ASSESSMENTOF WATER PRODUCTION FUNCTION OF WHEAT UNDER SUPPLEMENTARY IRRIGATION

EVALUATION DE LA FONCTION DE PRODUCTION D'EAU DU BLE PAR L'IRRIGATION SUPPLEMENTAIRE

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ABSTRACT

A field study was conducted to compare various genotypes of wheat to water using line source sprinkler irrigation. The effect of variable water supply on yield, features of water production function with the seasonal rainfall, performance of deficit and full irrigation during the growth stage of six wheat genotypes were studied. The treatments were set to meet 100% (W_1), 76% (W_2), 52% (W_3) and 39 % (W_4) crop water requirement during the growing season. The experiment was laid on a strip plot design to examine the effect of the fixed irrigation rates on six cultivars (C_1=TAJAN, C_2= N-80-6, C_3= N-80-7, C_4= N-80-19, C_5= N-81-18, C_6= Desconcido, a variety from CIMMYT) with four replications. Result indicated that the grain yield was affected by irrigation treatment and cultivars. The maximum grain yield was obtained in W_1C_2 treatment (4742 Kg/ha) and the minimum was in W_4C_1 (3546 Kg/ha). Investigation of water production functions have shown that under deficit irrigation, for 250 mm of seasonal rainfall with the same its distribution, there is no need to irrigate all of the cultivars. In the full irrigation strategy, with 250 mm of seasonal rainfall, the cultivars of C_1 to C_6 needed to 115, 122, 87, 94, 92 and 97 mm additional water, respectively as supplementary irrigation to maximize production. The quantitative comparison of deficit and full irrigation strategies showed that deficit irrigation was more useful for obtaining higher production as compared to that under full irrigation.

Key words: *Sprinkler irrigation, wheat genotypes, variable water supply.*

RESUME

Une enquête sur le terrain a été menée pour comparer les divers génotypes du blé utilisant l'irrigation par aspersion de source de ligne. L'étude examine l'impact d'approvisionnement en eau variable sur le rendement, les caractéristiques de production d'eau par la précipitation

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saisonnière, la performance d'irrigation totale et déficitaire lors de l'étape de croissance pour six génotypes du blé. Les traitements ont été mis pour satisfaire les besoins en eau agricole de 100% (W1), 76% (W2), 52% (W3) et 39% (W4) lors de la période de croissance. L'expérimentation a été faite sur un champ en bande pour examiner l'effet de quatre répétitions des taux d'irrigation fixes sur six variétés cultivées (C1=TAJAN, C2 = N-80-6, C3 = N-80-7, C4 = N-80-19, C5 = N-81-18, C6 = Desconcido, variété de CIMMYT). Le résultat a indiqué que le rendement de grain a été affecté par le traitement d'irrigation et les variétés cultivées.

Le rendement de grain maximal a été obtenu dans le traitement de W1C2 (4742 kg/ha) et le minimum dans W4C1 (3546 kg/ha). L'Enquête sur les fonctions de production d'eau a montré que dans le cadre d'irrigation déficitaire, avec une précipitation saisonnière de 250 mm, toutes les variétés cultivées n'exigeaient pas l'eau d'irrigation. Dans le cadre de l'irrigation totale, avec une précipitation saisonnière de 250 mm, les variétés cultivées de C1 à C6 exigeaient l'eau supplémentaire de l'ordre de 115, 122, 87, 94, 92 et 97 mm respectivement pour maximiser la production. La comparaison quantitative des stratégies d'irrigation totale et déficitaire a montré que l'irrigation déficitaire a donné lieu à la production élevée par rapport à l'irrigation totale.

Mots clés : *Irrigation par aspersion, génotypes du blé, approvisionnement en eau variable.*

1. INTRODUCTION

Water scarcity is one of the major problems for crop production. In the areas having limited water resources, deficit irrigation is the best irrigation management strategy for optimum production. In such conditions, using the saved water to irrigate new areas could increase total production and income. Supplementary irrigation plays a key role in the crop production in many countries of the word. In most of the rainfed areas, rainfall amount and its distribution is not adequate and favourable for the winter crops. Therefore, to increase crop production it is necessary to give supplementary irrigation to the crops at certain critical times during the crop growth stage. The amount of water needed to achieve maximum crop yield, depends on the crop evapotranspiration (ETa). Several studies have been shown that there is a linear relationship between yield and ETa during the growing season (Stewart and Hagan, 1973). However a nonlinear relation between yield and ETa was also observed on cotton (Grimes et al., 1961), potato (Khanjani and Busch, 1982), citrus, sugar beets & wheat (Doorenbos and Kassam, 1979) and on corn (Kipkorir et al ., 2000). Yield vs. ETa relation mainly depends on the climate, while the yield - water applied (rainfall + irrigation) not only depends to plants and climate, but also depends on the irrigation management. At present, supplementary irrigation covers 80% of cultivated areas of the world which contributes 60% the global production (Harris, 1991). Rainfed wheat yield in arid and semiarid regions of the world, including West Asia and North Africa varies from 0.6 to 1.5 t ha^{-1}, depending on the rainfall amount and its distribution. In these areas supplemental irrigation significantly increases yield and water productivity. The experimental results showed that a reduction of 50 mm water application from the water requirement of wheat did not affect the wheat grain yield and increased the water productivity (Sun et al., 2006; Zhang et al., 2005; Zhang et al., 2006). Wheat yield using supplemental irrigation in three locations of northern Syria with low (234 mm), medium (316 mm) and large (504 mm) rainfall, correspondingly increased by 350, 140 and 30 per cent, respectively, when supplemented by 212, 150 and 75 mm irrigation water, respectively, when compared to the non irrigated areas (Oweis, 1997). Also in the above mentioned locations rain productivity was 0.32, 0.73 and 0.99 kg m^{-3} and supplementary irrigation could increase irrigation productivity to 1.46, 2.2 and 1.92 kg m^{-3}, respectively. Quadratic form Wheat production function due to supplemental irrigation was derived in Karaj (Sepaskhah and Akbari, 2005), Syria (Zhang and Oweis, 1999), northern China (Zhang et al., 1999) and Oregon America (English and Nakamora, 1989). These studies indicate that irrigation water depth for achieving optimum water productivity is different mainly due to different climate. For example, the highest water productivity of wheat in northern Syria corresponded to 440-500 mm of water application (140-180 mm irrigation water); in northern China, to 400 mm (120-160 mm irrigation water) and in Oregon with 750-850 mm of water applied (350-450 mm irrigation water).

Water and crop production relationships help in selecting the strategy of best irrigation management. Improving water productivity with a view to producing more crops per unit of water used is considered as one of the important strategies for effective irrigation management in water-scarce areas, as water resources, and not the land, are major limitations The objective of this project is to consider response of different cultivars of wheat to different amount of water, determination of water production functions and to compare between full and deficit irrigation strategies under supplementary irrigation condition.

2. MATERIALS AND METHODS

A field experiment was conducted during wheat growing season (2005-2006) at the Gorgan Research Station of Gorgan city in Iran. The farm location is: 36° 54’ N, 54° 25’ E and 155 m amsl. Annual rainfall is medium and occurs mostly during the winters (Nov–Apr). Seasonal rainfall during the wheat growing season was about 250 mm. Relevant climatic data during the present study and for long term are given in Table 1.

Table 1. Weather parameters at the experimental field

Season	Parameters*	Dec	Jan	Feb	Mar	Apr	May	Jun
2005-06	P(mm)	60	41	32	38	27	38	12
	Tavg(oc)	8.2	5.1	10	13	16.5	21.2	27.8
	RH(%)	75	77	74	69	79	73	60
	n(hr)	4.7	4.4	5.4	5.5	5.4	5.7	9.2
Long-term	P(mm)	55	46	56	58	57	48	19
	Tavg(oc)	10.4	8	8	10	14	18	24
	RH(%)	76	76	74	73	78	64	60
	n(hr)	5.2	6.8	5.1	5.3	5.4	7.4	8.3

*Precipitation (p), average temperature (Tavg), (RH) relative humidity, sunshine hours (n)

Line source sprinkler irrigation was used to apply different amount of waters (Hanks et al., 1976). Four irrigation treatments (W_1, W_2, W_3 and W_4) were provided to represent decline in irrigation with distance from the line source (W_1 nearest and W_4 farthest). The experiment used a strip plot design to examine the effect of the fixed irrigation rates on six cultivars treatments (C_1=TAJAN, C_2= N-80-6, C_3= N-80-7, C_4= N-80-19, C_5= N-81-18, C_6= Desconcido) with 4 replications. Within each irrigation treatment, each strip was divided into six cultivars treatments along the length of the laterals (Fig 1).

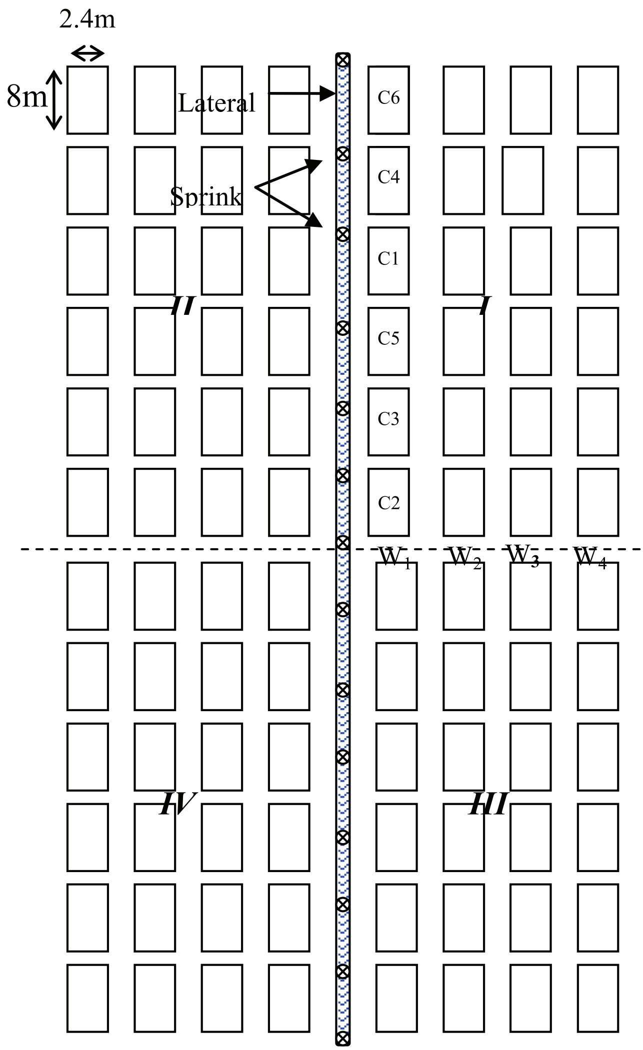

Fig. 1. The schematic of experimental field (I-IV: represents as replications)

A quadratic production function and simple linear cost function were used to describe various production of wheat related to different irrigation water in six cultivars (English, 1990). Optimum irrigation water was determined using above equations under different amounts of rainfall.

$$Y = a_0 + a_1(I+P) + a_2(I+P)^2 \tag{2}$$

$$C = b_0 + b_1(I + P) \tag{3}$$

Where Y= Wheat grain yield (t/ha), I = Irrigation water (mm), P= Rainfall (mm), C= Costs (Rial) (RLs ha^{-1}, 1000RLs=US$1), a_0, a_1, a_2, b_0 and b_1 are constants.

3. RESULTS AND DISCUSSION

Grain yield, seasonal irrigation water application and ETa for different cultivars of wheat are presented in Table 2.

The results show that, the water received by the plants and their corresponding ET_a decreased with distance from the line source in each treatment. Seasonal irrigation water application in W_2, W_3 and W_4 treatments was 76%, 52% and 39% of W1 treatment, respectively. Generally, there is a reduction in grain yield in all treatments with distance from the line source. The mean yield production in W_4 treatment (with 61% deficit irrigation) for six cultivars C_1 to C_6 was about 85%, 85%, 90%, 93% and 86% of W_1 treatment, respectively. Upon reducing water application from W_1 to W_4 (severe water stress), maximum reduction in grain yield was only 15%, mainly due to sufficient rainfall during the growing season (250mm). The highest (4725 kg/ha) and the lowest (3546 kg/ha) yield were obtained in treatments W_1C_2 and W_4C_1, respectively. Average yields of the 6 cultivars in the treatments W_1 (full irrigation) and W_4 (61 percent of W_1) were 4455 and 3923 kg/ha, respectively. It is found that by decreasing irrigation water to 61% of full irrigation, the yield reduction is about 12% of non-stress treatment. Wheat yield with supplemental irrigation under full irrigation (46% irrigation + 54% rainfall) was about 4760 kg/ha, but with applying 67 and 37 percent full irrigation, wheat yield decreased to 4740 and 3880 kg/ha, respectively (Schneider and Howell, 1996). Zhang and Oweis (1999) reported that wheat yield in terms of full supplemental irrigation (34% irrigation and 66% rainfall) was 5790 kg/ha, while using deficit irrigation equivalent to 67 and 33 % of full irrigation, wheat yield decreased to 5240 and 5150 kg/ha, respectively.

Table 2. Grain yield, accumulated irrigation water and ETa for different treatments.

Ci[1]	Grain yield (kg/ha)				Mean[2]	I (mm)				ETa (mm)			
	W_1	W_2	W_3	W_4		W_1	W_2	W_3	W_4	W_1	W_2	W_3	W_4
C1	4139	4177	4064	3546	3995a	99	69	59	39	392	372	349	325
C2	4742	4227	3993	4015	4244ab	109	75	54	35	400	349	345	339
C3	4507	4450	3959	4062	4245ab	111	77	62	34	389	374	348	334
C4	4262	4529	4144	3981	4229bc	100	81	55	37	376	369	339	331
C5	4522	4666	4432	4076	4424a	101	86	50	30	376	372	348	323
C6	4503	4089	3984	3861	4110bc	100	88	46	37	389	364	345	338
mean	4455	4356	4096	3923									

1- Cultivars; 2-Values followed by the same letters are not significant difference.

Wheat yield variation of different cultivars as a function of applied water (I+P) is illustrated in Figure 2. A quadratic form of production function was used to describe the relationship between applied water and yield. The general trend is similar to all the cultivars; initial increase in yield with increased application of irrigation water, then reaching to a maximum and followed by a decline in yield with further application of irrigation. Estimated wheat production function for any cultivars showed that they have different constants and different responses to water. Therefore, desirable cultivars of wheat can be chosen so as to give the deired response to a certain amount of water. For example, the cultivars $C_1 – C_6$ produced 4.2, 4.8, 4.5, 4.4, 4.6 and 4.2 t/ha against 350 mm applied water, respectively, (Fig. 2).

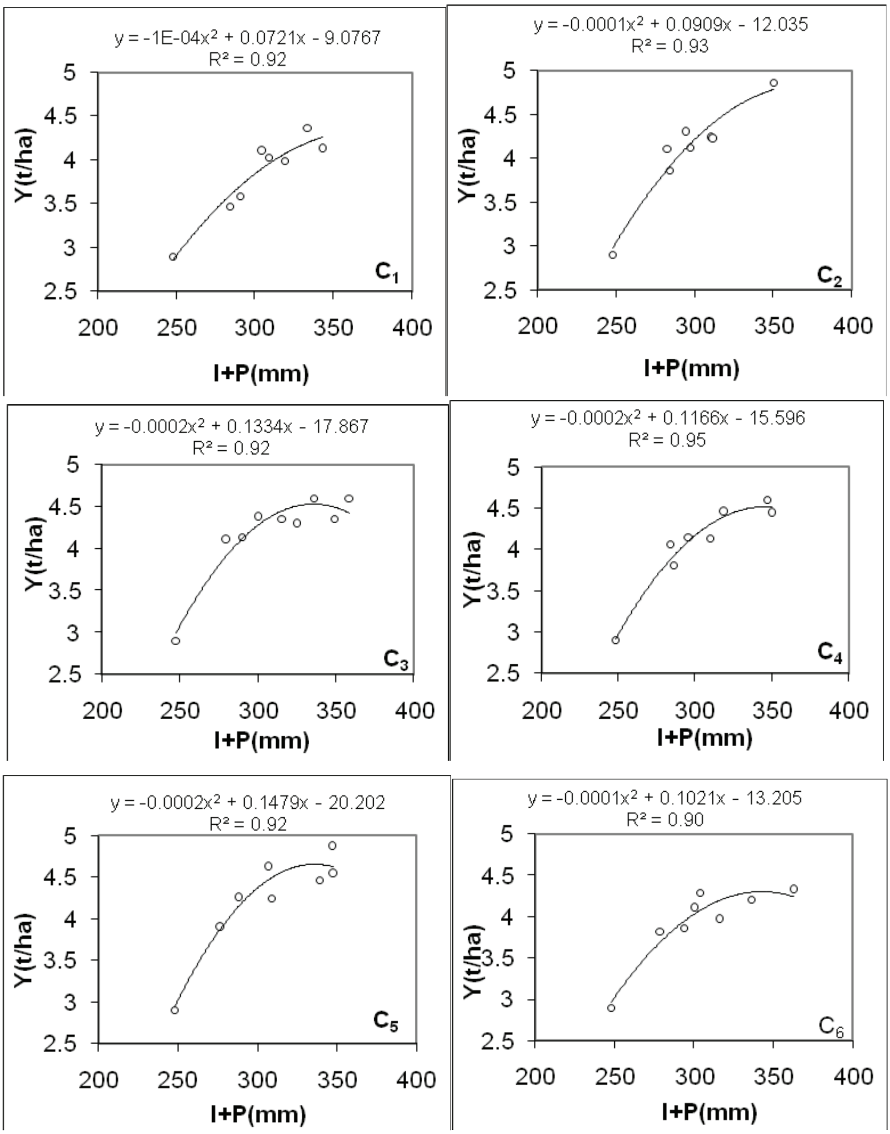

Fig. 2. Wheat grain yield as a function of applied water in different cultivars

Crop water production and cost functions were used to describe optimum scheduling of irrigation water. Due to the presence of effective rainfall in the region, optimum irrigation water under full irrigation (I_f) and deficit irrigation (I_d) were estimated as function of seasonal rainfall (with the assumption that wheat price equal to 1700 Rials/kg and production cost without irrigation costs are 2.5 million Rials/ha). The results revealed that, optimum irrigation water depth will be decreased when seasonal rainfall increased. Under full irrigation strategy for maximizing production in cultivars C_1 to C_6 were required to 362, 370, 335, 342, 340 and 345 mm of applied water. Optimum irrigation water under deficit irrigation for all cultivars as a function of seasonal rainfall was presented in Table 2. It is observed that under deficit irrigation, whenever during the wheat growing season 250 mm of rainfall occurs with a similar distribution of Golestan province, all cultivars do not require to irrigate. If rain does not happen (In terms of deficit irrigation) C_2 cultivar more water needed than the others (331 mm). So if it assumes the average value of 250 mm rainfall occurs during the wheat growing season similar to this region, in terms of full supplemental irrigation to all the cultivars are needed two or three irrigation water, but in deficit irrigation any cultivars do not require irrigation (Table 2).

Table 2. Optimum irrigation water as a function of seasonal rainfall in different cultivars of wheat

P(mm)	Cultivars					
	C_1	C_2	C_3	C_4	C_5	C_6
0	325	331	311	315	315	315
10	314	320	300	305	305	305
20	303	310	290	293	293	293
30	291	297	279	282	282	282
40	280	286	269	270	270	270
50	268	274	257	260	260	260
70	245	250	235	238	238	236
100	208	214	200	202	203	200
150	140	146	139	139	141	135
200	30	43	57	50	59	35

In water scarcity areas, adoption of deficit irrigation can reduce the amount of water needed by plants and the saved water can increase the irrigated area which will increase total production. Generally, when the farmers are faced with water scarcity and they cannot provide full irrigation the whole farm, they have two options (Oweis and Hachum, 2003): in the first case, they may apply all the water available for irrigation over a part of the farm and leave the remaining part as rainfed. In the second case, they may apply less water to irrigate the whole farm (deficit irrigation). The quantitative comparison of deficit and full irrigation strategies showed that deficit irrigation was more useful for obtaining higher total production as compared to full irrigation (Table 3). For example, in C_1 cultivar, if it is applied full irrigation (99 mm) to irrigate 1 ha and 1.54 ha is left as rain-fed, the total grain yield would be 7.27 ton. But instead, if full irrigation of one hectare is applied as deficit irrigation (39mm) for the whole of 2.54 ha land, the total grain yield would be 9.02 ton. This trend for the other cultivars are given in Table 3.

It is observed that in W4 treatment the total yield in C_1 to C_6 cultivars were increased by 24, 40, 47, 40, 48 and 32 per cent, respectively, when compared to the W_1 treatment.

Table 3. Comparison of total production in different cultivars of wheat at full (W_1) and deficit (W_4) irrigation.

Ci	IT[1]	I (mm)	Y (t/ha)	Area (ha)			Y(t/ha)			Increased Yield (%)
				irrigated	rain fed	total	irrigated	rain fed	total	
C_1	W_1 W_4	99 39	4.19 3.55	1 2.54	1.54 0	2.54 2.54	4.19 9.02	3.1 0	7.27 9.02	24
C_2	W_1 W_4	109 35	4.74 4.02	1 3.11	2.11 0	3.11 3.11	4.74 12.5	4.22 0	8.95 12.5	40
C_3	W_1 W_4	111 34	4.15 4.06	1 3.26	2.26 0	3.26 3.26	4.51 13.2	4.54 0	9.03 13.2	47
C_4	W_1 W_4	100 37	4.26 3.98	1 2.7	1.7 0	2.7 2.7	4.26 10.8	3.4 0	7.66 10.8	40
C_5	W_1 W_4	101 30	4.52 4.07	1 3.37	2.37 0	3.37 3.37	4.52 13.7	4.74 0	9.26 13.7	48
C_6	W_1 W_4	100 37	4.5 3.86	1 2.7	1.7 0	2.7 2.7	4.5 10.4	3.4 0	7.9 10.4	32

1- Irrigation Treatments

4. CONCLUSIONS

Optimal irrigation water application was considered through the use of the developed crop water production functions for six cultivars of wheat under supplementary irrigation. The Estimated wheat production function for any cultivar showed that they have different constants as well as different response to water. Based on the analysis of water production functions, when 250mm rainfall occurred during the growing season of wheat in the study year, no irrigation was required by any cultivar in deficit irrigation planning, but additional irrigation water will be required for maximizing production under full irrigation planning. In the water–scarce conditions, if water saved in deficit irrigation scheduling were allocated to new cropped areas, the total production would increase. The quantitative comparison of deficit and full irrigation strategies showed that deficit irrigation was more useful strategy for obtaining higher total production as compared to full irrigation. To minimize the risk with water stress on crop yield reduction, the sensitivity of different growth stages of wheat to water stress needs to be known.

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