ECONOMIC ANALYSIS OF DEFICIT-IRRIGATION UNDER VARIABLE SEASONAL RAINFALL FOR STRATEGIC CROPS (WHEAT AND BARLEY) IN A SEMI-ARID REGION OF IRAN

L'ANALYSE ECONOMIQUE DU DEFICIT SOUS-IRRIGATION VARIABLE SAISONNIERE DES PLUIES POUR LES CULTURES STRATEGIQUES (BLE ET ORGE) DANS UNE REGION SEMI-ARIDES DE I'IRAN

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ABSTRACT

Maximum yield may be obtained with fulfillment of the full crop water requirements. However, practicing deficit irrigation could increase the irrigated area or frequency of cultivation. Optimum water use in deficit irrigation is obtained by an economic analysis using production and cost functions. The objective of this paper was to conduct economic analysis for optimum seasonal irrigation water application by considering seasonal rainfall under water and/or land limitations for wheat and barley in Isfahan province, Iran. An equation was presented to determine the optimum amount of irrigation water under land limiting condition (w_l) for both crops, as a function of growth period's rainfall and unit price of irrigation water. Optimum amount of irrigation under water limiting condition (w_w) depends on rainfall. The results showed that values of w_w and w_l for different years decreased as the seasonal rainfall increased. The greatest applied water reduction occurred at water limiting condition (16-39%) for 0-0.25 m seasonal rainfall for wheat, and 27-58% for 0-0.2 m seasonal rainfall for barley. The greatest income per unit applied water was obtained for water limiting condition. It increased from 37% to 51% for 0-0.25 m seasonal rainfall for wheat and from 54% to 88% for 0-0.2 m seasonal rainfall for barley, with respect to maximum yield. In water limiting condition, the cultivated land increased from 20% to 64% and from 37% to 141% for wheat and barley, respectively. In order to attain more net benefit, values of w_w and w_l must be decreased by increasing the water price.

Keywords: Economic analysis, Deficit irrigation, Land limiting**,** Water limitation

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INTRODUCTION

Water shortage is the major constraint to agricultural production. The relationships between crop yield and water use have been a major focus of agricultural research in the arid and semi-arid regions (Zhang and Oweis, 1999). Water management is very important in these regions. Therefore, innovations are needed to increase the efficiency of using the available water resources. One approach is to develop new irrigation scheduling techniques, such as deficit irrigation, which are not necessarily based on full crop water requirement. Deficit irrigation is one way of maximizing water use efficiency (WUE) for higher yields per unit of irrigation water applied. In this method, the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season (English and Raja, 1996). Many researchers have studied the effects of deficit irrigation on crop production (Zhang et al., 1999; Kang et al., 2002). Maximum yield may be obtained with the fulfillment of complete crop water requirements. However, practicing deficit irrigation could increase the irrigated area or frequency of cultivation. Optimum water use in deficit irrigation is obtained by an economic analysis using yield and cost functions as described by English and James (1990). However, there is uncertainty or risk associated with these estimates of optimal water use due to the fact that water-production function is affected by a number of unpredictable factors, among which the amount of seasonal rainfall is an important one, which has not been considered in deficit irrigation analysis. The fact that there is a risk does not preclude using deficit irrigation. English (1981) has shown that farmers will adjust their water use to reduce risk, but will accept some degree of risk in exchange for potential economic gains. Nevertheless, the concern for risk implies that the effects of seasonal rainfall on crop production function should be considered. Seasonal rainfall was considered in the economic analysis for optimum seasonal irrigation water application for cotton (a summer crop) and wheat (a winter crop) by Sepaskhah and Akbari (2005).

The objective of this paper was to conduct an economic analysis for optimum seasonal irrigation water application by considering seasonal rainfall under water and land limitations for wheat and barley in Isfahan province, central Iran.

MATERIALS AND METHODS

1- Conceptual model

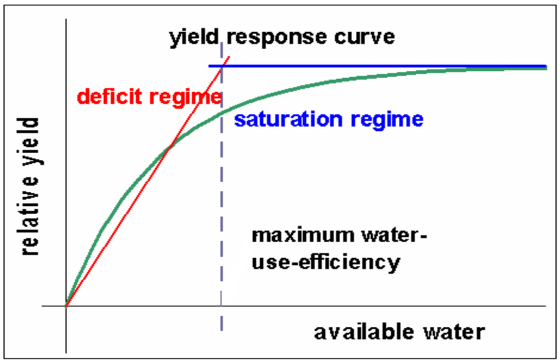
Crop yield increases with water availability in the root zone, until saturation level, above which there is little effect or may be adverse effects. Yield response curve of specific crops depends on weather conditions and soil type as well as agricultural inputs (Figure 1).

The curvilinear revenue function of Figure 2 represents a gross income curve. The level of irrigation that would maximize yield is shown as w_m. The straight line represents a cost function relating total production costs to applied water. If land is limiting, optimum irrigation strategy would be to apply the amount of water (w_l) which maximizes net income derived from each unit of land. This will be somewhat

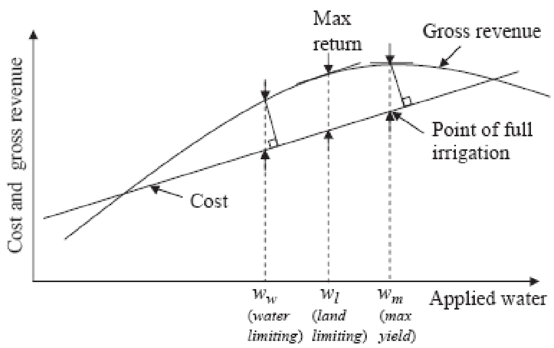
less than w_m (since the two curves are diverging to the left of w_m). If more water is used, the profit will be reduced as the curves converge. According to economic theories, w_l will be a point where the value of marginal product just equals marginal costs. Here, the slope of cost function equals the slope of gross income curve.
If applied water is reduced to a level below w_l an equivalent income point will be reached where w_w results in a net income per unit of land just equal to the net income from full irrigation. Within the range of w_m and w_l, profit will be greater than that at full irrigation. It is possible to derive a set of equations to estimate values of aforementioned variables (w_m, w_l and w_w). Such equations would be useful for analysis of optimum water use for system design and operation (Hargreaves and Samani, 1984). The profit to be realized from irrigation will be determined by the amount of water applied, antecedent soil moisture content, shape of the crop production function, variable and fixed costs of irrigation, and crop price. The amount of applied water may be complemented by seasonal rainfall which is variable in different years. Therefore, the derivation procedure for $w_{m,}$ w_l, and w_w under presence of seasonal rainfall is different from those under the absence of seasonal rainfall.

2- Deficit irrigation analysis

Deficit irrigation of wheat and barley were analyzed with the method of English (1990):



"Figure 1". Relationship between relative yield and available water (Relations entre le rendement relatif et la disposition de l'eau)



"Figure 2". Revenue and cost functions (Des recettes et des fonctions de coût)

$$I_f(w) = A.I_l(w) \quad (1)$$

$$I_l(w) = P_c y(w) - c(w) \quad (2)$$

where, A is total irrigated area (ha), w is applied water per unit area of land (m^3ha^{-1}), y(w) is yield per unit area (kg ha^{-1}), c(w) is production costs per unit area (Rials ha^{-1}), P_c is crop price (Rials kg^{-1}), $I_l(w)$ is net income per unit area (Rials ha^{-1}), and $I_f(w)$ is net income from all irrigated lands (Rials ha^{-1}). At the present time, each US Dollar is 10060 Rials.

The level of water use that will maximize yield (w_m) can be determined by taking the derivative of yield function:

$$\frac{\partial y(w)}{\partial w} = 0 \quad (3)$$

The value of w that satisfies Eqn. (3) will be w_m.

To determine the level of water use that will maximize net income when land is limiting, we take partial derivative of Eqn. (1) with respect to w:

$$\frac{\partial I_f(w)}{\partial(w)} = A\frac{I_l(w)}{\partial w} + I_l\frac{\partial A}{\partial w} \quad (4)$$

If land is a limiting factor, A is presumed constant. Therefore by setting its derivative to zero and eliminating A, then optimum level of water can be found as:

$$\frac{\partial I_l(w)}{\partial(w)} = 0 \quad (5)$$

Equation (5) can be written as:

$$\frac{\partial I_l(w)}{\partial(w)} = P_c\frac{\partial y(w)}{\partial(w)} - \frac{\partial c(w)}{\partial(w)} \quad (6)$$

Therefore when land is limiting the optimum level of water can be written as:

$$P\left(\frac{\partial y(w)}{\partial (w)}\right) = \frac{\partial c(w)}{\partial (w)} \tag{7}$$

and when water is limiting, Eqn. (4) is written as:

$$A\frac{\partial I_l(w)}{\partial (w)} + I_l(w)\frac{\partial A}{\partial w} = 0 \tag{8}$$

$$w[Pc\frac{\partial y(w)}{\partial w} - \frac{\partial c(w)}{\partial w}] = Pcy(w) - c(w) \tag{9}$$

Solving Eqn. (7) and Eqn. (9) for w will yield the optimal values of applied water, w_l and w_w.
By substituting w_m into Eqn. (2) the net income under full irrigation is determined as:

$$I_l(w_m) = P_c y(w_m) - c(w_m) \tag{10}$$

The yield and costs functions can be represented by:

$$y(w) = a_1 + b_1 w + c_1 w^2 \tag{11}$$

$$c(w) = a_2 + b_2 w \tag{12}$$

where a_1, b_1, c_1, a_2 and b_2 are constant, y(w) is yield per unit of land (kg ha^{-1}), c(w) is production costs per unit of land (Rials ha^{-1}) and w is water consumption under the absence of annual rainfall.
The two levels of water use can then be shown as:

$$w_m = -\frac{b_1}{2c_1} \tag{13}$$

$$w_l = \frac{b_2 - P_c b_1}{2P_c c_1} \tag{14}$$

$$w_w = \left[\frac{P_c a_1 - a_2}{P_c c_1}\right]^{0.5} \tag{15}$$

3- Deficit irrigation analysis under the presence of rainfall

The yield function under the presence of rainfall can be represented by:

$$y(w') = a_1' + b_1' w' + c_1' w'^2 \tag{16}$$

where, a 1, b 1 and c 1 are constants and w is sum of seasonal applied water and rainfall (R) as:

$$w' = w + R \tag{17}$$

Therefore, Eqn. (16) is expanded as:

$$y(w') = a_1' + b_1' R + c_1' R^2 + (b_1' + 2c_1' R)w + c_1' w^2 \tag{18}$$

Equations (12) and (13) are modified as follows for determination of w_w and w_l:

$$w_w = \left\{ \left[P_c (b_1' R + c_1' R^2 + a_1') - a_2 \right] / (P_c c_1') \right\}^{0.5} \tag{19}$$

$$w_l = (a_2 - P_c b_1') / (2 P_c c_1') - R \tag{20}$$

4- Site description

Isfahan province is located at 32° 39′ to 32° 50′ N latitude and 51° 43′ to 51° 50′E longitude. Isfahan has arid and semiarid climates, mostly characterized by low rainfall and high potential evapotranspiration. The main river of the province (Zayandehrud), runs for some 350 km roughly west-east from the Zagros Mountains to the Gavkhuni swamp. The average rainfall of Isfahan is about 120 mm, most occurring in December to April, and is less than 1/6 of average rainfall in the world (860 mm). In addition, this sparse precipitation is also non-uniform with respect to time and location. Another important climatic element is extreme temperature changes that sometimes range from –10 ^{o}C to +50 ^{o}C. Severe drought is also

recognized as a feature of Isfahan’s climate. In the last three years, the province has suffered severe dryness and this lack of rainfall has resulted in extensive losses. Temperatures are hot in summer, reaching an average of 30 °C in July, but are cool in winter, dropping to an average minimum of 3 °C in January.
Main winter crops are wheat and barley (November–May/June), and summer crops are rice (June–October) and vegetables (March–October). But because of recent droughts, the agricultural acreage and production has decreased.
The data which are used in this research include annual precipitation and yields of wheat and barley during 1983-2004 in Isfahan (Table 1) and also the production cost.

Table 1. Annual yield (wheat and barley) and rainfall in different years in Isfahan province (Le rendement annuel (blé et orge) et les précipitations dans les différentes années dans la province d'Ispahan)

Year	Wheat ($kg\ ha^{-1}$)	Barley ($kg\ ha^{-1}$)	Rainfall (mm)
1983	3306	3100	88.5
1984	3403	3216	167.7
1985	3236	3068	62.1
1986	3602	3635	165.1
1987	3227	3229	61
1988	4298	3717	70.9
1989	3500	3240	139.3
1990	4004	3842	77.5
1991	4078	3640	122.4
1992	4691	3672	122.6
1993	4075	4123	198.8
1994	4520	3852	125.3
1995	4317	3825	123
1996	4154	5127	147.9
1997	3612	3963	121.5
1998	3992	4292	157
1999	3628	3947	115.3
2000	2996	3153	88.1
2001	3188	3429	91.2
2002	3889	3983	126.6
2003	4339	4136	127.8
2004	4837	4281	215.7

Results and discussions

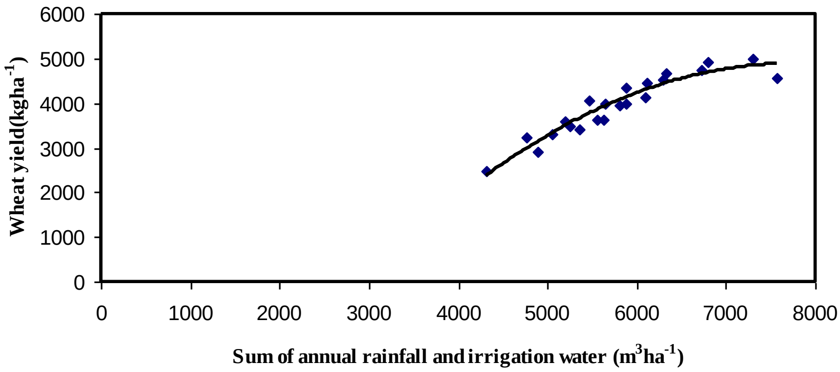
1- Wheat and barley production function

The applied water plus rainfall production function was obtained by multiple regression analysis as follows:

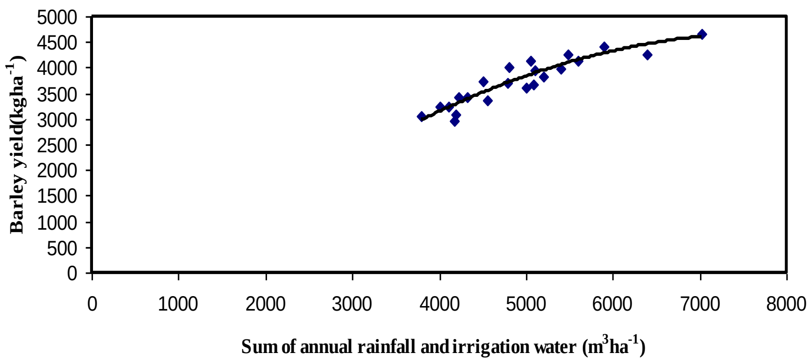
$$y(w) = -0.0002w^2 + 3.269\,w - 7817.5 \tag{21}$$

$$y(w) = -0.0001w^2 + 1.616\,w - 1681.5 \tag{22}$$

where R^2 = 0.916 for wheat and 0.866 for barley, y(w) is wheat yield (Eq. 19) and barley yield (Eq. 20) in kg ha^{-1}, and w is the applied irrigation plus annual rainfall (w+r) in $m^3\,ha^{-1}$. The relationship between y(w) and w is shown in Figs. 3 and 4.



"Figure 3". The relationship between wheat yield and sum of annual rainfall and irrigation water (La relation entre le rendement du blé et la somme des précipitations annuelles et l'eau d'irrigation)(a)



"Figure 4". The relationship between yield of barley and sum of annual rainfall and irrigation water(La relation entre le rendement de l'orge et le total des précipitations annuelles et l'eau d'irrigation)

2- Production cost function

The production cost (not including irrigation cost) was calculated as 6000000 Rials ha^{-1} and 5000000 Rials ha^{-1} for wheat and barley respectively. This cost included land preparation, seeding, fertilizer, pesticides and herbicides, harvest, transport and land rent. Therefore the production cost including fixed and variable costs for wheat and barley are:

$$C(w) = 1500w + 6000000 \quad (21)$$

$$C(w) = 750w + 5000000 \quad (22)$$

where C(w) is production cost in Rails ha $^{-1}$ and w is applied water in m^3 ha^{-1}.

3- Determination of optimal water consumption in land limiting condition

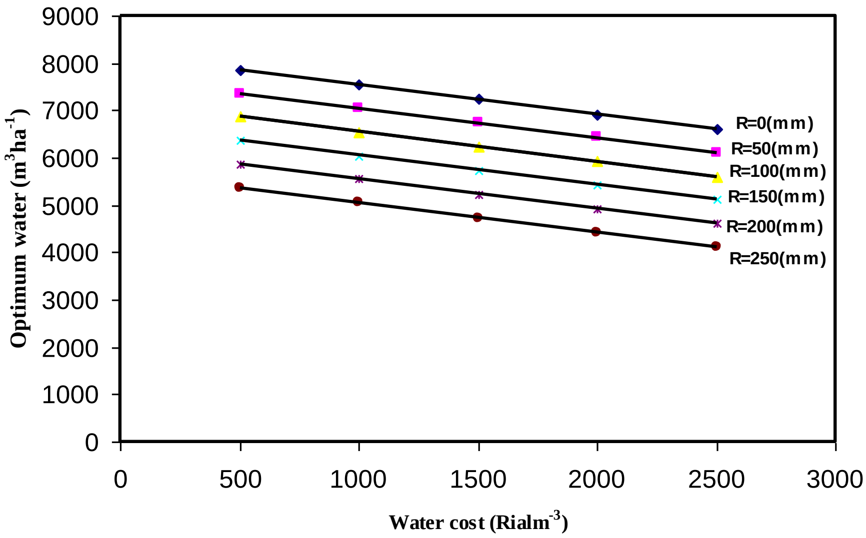
Equations 23 and 24 show the relationship between optimum irrigation and annual rainfall at different water costs for wheat and barley, respectively:

$$W_l = -0.625\ P(w) - 10R + 8072.8 \quad (23)$$

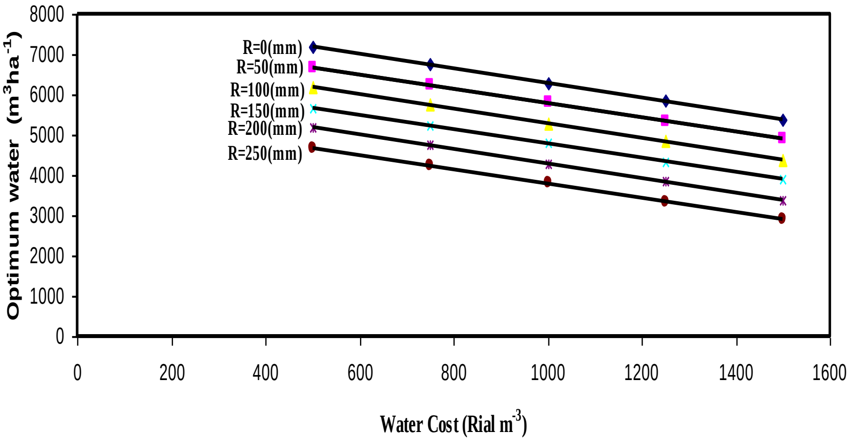
$$W_l = -1.7857\ P(w) - 10R + 8081.5 \quad (24)$$

Where W_l is optimum water under land limiting in m^3 ha^{-1}, P(W) is water cost (Rials m^{-3}) and R is annual rainfall (mm).

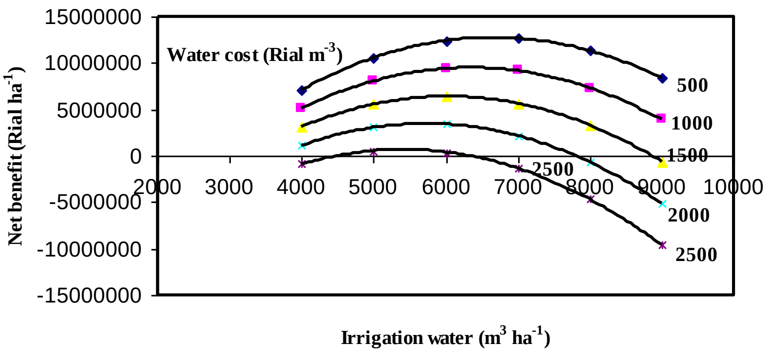
Figures 5 and 6 show the relationship between optimum water and different costs, at different annual rainfalls. These figures indicate that at a constant rainfall, the value of optimum applied water increased as the cost of water increased. Figures 7 and 8 show the relationship between net income and applied water at different water costs and given annual rainfall (120 mm). These figures indicate that in order to attain more net benefit, the value of w_l with a given amount of rainfall should be decreased with increasing the water price.



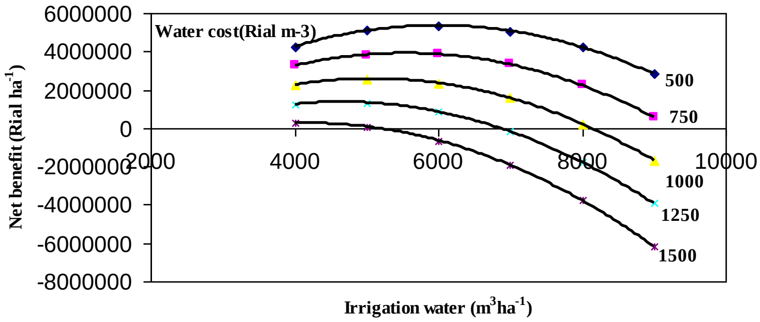
“Figure 5”. Relationship between optimum water and different cost at different annual rainfall for wheat (Relations entre l'eau optimale et des coûts différents à des précipitations annuelles différentes pour le blé)



“Figure 6”. Relationship between optimum water and different cost at different annual rainfall for barley(Relations entre l'eau optimale et des coûts différents à des précipitations annuelles différentes pour l'orge)



“Figure 7” - Relationship between net income and applied water at different water costs and given annual rainfall (120 mm) for wheat. (Relations entre le bénéfice net et appliquées de l'eau à différents coûts de l'eau et compte tenu des précipitations annuelles (120 mm) pour le blé.)



“Figure 8” - Relationship between net income and applied water at different water costs and given annual rainfall (120 mm) for barley. (Relations entre le bénéfice net et appliquées de l'eau à différents coûts de l'eau et compte tenu des précipitations annuelles (120 mm) pour l'orge)

4- Determination of optimal water consumption in water limiting condition

In the study area, water is limited. Therefore, the economic analysis for w_w was performed. Optimum amount of irrigation under water limiting condition (w_w) is dependent on rainfall. The results showed that values of w_w for different years decreased as the seasonal rainfall increased. The greatest applied water reduction occurred at water limiting condition (16-39% for 0-0.25 m seasonal rainfall) for wheat, and 27-58% for 0-0.2 m seasonal rainfall for barley. The least value of w_w was obtained for the highest amount of rainfall. Results are shown in Tables 2 and 3.

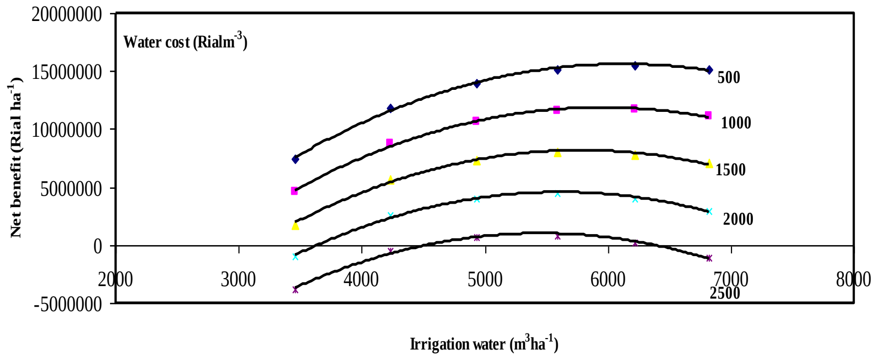
Table 2. Optimum applied water under water limiting condition and maximized yield for wheat (Optimum appliquée de l'eau sous l'eau en limitant l'état et le rendement maximum pour le blé)

Rainfall (mm)	Optimum applied water in maximized yield condition (m^3ha^{-1})	Optimum applied water under water limiting condition (m^3ha^{-1})	Percentage of decreasing irrigation
0	8172.7	6825.5	16.5
500	7672.7	6218.1	18.9
1000	7172.7	5589.4	22.1
1500	6672.7	4931.4	26.1
2000	6172.7	4230.4	31.5
2500	5672.7	3460.3	39.0

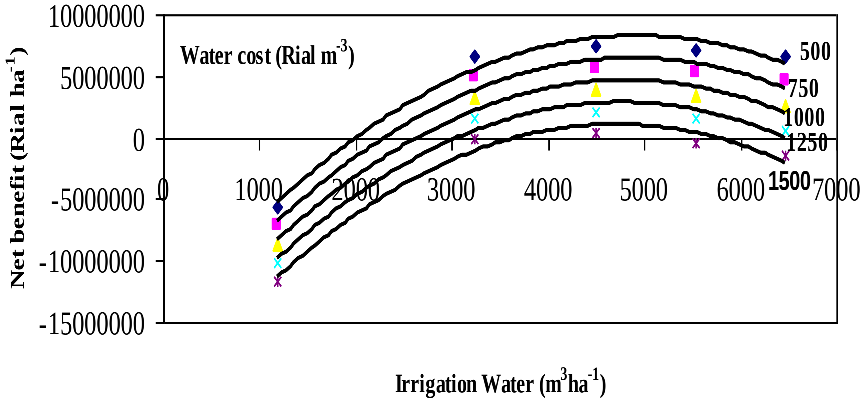
Table 3. Optimum applied water under water limiting condition and maximized yield for barley (Optimum appliquée de l'eau sous l'eau en limitant l'état et le rendement maximum pour l'orge)

Rainfall (mm)	Optimum applied water in maximized yield condition (m^3ha^{-1})	Optimum applied water under water limiting condition (m^3ha^{-1})	Percentage of decreasing irrigation
0	8081.5	5888.3	27.1
500	7581.5	5180.8	31.7
1000	7081.5	4416.9	37.6
1500	6581.5	3560.6	45.9
2000	6081.5	2519.1	58.6

Figures 9 and 10 show the relationships between net income and applied water at different water costs and given annual rainfall (120 mm) under water limiting condition. These figures indicate that in order to attain more net profit, values of w_l in a given amount of rainfall should be decreased with increasing water price.



“Figure 9” . Relationship between net income and applied water at different water costs and given annual rainfall (120 mm) for wheat under water limiting condition. (Relations entre le bénéfice net et appliquées de l'eau à différents coûts de l'eau et compte tenu des précipitations annuelles (120 mm) pour le blé sous l'eau en limitant l'état.)



“Figure 10”. Relationship between net income and applied water at different water costs and given annual rainfall (120 mm) for barley under water limiting condition. (Relations entre le bénéfice net et appliquées de l'eau à différents coûts de l'eau et l'état donné des précipitations annuelles (120 mm) pour l'orge sous l'eau en limitant)

The values of optimum water and the net income for the maximum yield and under land and water limiting conditions for wheat and barley are shown in table 4 and 5.

Summaries and Conclusions

Limiting land and water causes reduction in optimum water application with respect to maximum yield. The greatest applied water reduction (16-39% for 0-0.25 m seasonal rainfall) occurred at water limiting condition for wheat, and 27-58% for 0-0.2 m seasonal rainfall for barley. In water limiting condition, with decreased water consumption, the cultivated land increased 20-64% and 37-141% for wheat and barley, respectively. In order to attain more net profit, values of w_w and w_l with a given amount of rainfall decreased with increasing the water price. The income per unit water was increased for land limiting condition, but it increased more for water limiting condition.

References

1- English, M. J. 1981. The uncertainty of crop models in irrigation optimization. Trans. ASAE, 24: 917-928.

2- English, M. and L. James. 1990. Deficit irrigation. II: Observation in Colombia basin. J. Irrig. Drain. Eng., ASCE, 116(3): 413-426.

3- English, M. and S. N. Raja. 1996. Perspective on deficit irrigation. Agric. Water Manage., 32: 1-14.

4- Hargreaves, G. H., and Z. A. Samani. 1984. Economic considerations of deficit Irrigation. J. Irrig. Drain. Eng., ASCE, 110(4), 343-358.

5- Kang, S., L. Zhang, Y. Liang, X. Hu, H. Cai, and B. Gu. 2002. Effect of limited irrigation on yield and water use efficiency of winter wheat in the Loess Plateau of China. Agric. Water Manage., 55: 203-216.

6- Sepaskhah, A. R. and D. Akbari. 2005. Deficit irrigation planning under variable seasonal rainfall. Biosys. Eng. 92(1): 97-106.

7- Zhang, H., and T. Oweis. 1999. Water-yield relations and optimal irrigation scheduling of wheat in the Mediterranean region. Agric. Water Manage., 38: 195-211.

8- Zhang, H., X. Wang, M. You, and C. Liu. 1999. Water-yield relations and water use efficiency of winter wheat in North China plain. Irrig. Sci. 19: 37-45.

“Table 4”. Optimum water, grain yield and net income under the present market value for wheat (en eau optimale, le rendement en grains et le revenu net inférieur à la valeur actuelle du marché pour le blé)

Seasonal rainfall (mm)	Optimum water (m^3 ha^{-1})	Optimum water depth (m)	Grain yield (kg ha^{-1})	Net income (Rial ha^{-1})	Net income (Rial m^{-3})	Land area increase (%)
Maximum yield						
0	8172	0.817	5541	3905950	477	
50	7672	0.767	5541	4655950	606	
100	7172	0.717	5541	5405950	753	
150	6672	0.667	5541	6155950	922	
200	6172	0.617	5541	6905950	1118	
250	5672	0.567	5541	7655950	1349	
Land limiting						
0	7235	0.723	5365	4609074	637	
50	6735	0.673	5365	5359074	795	
100	6235	0.623	5365	6109074	979	
150	5735	0.573	5365	6859074	1195	
200	5235	0.523	5365	7609074	1453	
250	4735	0.473	5365	8359074	1765	
Water limiting						
0	6825	0.682	5178	4474760	655	19.7
50	6218	0.621	5118	5145117	827	23.4
100	5589	0.558	5039	5775432	1033	28.3
150	4931	0.493	4934	6342205	1286	35.3
200	4230	0.423	4786	6801336	1607	45.9
250	3460	0.346	4562	7058697	2039	63.9

"Table 5". Optimum water, grain yield and net income under the present market value for barley (en eau optimale, le rendement en grains et le revenu net inférieur à la valeur actuelle du marché de l'orge)

Seasonal rainfall (mm)	Optimum water (m^3 ha^{-1})	Optimum water Depth (m)	Grain yield (kg ha^{-1})	Net income (Rial/ha)	Net income (Rial m^{-3})	Land area increase (%)
Maximum yield						
0	8081	0.808	4850	2517654	311	
50	7581	0.758	4850	2892654	381	
100	7081	0.708	4850	3267654	461	
150	6581	0.658	4850	3642654	553	
200	6081	0.608	4850	4017654	660	
Land limiting						
0	6742	0.674	4670	3019886	447	
50	6242	0.624	4670	3394886	543	
100	5742	0.574	4670	3769886	656	
150	5242	0.524	4670	4144886	790	
200	4742	0.474	4670	4519886	953	
Water limiting						
0	5888	0.588	4368	2815722	478	37.2
50	5180	0.518	4273	3079436	594	46.3
100	4416	0.441	4139	3278090	742	60.3
150	3560	0.356	3936	3353065	941	84.8
200	2519	0.251	3580	3136129	1244	141.4