supplementary	-	0	-
Wheat	Full	5400	27200	-
	Deficit	-	0	-
	Rainfed	0	3426	9165
	Supplementary (65-mm in November_1)	2900	4779	-
Corn	Full	11400	6800	-
	Deficit	-	0	-
Tomato	Full	58900	4250	-
	Deficit	-	0	-
Chickpea	Rainfed	0	0	916
	Supplementary (100-mm in May_2)	1800	821	-
Lentil	Rainfed	0	0	4582
	Supplementary (100-mm in May_2)	2000	4103	-

Table 19: Yield and allocated areas to each crop in the dry period (up to 6000m).

Crop	Irrigation Treatments	Yield (kg/ha)	Area (ha)	Rainfed Lands Beyond the Network (ha)
Barley	Full	6200	0	-
	Deficit (30-mm in November_1, 60-mm in May_2)	5800	8500	-
	Rainfed	0	3707	2322
	Supplementary	-	0	-
Wheat	Full	5400	27200	-
	Deficit	-	0	-
	Rainfed	0	7576	5015
	Supplementary (65-mm in November_1)	2000	4779	-
Corn	Full	11400	6800	-
	Deficit	-	0	-
Tomato	Full	58900	4250	-
	Deficit	-	0	-
Chickpea	Rainfed	0	0	501
	Supplementary (100-mm in May_2)	1800	1236	-
Lentil	Rainfed	0	0	2507
	Supplementary (100-mm in May_2)	2000	6178	-

Unlike deficit irrigation, there are considerable differences between supplementary irrigation treatments in normal and wet climatic conditions. By comparing the values in Tables 8 and 13, it can be seen that in wet period, the second most profitable crop for supplementary irrigation in spring is wheat, while in normal condition, this crop is chickpea. The main reason is the considerable increase of wheat yield under supplementary irrigation which can compensate for higher chickpea price as compared to wheat.

D. Dry Climatic Condition

The allocated areas to each crop under different irrigation treatments are presented in Tables 17 to 21 in dry climatic condition. These results are very consistent with the results in normal and wet conditions with barley as the best crop for deficit irrigation. The only difference is that barley deficit irrigation levels are higher to supply more water for supplementary irrigation in rainfed lands. Also, it is obvious that supplementary irrigation is much more vital to rainfed lands since the yield of all rainfed crops are nearly zero in dry periods. The area allocated to supplementary irrigated wheat is constant for the water conveyance distance of 4000-10000m from the network. In the distance of 4000m, 80mm supplementary irrigation in autumn and 60mm in spring; in the distance of 6000m, 80mm supplementary irrigation in autumn and 10mm in spring; and in the distance of 8000-10000m, only 80mm supplementary irrigation in autumn is justifiable.

Table 20: Yield and allocated areas to each crop in the dry period (up to 8000m).

Crop	Irrigation Treatments	Yield (kg/ha)	Area (ha)	Rainfed Lands Beyond the Network (ha)
Barley	Full	6200	0	-
	Deficit (30-mm in November_1, 60-mm in May_2)	5800	8500	-
	Rainfed	0	4569	642
	Supplementary	-	0	-
Wheat	Full	5400	27200	-
	Deficit	-	0	-
	Rainfed	0	10451	2140
	Supplementary (80-mm in November_1)	1800	4779	-
Corn	Full	11400	6800	-
	Deficit	-	0	-
Tomato	Full	58900	4250	-
	Deficit	-	0	-
Chickpea	Rainfed	0	1302	214
	Supplementary (100-mm in May_2)	1800	221	-
Lentil	Rainfed	0	0	1070
	Supplementary (100-mm in May_2)	2000	7615	-

Table 21: Yield and allocated areas to each crop in the dry period (up to 10000m).

Crop	Irrigation Treatments	Yield (kg/ha)	Area (ha)	Rainfed Lands Beyond the Network (ha)
Barley	Full	6200	0	-
	Deficit (30-mm in November_1, 60-mm in May_2)	5800	8500	-
	Rainfed	0	4569	642
	Supplementary	-	0	-
Wheat	Full	5400	27200	-
	Deficit	-	0	-
	Rainfed	0	10451	2140
	Supplementary (80-mm in November_1)	1800	4779	-
Corn	Full	11400	6800	-
	Deficit	-	0	-
Tomato	Full	58900	4250	-
	Deficit	-	0	-
Chickpea	Rainfed	0	1302	214
	Supplementary	1800	221	-
Lentil	Rainfed	0	0	1070
	Supplementary (100-mm in May_2)	2000	7615	-

As to lentil, with increasing the conveyance distance, the allocated areas to supplementary irrigation increase. According to the values in Table 17, the best choices for spring supplementary irrigation are lentil and chickpea, respectively.

CONCLUSIONS

The results of this study revealed that using new management, total net income increases in rainfed and irrigated lands as compared with the conventional management. The increased values are 11.2, 13.5, 19.2, 16.6 and 15.8% in normal climatic condition, 9, 10.9, 17, 15.9 and 13.4% in wet climatic condition, and 8.1, 12.5, 16.1, 19.1 and 19.9% in dry climatic condition for the conveyance distances of 2000, 4000, 6000, 8000 and 10000m, respectively. Also, Results of Ramezani Etedali *et al*. (2013) showed that the total income was increased about 14%, if the saved water in irrigated lands is used for supplementary irrigation in rainfed lands in Kermanshah and Lorestan provinces of Iran. Also, under three different climatic conditions, barley is the only option for deficit irrigation in the lands of Qazvin irrigation and drainage network. The depths of deficit irrigation in barley lands and under normal, wet and dry climatic conditions are 20, 25 and 30mm in November_1 and 50, 50 and 60mm in May_2, respectively. Meanwhile, lentil is the optimum option for supplementary irrigation because of its higher economic value. Under normal climatic condition, the best irrigation treatment for lentil is 75mm in May_3, and under wet and dry conditions, it is 75 and 100mm irrigation in May_2, respectively. Moreover, in chickpea cultivation, the best time for supplementary irrigation is May_2 (80mm), May_3 (80mm) and June_1 (100mm) under dry, wet and normal climatic conditions, respectively. In rainfed wheat lands, a 50, 65 and 80mm irrigation in November_1 and a 90, 90 and 100mm irrigation in May_2 are the best options under dry, wet and normal climatic conditions, respectively. In rainfed barley lands, a 45, 55 and 60mm irrigation in November_1 and an80, 80 and 85mm irrigation in May_2 are the best options under different climatic conditions.

REFERENCES

Agricultural-Jihad Bureau of Qazvin Province. www.jkqazvin.ir.

Carvallo H., Holzapfel E., Lopez M., Marino M. (1998). Irrigated cropping optimization. *Journal of Irrigation and Drainage Engineering ASCE*, **124**: 67-72.

Hallaji K., Yazicigil H. (1996). Optimal management of a coastal aquifer in southern Turkey. *J. of Water Resources Planning and Management ASCE*, **122**(4): 233-244.

Harmsen K. (1984). Nitrogen fertilizer uses in rainfed agriculture. *Fertilizer. Research.* **5**: 371-382.

Hlavek R. (1992). Selection Criteria for Irrigation System. ICID, New Delhi.

ICARDA. (2005). Supplemental Irrigation in Iran: Increasing and stabilizing wheat yield in rainfed highlands. *On-farm Water Husbandry Research Report Series*, Iran.

Mainuddin M, Das Gupta A, Raj Onta P. (1997). Optimal crop planning model for an existing groundwater irrigation project in Thailand. *Agricultural Water Management*, **33**: 43-62.

Paudyal G.N. and Gupta A.D. (1990). Irrigation planning by multilevel optimization. *Journal of Irrigation and Drainage Engineering ASCE*, **116**(2): 273-291.

Raes D., Steduto P., Hsiao T.C., Fereres E. (2009). Aqua Crop-The FAO crop model for predicting yield response to water: II. Main algorithms and soft ware description. *Agronomy Journal*, **101**: 438-447.

Raju K.S., Kumar D.N. (1999). Multicriterion decision making in irrigation planning. *Agricultural System*, **62**. 117-129.

Ramezani Etedali H., Liaghat A., Parsinejad M., Ramezani Etedali M. (2012). Status of Agricultural Droughts Based on Soil Moisture in Qazvin Synoptic Station. *Journal of Water Research in Agriculture*, **26**(1): 83-93. (In Persian).

Ramezani Etedali H., Liaghat A., Parsinejad M., Tavakkoli A.R., Bozorg Haddad O., Ramezani Etedali M. (2013). Water Allocation Optimization for Supplementary Irrigation in Rainfed Lands to Increase Total Income (Case Study: Upstream Karkheh River Basin). *Journal of Irrigation and Drainage*, **62**: 74-83.

Ramezani Etedali H. (2012). Development of an Optimization Model for Water Allocation in Irrigated and Rainfed Lands to increase Economical Productivity. Ph.D. Thesis. University of Tehran, Iran. (In Persian).

Reca J., Roldan J., Alcaide M., Lopez R., Camacho E. (2001). Optimization model for water allocation in deficit irrigation systems. I. Description of the model. *Agricultural Water Management*, **48**: 103-116.

Rockström J., Hatibu N., Oweis T., Wani S.P. (2007). Managing water in rainfed agriculture in: Molden, D. (ed.) Water for food, Water for life: a Comprehensive International Water Management Institute (IWMI), Colombo, Sri Lanka, pp. 315-348.

Sethi L.N., Panda S.N., Nayak M.K. (2002). Optimal crop planning and conjunctive use of water resources of a coastal river basin. *Water Resource Management*, **16**(2): 145-164.

Sethi L.N., Sudhindra N., Panda S.N., Manoj K., Nayak M.K. (2006). Optimal crop planning and water resources allocation in a coastal groundwater basin, Orissa, India. *Agriculture water management,* **83**(3): 209-220.

Singh D.K., Jaiswal C.S., Reddy K.S., Singh R.M., Bhandarkar D.M. (2001). Optimal cropping pattern in a canal command area. *Agricultural Water Management,* **50**(1), 1-8.

Tavakkoli A.R., Liaghat A., Alizadeh A., Oweis T., Parsinejad M. (2010). Improvement of water productivity by conjunctive management of limited irrigation and advanced agronomic practices in rainfed cereals farming areas. PhD Thesis. University of Tehran, Iran. (In Persian).

Tavakkoli A.R., Oweis T. (2004). The role of supplemental irrigation and nitrogen in producing bread wheat in the highlands of Iran. *Agricultural Water Management,* **65**, 225-236.

Tavakkoli A.R., Oweis T., Ferri F., Haghighat A., Belson V., Pala M., Siadat H., Ketata H. (2005). Supplemental irrigation in Iran: Increasing and stabilizing wheat yield in rainfed highlands. *On-farm Water Husbandry Research Report Series* No. 5. 46 pp.

Tehran Regional Water Company. (2006). Review of Qazvin Irrigation and Drainage Network. Final report. (In Persian).

Zhang L., Oweis T. (1999). Water- yield relation and optimal irrigation scheduling of wheat in the Mediterranean region. *Agricultural Water Management,* **38**: 195-211.