LINKED WATER ALLOCATION IN IRRIGATED AND RAINFED LANDS

ALLOCATION D'EAU LIEE AUX TERRES IRRIGUEES ET AUX TERRES IRRIGUEES PAR L'EAU PLUVIALE

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ABSTRACT

There are many restrictions on water resources in arid and semiarid regions of the world. Thus, any water that is allocated for irrigation must be properly managed to maximize its use efficiency. Limited number of supplementary irrigation as a management strategy is useful in improving yield and water use efficiency in rainfed crops. But when and how to do that is the main challenge, because water resources are restricted. Therefore, a compromise in water allocation between irrigated and rainfed crops could be a desirable solution. In this study, optimizing models are used for managing water allocation in irrigated and rainfed fields. The 1st step investigates irrigation feasibility of the rainfed fields in terms of slope and distance. The water resources for single/supplementary irrigation in rainfed fields are saved through deficit irrigation in irrigated fields. Comprehensive studies have confirmed that the increased yields by single/supplementary irrigation in rainfed fields are greater than the decreased yields using deficit irrigation in irrigated fields. Therefore, the 2nd step optimizes water allocation between irrigated and rainfed fields in order to maximize total economic benefits (first scenario). The results of this study showed that the total benefit of grain and legume crops were increased by 442,874 and 397,149 million rials (1 USD = 10500 rials) in Kermanshah and Lorestan provinces, respectively. If the saved water is applied only for supplementary irrigation on rainfed grain crop fields, the total benefit increases by 8.3 and 16.3 per cent in Kermanshah and Lorestan provinces, respectively, as compared to the current total benefit, but, it decreases by 2.4 and 2.8 per cent, respectively, in these two provinces as compared to the first scenario.

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Key words: *total benefit, supplementary irrigation, deficit irrigation, optimization.*

RESUME

Il existe beaucoup de restrictions sur les ressources en eau dans les régions arides et semiarides du monde. Donc, toute eau allouée à l'irrigation doit être correctement gérée pour maximiser son efficience d'utilisation. Le nombre limité d'irrigation supplémentaire telle qu'une stratégie de gestion est utile pour améliorer le rendement et l'efficience d'utilisation De l'eau en agriculture pluviale. Le grand défi qui se pose ici est de rechercher le temps et le moyen approprié pour utiliser l'eau supplémentaire dans la situation de la disponibilité limitée de l'eau. Donc, la solution désirable est d'accepter un compromis entre l'allocation d'eau aux cultures irriguées et aux cultures irriguées par l'eau pluviale. Dans cette étude, les modèles d'optimisation sont utilisés pour la gestion d'eau. La 1ère étape examine la faisabilité d'irrigation des champs irrigués par l'eau pluviale en ce qui concerne la pente et la distance. Les ressources en eau d'irrigation simple/supplémentaire des champs irrigués par l'eau pluviale sont économisées par l'irrigation déficitaire.

Les études compréhensives ont confirmé l'augmentation du rendement par l'irrigation simple/supplémentaire dans les champs irrigués par l'eau pluviale. Les rendements diminuent en utilisant l'irrigation déficitaire dans ces champs. Donc, la 2ème étape optimise l'allocation d'eau entre les champs irrigués et les champs irrigués par l'eau pluviale pour maximiser les avantages économiques totaux (premier scénario). Les résultats de cette étude ont montré que l'avantage total de grain et de culture légumineuse a été augmenté de 442,874 et 397,149 millions de rials (1 $ EU = 10500 rials) dans les provinces de Kermanshah et de Lorestan respectivement. Si l'eau économisée est appliquée seulement en irrigation supplémentaire des champs irrigués par l'eau pluviale, l'augmentation d'avantage total était de 8,3 et 16,3 pour cent dans les provinces de Kermanshah et de Lorestan respectivement, par rapport à l'avantage total actuel. Mais, il diminue de 2,4 et 2,8 pour cent respectivement, dans ces deux provinces par rapport au premier scénario.

Mots clés : *Avantage total, irrigation supplémentaire, irrigation déficitaire, optimisation.*

1. INTRODUCTION

There are many restrictions on water resources quantity and quality in arid and semiarid regions. Management of water allocation in irrigated fields is essential for maximizing water use efficiency. The traditional irrigation is based on providing adequate water to maximize crop yields (Doorenbos and Pruitt, 1992). Because of water supply constraints, this concept is changing (English et al., 2002; Bouman, 2007).

On the other hand, rainfed fields cover 82% of all agricultural lands and produce 60% of the yield in the world (Tavakoli, 2005). In rainfed fields of Iran, water use efficiency (WUE) is 0.3-0.5 kg/m3. The average yield is 20% of the potential yield in rainfed fields and it could be increased to 80% through good management practices (Rockstrom et al., 2007).

The potential to improve productivity in the semi-arid regions depends on appropriate adaptation to rainfall patterns. Supplementary irrigation (SI) is a common practice in rainfed fields of the Mediterranean-type climate (Duivenbooden et al., 1999). Application of a limited amount of water to rainfed crops increased crop yield substantially and stabilized it over years (Oweis et al., 1999a). For highest impact, water is applied at the most sensitive stages of crop growth. It was found that one to three irrigations of 75–200 mm total (depending on the annual amount of rainfall and its distribution) are needed in the rainfed zone in the north of Syria where the annual rainfall ranges between 250 and 500 mm. These irrigations are mostly needed in April and May. The farmer in the Mediterranean-type climate sows all the area with wheat in early November. This is recommended if enough moisture is available. Supplementary irrigation is needed when natural precipitation is not adequate to secure grain and forage production (Abu-Awwad and Kharabsheh, 2000).

Magombeyi et al. (2009) in the Limpopo Basin for three different rainfall seasons found large yield responses to supplementary irrigation of maize, ranging from 67 to 314 per cent, with the highest responses in the driest years. The amounts of supplementary irrigation to achieve these responses were relatively small–110 mm in the driest year, and 50 mm in the wettest year.

The potential for supplementary irrigation was investigated in the semi-arid Karkheh river basin (Tavakoli et al. 2008). Use of a single supplementary irrigation roughly doubled the yields of wheat and barley by giving enough time for good crop establishment before the onset of winter frosts. While full supplementary irrigation gave maximum yield, applying one irrigation in spring increased wheat grain yield by about one-third, but with much lower irrigation water productivity (0.9 kg/m^3) than for a single irrigation prior to sowing (3.4 kg/m^3). In water scarce situations, the timing of the supplementary irrigation is critical. Results from SI research show substantial increases in crop yields in response to the application of relatively small amounts of SI (Oweis, et al., 1998).

Single and supplementary irrigation are new management strategies for improving yield and water use efficiency in rainfed fields (Zhang and Oweis. 1999, Tavakoli, et al. 2004, 2005). But water allocation for these practices in rainfed fields is the main challenge because water resources are restricted. So the purpose of this paper is to present a water allocation management between irrigated and rainfed fields in order to increase food productivity and total economic benefit.

2. MATERIALS AND METHODS

Kermanshah and Lorestan are the two main provinces in southwest of Iran, located in the upstream of Karkheh river basin (Fig. 1). Both the provinces have a semi-arid to arid climate and most of the agricultural area is rainfed and livelihoods depend mainly on rainfed farming. Grains (such as wheat and barley) and legumes (such as chickpea and lentil) are planted in large area of irrigated and rainfed fields in both the provinces. Chickpea and lentil are planted in rainfed farming. These crops have almost the same planting and harvesting time.

Supplementary irrigation is strongly recommended to increase crop and water productivity in rainfed fields of upstream Karkheh river basin (Tavakoli and Oweis, 2004). But water allocation for these practices in rainfed fields is the main challenge because water resources are restricted. In addition, some technical restrictions such as; topography, slope and distance to water resources, pose problems for the rainfed fields if supplementary irrigation is to be used on those area.

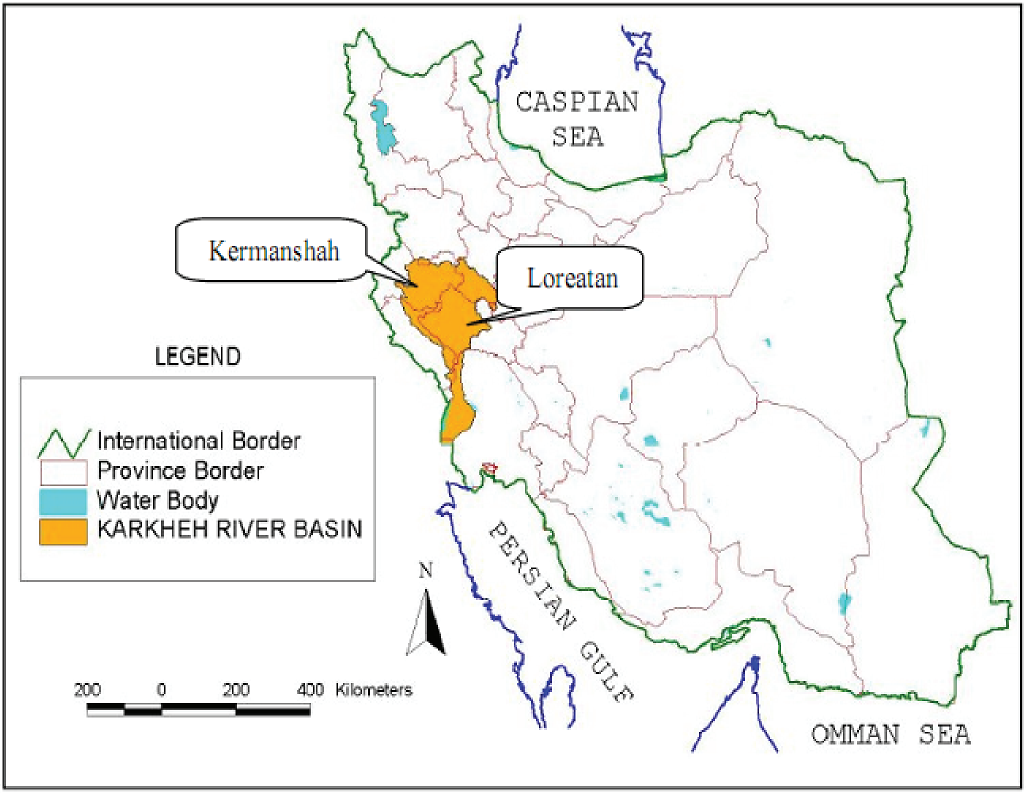

Fig. 1. The location of Kermanshah and Lorestan provinces and the upstream of Karkheh river basin (Tavakoli et al., 2011)

Tavakoli et al., (2011) identified potential areas that would be prime candidates for government programs to introduce supplementary irrigation. They applied Geographic Information Systems (GIS) tools. In their most simple concept, such areas would be characterized by the presence of arable soils, non-constraining slopes, agricultural land use, and within a distance from, or an elevation difference with, existing irrigation schemes that does not impose uneconomical costs of water conveyance or pumping. Another typical question that agricultural planner might ask is how much (and where) additional land within the neighborhood of existing irrigation schemes would be needed if the available water discharge is to be used to provide supplementary irrigation in winter. For this, iso-potential maps were used with overlaying of single vector themes related to terrain and land use. At least 3 layers were considered adequate in order to generate the iso-potential map: land use/land cover, slope map, river segment layer and a detailed soil map to determine priorities of allocation.

Also the results of Tavakoli et al., (2010), Mousavi and Shakarami (2008) and Gorji et al., (2004) are used for estimation of yield in rainfed fields that receive supplementary irrigation. The results of Tavakoli et al., (2010) confirmed the effect of supplementary irrigation on wheat and barley yields in the Kermanshah and Lorestan provinces (upper Karkheh river basin). Also Mousavi and Shakarami (2008) carried out an experiment in 2008 to investigate the effects of different irrigation regimes and Chickpea cultivars on chickpea production in Lorestan. The experiment was split–plot in a randomized complete block design with 3 replications. Supplementary irrigation at 8 levels (1-rainfed without irrigation, 2-Irrigation after Sowing, 3-Irrigation at flowering, 4-Irrigation at pod fill, 5-Irrigation at sowing+flowering, 6-rrigation at sowing+pod fill, 7- Irrigation at flowering+pod fill, 8-Irrigation at sowing+flowering+pod fill) was allocated to main plots. 20 mm water was applied for every irrigation. Also Gorji et al. (2004) investigated the effect of supplementary irrigation in sowing+flowering+pod fills periods on lentil. The total water application was 40 mm.

In this study, an optimizing model will be used for water allocation in irrigated and rainfed fields. The water resources for supplementary irrigation in rainfed fields are saved through deficit irrigation in irrigated fields. The supplementary irrigation in rainfed fields and deficit irrigation in irrigated fields have dissimilar effect on yield, the first one increases and the second one decreases the yield. Thus, the model optimizes water allocation between both the areas (rainfed and irrigated lands) to maximize total benefit. Finally, for every crop the optimum area for full irrigation, deficit irrigation, supplementary irrigation and rainfed are determined by considering total benefits. In this study the objective function (total benefit) is used as Eq. 1:

$$OF: \ Maximize \quad TB = \sum_{c=1}^{k} \sum_{i=1}^{n} \left[B_{c,i} \right] \qquad (1)$$
$$B_{c,i} = Y_{c,i} \times P_{c,i} \times A_{c,i}$$

Which TB (Rials) is the total benefit from irrigated and rainfed fields, c is crop index in irrigated and rainfed fields, i is irrigation managements (full, 30, 40 and 50% deficit irrigation and supplementary irrigation and rainfed). Also Y is the yields per unit area (kg/ha) and P is the price of crops (rials/kg) (the prices of wheat, barley, chickpea and lentil were taken from Jihad-Agriculture ministry to be 3050, 2700, 6480 and 6480 rials/kg, respectively) and A is the crop area under different irrigation managements (ha).

The main constraints of the objective function are:

The total irrigated area for each crop under different irrigation managements (full, 30, 40 and 50% deficit irrigation) in each province is equal to total available irrigated area for that crop (TAIAC) (Eq. 2).

$$\sum_{c=1}^{k} \sum_{i=1}^{n} \left[A_{c,i} \right] = TAIAC \qquad (2)$$

Also, the total rainfed area for each crop under different rainfed managements (the different treatments of supplementary irrigation and rainfed) in each province is equal to total available rainfed area for that crop (TARAC) (Eq. 3).

$$\sum_{c=1}^{k} \sum_{i=1}^{n} \left[A_{c,i} \right] = TARAC \qquad (3)$$

Other constraint considers suitable rainfed area for supplementary irrigation. The total rainfed area for each crop under different treatments of supplementary irrigation in each province is lower or equal to the suitable rainfed area for supplementary irrigation (PSRASI*TARAC) (Eq. 4).

$$\sum_{c=1}^{k}\sum_{i=1}^{n}\left[A_{c,i}\right] \leq PSRASI*TARAC \qquad (4)$$

The total water volume for irrigation in rainfed and irrigated fields is equal to total available water volume in each province (TAWV: m^3).

$$\sum_{c=1}^{k}\sum_{i=1}^{n}\left[d_{c,i}*10*A_{c,i}\right] = TAWV \qquad (5)$$

Where $d_{c,i}$ is depth of applied water for each crop under different irrigation managements (mm) and A is area (ha). The Lingo 8.0 was used for optimizing model.

3. RESULTS AND DISCUSSION

The areas and yields of two main grains (wheat, barley) and two main legumes (chickpea and lentil) in both the provinces are presented in Table 1. The area of rainfed fields is more than the one in irrigated fields.

Table 1. The areas and yields of wheat, barley, chickpea and lentil in the Kermanshah and Lorestan provinces (2008-2009)

Crop	Kermanshah		Lorestan	
	Area (ha)	Grain yield (kg/ha)	Area (ha)	Grain yield (kg/ha)
Wheat (irrigated)	78461	5305	50591	3087
Wheat (Rainfed)	347238	1175	323503	1121
Barley (Irrigated)	17737	468	9029	2575
Barley (Rainfed)	163302	1335	129949	1067
Chickpea (Rainfed)	135152	351	101149	293
Lentil (Rainfed)	1326	574	17417	345
Total irrigated	160190	-	115815	-
Total Rainfed	647018	-	578442	-

Tavakoli et al., (2011) reported that upstream of Karkheh river basin about 36.7% of rainfed areas have 0-5% slope, 50.2% have 0-8%, 62.9% have 0-12%, 79.20% have 0-20% slope and 20.8% are not suitable for cultivation. Almost 31.4% of the suitable rainfed areas are located within 1000 meter-border strips adjusted to irrigation areas. Frequency of 0-5%, 5-8%, 8-12% and 12-20% slope classes are 17, 4.8, 4.4 and 5.3%, respectively. Nearly

46.5% of the suitable rainfed areas are located within a 1000 meter buffer distance from surface streams. Frequency of 0-5, 5-8, 8-12 and 12-20% slope classes inside river buffer zones are 22.4, 7.9, 7.2 and 9%, respectively. Finally 15.6% of the rainfed fields has first priority and 4.3% has second priority for supplementary irrigation development in rainfed fields upstreamof Karkheh river basin (Fig. 2). Consequently, the results showed that about 20% of the rainfed fields upstream of Karkheh river basin are suitable for supplementary irrigation (PSRASI≤0.20) which was included in the objective constraints.

Tavakoli et al., (2010) studied the effect of supplementary irrigation on wheat and barley yields during 2005-08 cropping seasons in the Kermanshah and Lorestan provinces (Upper Karkheh River Basin). The treatments included four levels of supplementary irrigation: Rainfed, single irrigation of 50 mm at spring time (SI spring), single irrigation of 75 mm at planting time (SI planting) and 125 mm irrigations at planting and spring times (SI planting+spring) (Table 2).

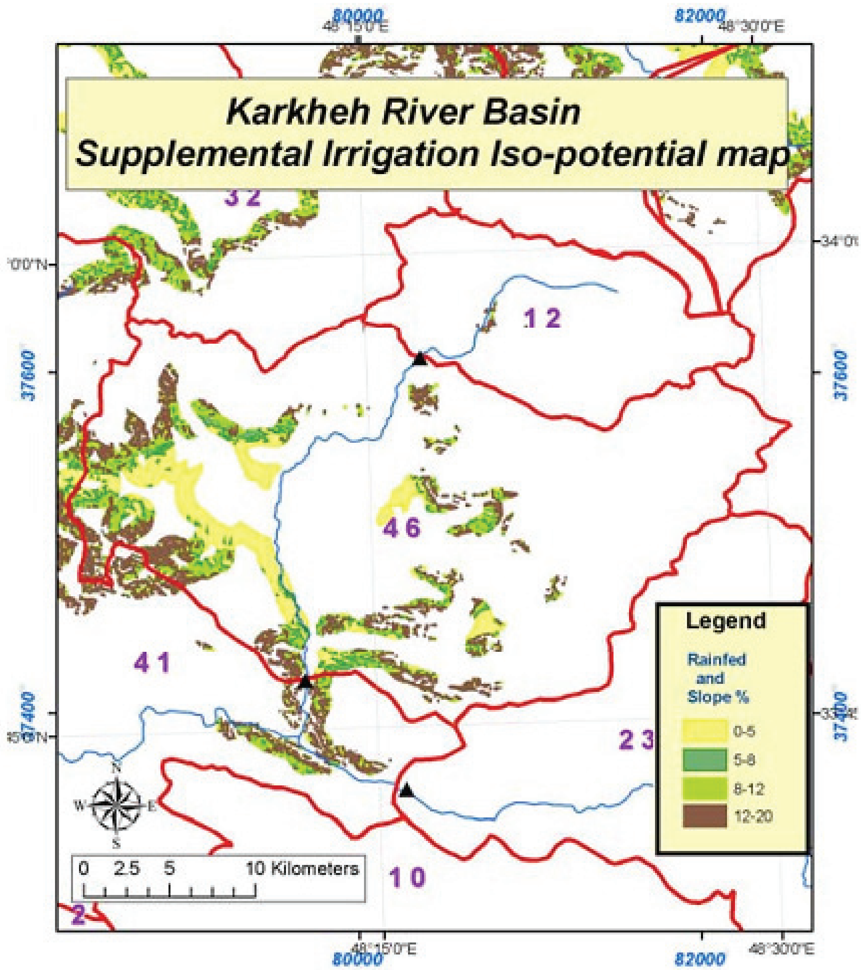

Fig. 2. Suitable rainfed areas for supplementary irrigation in upper Karkheh river basin (Tavakoli et al. 2011)

Table 2. The results of yields of wheat and barley under different treatments supplementary irrigation

Province	Crop	SI planting (75 mm)	SI spring (50mm)	SI planting+spring (125 mm)
Kermanshah	Wheat	2429	2559	2773
	Barley	2634	2939	2630
Lorestan	Wheat	2764	2983	3425
	Barley	2494	2143	-

Also the results of Mousavi and Shakarami (2008) and Gorji et al. (2004) for investigation of the effect of supplementary irrigation on chickpea and lentil are presented in table 3.

Table 3. The results of yields of chickpea and lentil under different treatments supplementary irrigation

Crop	SI sowing (20 mm)	SI flowering (20 mm)	SI pod fill (20 mm)	SI sowing+ flowering (40 mm)	SI sowing+ pod fill (40 mm)	SI flowering+ pod fill (40 mm)	SI sowing+ flowering+ pod fill (60 or 40 mm) *
Chickpea	418	626	495	695	592	878	1139
Lentil	-	-	-	-	-	-	752

• For Chickpea, 60 mm and for Lentil, 40 mm water was applied.

Results of Ramezani et al. (2009) showed that 30, 40 and 50% deficit irrigation caused about 15, 22 and 35% yield reduction in wheat and 15, 17 and 25% yield reduction in barley.

Considering the aforementioned results, the objective function and constraints are modified for Kermanshah and Lorestan provinces. The results of the first optimizing model for area (optimized area) and total benefit are presented in Table 4.

Table 4. The results of the first optimized areas of each crop under different treatments irrigation

Crops	Irrigation managements	Kermanshah		Lorestan	
		present Area (ha)	optimized Area (ha)	present Area (ha)	optimized Area (ha)
Wheat	Full irrigation	78461	32952.56	50591	0
	30% deficit irrigation	0	45508.44	0	0
	40% deficit irrigation	0	0	0	50591
	50% deficit irrigation	0	0	0	0
	SI plating	0	0	0	0
	SI spring	0	69447.6	0	64700.6
	SI planting+spring	0	0	0	0
	Rainfed	347238	277790.4	323503	258802.4
Barley	Full irrigation	17737	0	9029	0
	30% deficit irrigation	0	0	0	0
	40% deficit irrigation	0	17737	0	0
	50% deficit irrigation	0	0	0	9029
	SI plating	0	0	0	25989.8
	SI spring	0	32660.4	0	0
	SI planting+spring	0	0	0	0
	Rainfed	163302	130641.6	129949	103959.2
Chickpea	SI sowing	0	0	0	0
	SI flowering	0	27030.4	0	10901.33
	SI pod fill	0	0	0	0
	SI sowing+ flowering	0	0	0	0
	SI sowing+ pod fill	0	0	0	0
	SI flowering+ pod fill	0	0	0	0
	SI sowing+ flowering+ pod fill	0	0	0	9328.475
	Rainfed	135152	135134	101149	91802.52
Lentil	SI sowing+ flowering+ pod fill	0	265.2	0	0
	Rainfed	1326	1060.8	17417	17417
Total benefit (Rials)		3.639E+12	4.036E+12	2.251E+12	2.694E+12

If the first optimized area and the modern managements are used in both provinces, the total benefit from these crops increases 10.9 and 19.7% which is equal to 442,874 and 397,149 million rials (1 USD = 10500 rials) in Kermanshah and Lorestan provinces, respectively. Also if the results of optimizing model are used, the total production of wheat, barley, chickpea and lentil increase 7.3, 12.7, 35.7 and 6.2% in Kermanshah and 16.6, 19.3, 49.5 and 0.0% in Lorestan province (Figs. 3 and 4).

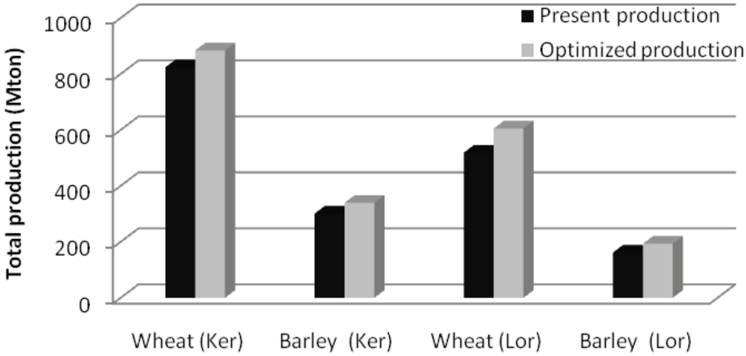

Fig. 3. The total production of wheat and barley in Kermanshah and Lorestan provinces

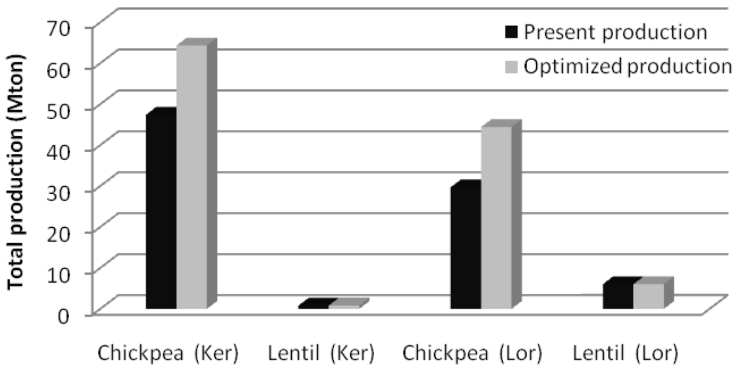

Fig. 4. The total production of chickpea and lentil in Kermanshah and Lorestan provinces

Figure 4 shows that chickpea has the maximum increased production rate. But the grains (especially wheat) are strategic crops that are considered as constraints in optimizing model (the second optimizing model). The results of second optimizing model considering only supplementary irrigation in rainfed fields of grains are presented in Table 5. This table shows that the total benefit increases 8.3 and 16.3% in Kermanshah and Lorestan provinces, respectively as compared to the current situation. However it is decreased by 2.4 and 2.8%, respectively as compared to the first optimizing model. Therefore, the second optimizing model doesn't have noticeable effect on total benefit.

The results of the second optimizing model indicate that the total production of wheat and barley increase 7.9 and 12.7% in Kermanshah and 35.2 and 30.2% in Lorestan province (Fig. 5) and the total production of chickpea and lentil are equal to the present and optimized production. Also the production of wheat and barley was increased 0.6 and 0.0% in Kermanshah and 15.9 and 9.1% in Lorestan province as compared to the first optimizing model. However, the production of chickpea and lentil decreases 26.3 and 5.8% in Kermanshah and 33.1 and 0.0 in Lorestan as compared to the first optimizing model (Fig. 6).

Table 5. The results of the second optimized areas of each crop under different treatments irrigation

Crops	Irrigation managements	Kermanshah		Lorestan	
		present Area (ha)	optimized Area (ha)	present Area (ha)	optimized Area (ha)
Wheat	Full irrigation	78461	39077.18	50591	0
	30% deficit irrigation	0	39383.82	0	23886.2
	40% deficit irrigation	0	0	0	26704.8
	50% deficit irrigation	0	0	0	0
	SI plating	0	0	0	0
	SI spring	0	69447.6	0	64700.6
	SI planting+spring	0	0	0	0
	Rainfed	347238	277790.4	323503	258802.4
Barley	Full irrigation	17737	0	9029	0
	30% deficit irrigation	0	0	0	0
	40% deficit irrigation	0	17737	0	9029
	50% deficit irrigation	0	0	0	0
	SI plating	0	0	0	25989.8
	SI spring	0	32660.4	0	0
	SI planting+spring	0	0	0	0
	Rainfed	163302	130641.6	129949	103959.2
Chickpea	Rainfed	135152	135152	101149	101149
Lentil	Rainfed	1326	1326	17417	17417
Total benefit (Rials)		3.639E+12	3.939E+12	2.251E+12	2.619E+12

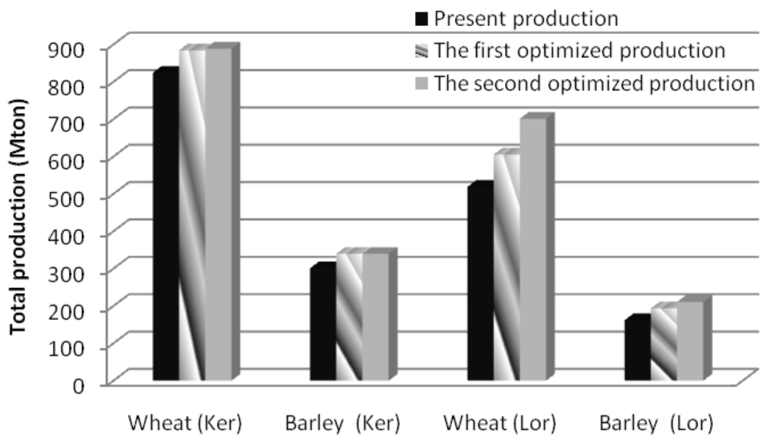

Fig. 5. The present, first and second total production of wheat and barley

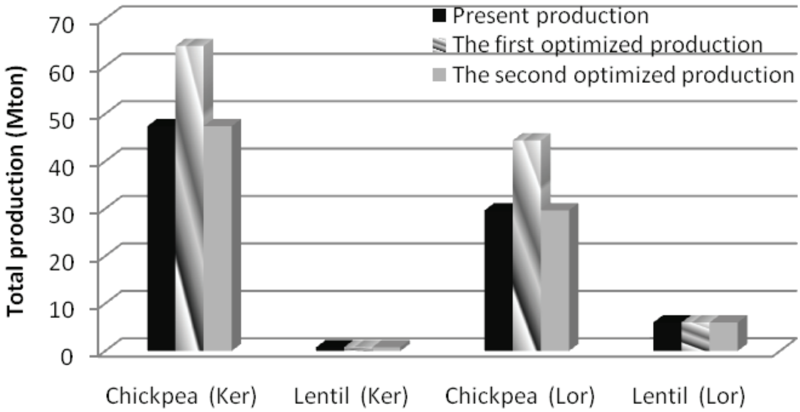

Fig. 6. The present, first and second total production of chickpea and lentil

4. CONCLUSIONS

Supplementary irrigation is new management strategies for improving yield and water use efficiency in rainfed fields. But water allocation for these practices in rainfed fields is the main challenge because water resources are restricted. So water allocation management between irrigated and rainfed fields and optimization the total benefit from irrigated and rainfed fields are necessary. The results showed that the total benefit from grains and legume crops increase about 10.9 and 19.7% in Kermanshah and Lorestan provinces, respectively. Also if only supplementary irrigation is done in rainfed fields of grains, the results showed that the total benefit increases 8.3 and 16.3% in Kermanshah and Lorestan provinces, respectively, as compared to the current situation. But it decreases 2.4 and 2.8% in Kermanshah and Lorestan provinces, respectively as compared to the first optimizing model. The total benefit increases 8.3 and 16.3% in Kermanshah and Lorestan provinces, respectively as compared to the current situation. However it is decreased by 2.4 and 2.8% in Kermanshah and Lorestan provinces, respectively, as compared to the first optimizing model. Therefore, the second optimizing model doesn't have noticeable effect on total benefit.

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