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Full Length Research Paper

Determination of the yield response factor for field crop deficit irrigation

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The irrigation network of Taleghan Dam Reservoir was used to determine yield response factor for maize (*Zea mays*), winter wheat (*Triticum aestivum*), and barley (*Hodeum vulgare*) in the Qazvin Plain of Iran. Dependent variable actual crop yield and independent variables including climate data were obtained from Qazvin Plain Irrigation Company. Data were gathered from five fields in Qazvin province between 2002 to 2009. Potential evapotranspiration was calculated by the Penman-Monteith method. Actual evapotranspiration (ET_a) was measured based on the irrigation requirement at the fields. Yield response factor (K_y) was obtained for four crop stages including vegetative, flowering, grain filling, and ripening, and calculated for the total growing period. The K_y values for maze, winter wheat and barley in different stages of their growth periods including vegetative, flowering, grain filling, ripening and total growing period were equal to (0.48, 1.45, 0.55, 0.29 and 1.55), (0.60, 0.68, 0.87, 0.69 and 1.20) and (0.50, 0.82, 0.75, 0.57 and 1.10), respectively. The bias error less than 15% between averages of estimated and observed yields verified the results. These results were compared with K_y obtained by FAO and other studies separately. There is a satisfactory correlation between K_y calculated using this research and other studies.

Key words: Yield response factor, actual and maximum evapotranspiration, actual and maximum yield.

INTRODUCTION

Water is a diminishing resource in Iran and around the globe with an increasing competition among agricultural, industrial and domestic sectors (Kaveh, 2008). According to the results of other works in Iran, the allocation of water for agriculture is about 90% of total regional water consumption (Kaveh, 2008). The upper limits for yield are set by soil fertility, climatic conditions and management practices (Bauder et al., 1988). Where all of these are optimal throughout the growing season, yield reaches the maximum value as does evapotranspiration (ET_m) water storage (SWS) has an impact on water availability (WA) for a crop and, subsequently, on actual yield and actual evapotranspiration (ET_a) (English, 1990). A standard formulation, Equation 1, relates these four parameters (Y_A , Y_M , ET_A , ET_M) to a fifth: K_y, which links relative yield decrease to relative evapotranspiration deficit (Vaus and Pruitt, 1983):

$$1 - \frac{Y_A}{Y_M} = K_Y \left(1 - \frac{ET_A}{ET_M}\right) \quad (1)$$

Where: Y_a = Actual yield (kg/ha); Y_m = Maximum yield

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Abbreviations: **ET_a,** Actual evapotranspiration; **ET_m,** maximum evapotranspiration; **K_y,** yield response factor; **SWS,** soil water storage; **WA,** water availability; **Y_a,** actual yield; **Y_m,** maximum yield.

Table 1. Amounts of maximum evapotranspiration.

Winter wheat		Barley		Maize	
Date	**ET_m**	**Date**	**ET_m**	**Date**	**ET_m**
10.11	30	10.11	30	5.4	11
10.21	36	10.21	36	5.14	11
10.31	49	10.31	49	5.24	19
11.10	44	11.10	44	6.3	33
11.20	44	11.20	39	6.13	53
11.30	45	11.30	32	6.23	81
12.10	32	12.10	18	7.3	76
12.20	20	12.20	7	7.13	76
12.30	7	12.30	6	7.23	88
1.9	6	1.9	5	8.2	79
1.19	5	1.19	5	8.12	62
1.29	5	1.29	5	8.22	49
2.8	5	2.8	4	9.1	26
2.18	4	2.18	4	-	-
2.28	4	2.28	4	-	-
3.10	4	3.10	2	-	-
3.20	2	3.20	2	-	-
3.30	2	3.30	2	-	-
4.9	2	4.9	8	-	-
4.19	8	4.19	10	-	_
4.29	10	4.29	16	-	-

Table 2. Actual yield for all crops (ton/ha).

Year	2002	2003	2004	2005	2006	2007	2008	2009
Winter wheat	3.554	3.819	3.885	4.156	4.619	3.857	3.105	4.487
Maize	7.316	7.736	8.261	7.043	8.289	9.808	8.947	9.032
Barley	3.343	3.116	3.295	3.495	3.135	3.121	2.352	4.14

(kg/ha); ET_a = Actual evapotranspiration (mm); ET_m = Maximum evapotranspiration (mm); K_y= Yield response factor.

Furthermore, the K_y for total growing period is calculated using Equation 2, according to Jensen (1968):

$$\frac{Y_A}{Y_M} = \prod_{I=1}^{N}[1 - K_{Y,I}(1 - \frac{ET_{A,I}}{ET_{M,I}})] \quad (2)$$

Where: $K_{y,i}$ = Yield response factors for different growth stages ET_{ai} = The actual evapotranspirations in various growth stages, and ET_{mi} = Maximum evapotranspiration in vegetative period,flowering, grain filling, and ripening period calculated using CROPWAT PC software (FAO, 1992).

Maximum evapotranspiration for different crops are presented in Table 1. Furthermore, Table 2 shows the actual yield for three crops including winter wheat, maize and barely during an 8 years period (2002 to 2009) (Iranian Ministry of Agriculture, 2009). According to reports of Seed and Plants Improvement Institute of Iran, maximum yield per hectare are presented in Table 3 (Iranian Ministry of Agriculture, 2009). Using K_y for planning, design and operation of irrigation projects allows quantification of water supply and water use in terms of crop, yield and total productions for a project area (English, 1994). When irrigation water is limited, but distributed equally over the total growing season, the crops with the higher K_y values will suffer a greater yield loss than the crops with a lower K_Y values (English, 1994). Both the likely losses in yield and the adjustments required in water supply to minimize such losses can be quantified (English, 1994). Similarly, such quantification is possible when the likely yield losses arise from differences in the K_y of individual growth periods (English, 1994). The yield response to water deficit of different crops is of major importance in production planning.

Table 3. Maximum yield for all crops in Qazvin province.

Crop	Y_m (kg/ ha)
Maize	10000
Barley	4700
Winter wheat	6000

Table 4. Required parameters for application efficiency measuring.

Irrigation No.	Measuring time (min)	Sampling depth (cm)	%Weight moisture (before irrigation)	%Weight moisture (after irrigation)	Density block (g/cm^3)	Total inflow volume for 5 furrows (L)
1	25.0	0-30	12.94	22.40	1.42	55275.80
		30-60	16.13	23.10	1.49	
2	89.5	0-30	10.85	22.40	1.42	65014.78
		30-60	13.29	23.10	1.49	
3	720.0	0-30	10.11	23.50	1.42	1935200
		30-60	13.10	24.10	1.49	
4	720.0	0-30	8.50	22.40	1.42	2095200
		30-60	10.40	23.10	1.49	
5	720.0	0-30	8.00	22.40	1.42	2086560
		30-60	10.10	23.10	1.49	

Using different maize hybrids, the K_Y values of 1.00 for the hybrid Kn606 and 1.50 for the hybrid H708 were derived in Portugal (Popova et al., 2006).

Furthermore, K_y for total time of the maize growth was calculated 1.33 in Romania (Moutannet, 2001). The irrigation scheduling in the recent research was such as to maintain the soil water storage at 50 to 70% of soil capacity. The K_y for Brazilian maize genotypes ranging from 0.40 to 0.50 in the vegetative, 1.40 to 1.50 in flowering, 0.30 to 0.60 in yield formation, and 0.10 to 0.30 during ripening in Brazil (Andrioli and Sentelhas, 2009). The total season K_y for winter wheat was calculated as 1.01 in Turkey (Metin and Yazar, 2006) and for three growth stages of wheat, K_y was obtained in Chile 0.55, 0.90, and 0.44 vegetative, flowering, and ripening respectively (Moutonnet, 2001), yield response factor estimation will be the first step.

The main goal of this research was to determine K_y under deficit irrigation in northwest Iran for maize, winter wheat, and barley. The K_y values for maize have been reported 1.25 to 1.40, 0.99 to 1.04, 1.90 and 1.54 to 1.74 for total growth period in Brazil, Turkey, Tanzania and U.S.A respectively (Doorenbos and Kassam, 1994; Mengu and Ozgurel, 2008; Dagdelen et al., 2005; Igbandum et al., 2006; Payero et al., 2008). The knowledge of K_y makes it possible to choose the best crops for a specific location and season, according to water deficit condition, reducing yield losses during the growing season. Since water is the main limiting factor in Qazvin plane. It is necessary for farmers to use deficit irrigation to apply this method.

MATERIALS AND METHODS

The Qazvin Irrigation Network, totaling 600 km^2 located in the northwest of Iran is fed by the Taleghan Dam Reservoir and legal wells. First, the volume of water supplied by TDR and legal wells was checked using annual dam data for an 8 years period, (2002 to 2009). Using measured parameters presented in Table 4 and according to an irrigation schedule shown by Table 5. Application efficiencies in 18 fields ranging in area from 3.0 to 5.5 ha and at five irrigation times were calculated and shown in Table 6. Furthermore, ET_a was measured based on the irrigation requirement at the fields.

RESULTS AND DISCUSSION

A comparison between our data and data from FAO (1979) was presented in Table 7. According to this recent table, calculated data were different with data presented. The results of this research do compare well with K_y computed by Andrioli and Sentelhas (2009). For maize and our K_y for winter wheat also compare well to those

Table 5. Farming and irrigation schedule.

Crop	Planting date	First irrigation	Irrigation interval (day)	Total irrigation times	Harvesting date
Barley	22 Sep.	19 Mar.	20	5	22 Jun
Maize	5 Apr.	22 May	10	12	7 Sep.
Winter wheat	12 Sep.	10 Mar.	20	6	11 Jul.

Table 6. Amounts of measured application efficiency.

Irrigation No.	Application efficiency (%)
1	61.43
2	44.5
3	55.31
4	39.09
5	58.46
Average	51.75

Table 7. Compare between K_y computed with FAO.

Crop	Vegetative		Flowering		Grain filling		Ripening		Total growing period	
	Qazvin	FAO	Qazvin	FAO	Qazvin	FAO	Qazvin	FAO	Qazvin	FAO
Maize	0.48	0.4	1.45	1.5	0.55	0.5	0.29	0.2	1.55	1.25
Barley	0.5	0.2	0.82	0.6	0.75	0.5	.57	0.4	1.1	1
Winter wheat	0.6	0.2	0.87	0.6	0.68	0.5	0.69	0.4	1.2	1

Table 8. Regression analysis output (ANOVA[b]).

Model		Sum of squares	Df	Mean square	F	Sig.
	Regression	2.125	1	2.125	125.477	0.000[a]
1	Residual	0.203	12	0.017		
	Total	2.328	13			

a. Predictors: (Constant), FAO; b. dependent variable: computed.

Table 9. Regression analysis output (coefficients[a]).

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.	95% confidence interval for B	
		B	Std. error	Beta			Lower bound	Upper bound
1	(Constant)	0.113	0.066		1.699	0.115	-0.032	0.257
	FAO	0.999	0.089	0.955	11.202	0.000	0.805	1.194

a. Dependent variable: computed.

presented by Moutonnet (2001). The K_y value of the maize for total growing period was higher than 1.25 reported by Doorenbos and Kassam (1994). Also, this value was higher than the ones determined by Dagdelen et al. (2006) and Mengu and Ozgurel (2008) in Turkey, which ranged from 0.99 to 1.04. However, the obtained value in the present study was close to that observed by Igbadun et al. (2006) in Tanzania (1.90), and by Payero et al. (2008) in Nebraska, USA (from 1.54 to 1.74). The regression was analysis using SPSS16 PC software and the results were presented in Tables 8 and 9 respectively.

Furthermore Figure 1 shows calculated and presented data correlation. Therefore, although there was a

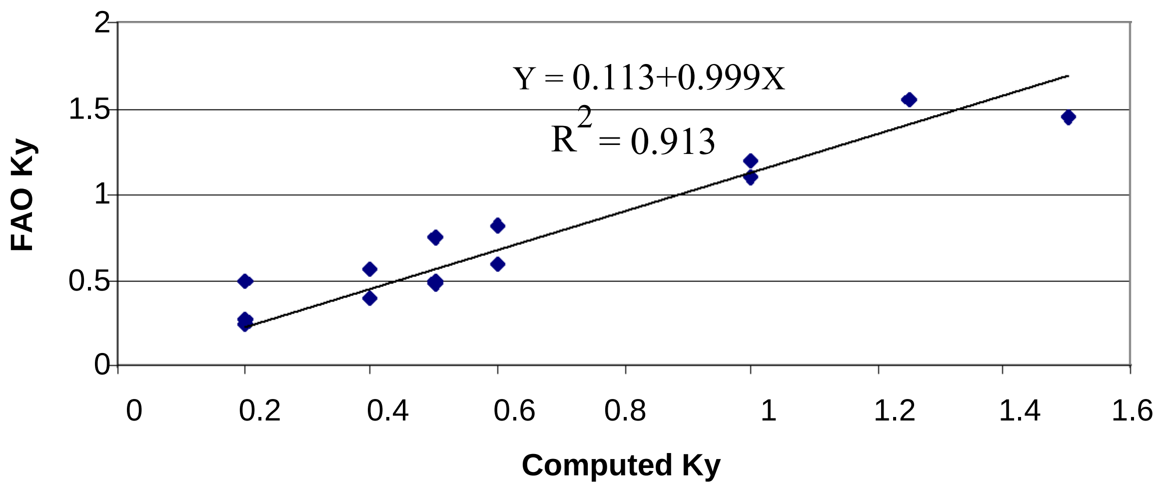

Figure 1. The releationship between FAO and computed.

Table 10. Comparison between the averages of observed and estimated actual yield (2002-2009).

Crop	Y_a (estimated) Kg/ha	Y_a (observed) Kg/ha	Mean bias error (%)
Maize	7451	8304	-14
Winter wheat	3364	3935	-10
Barley	2780	3250	-14

significant relationship between these two sets of data, the values obtained by our research were higher than the values published by FAO (1979). To verify our results, averages of observed and estimated actual yields were compared together using Equation 1 (2002 to 2009). The results of these comparisons are presented in Table 10. The estimated actual yields were close to observed data, with the mean bias error ranging from -10 to -14%. The mean bias error for maize was equal to -10%. This error was similar to those found by Soler et al. (2007), who used the DSSAT CERES- Maize model, to estimate actual yields of rainfed and irrigated maize, in the state of Sao Paulo, Brazil (-10.70 to +11.3%). Furthermore, the bias error was higher than the values reported by Kelber and Pualo (2009) in Brazil which ranged from -5.7 to +5.8%.

Conclusions

Based on this comparative analysis, the average K_y value calculated in this research was higher than the values reported by FAO (1979). Consequently, the reductions in yield through deficit irrigation are higher than those reported by FAO (1979). Data sets used in this research should be expanded using more well managed field experiments on different soils and in different climatic conditions.

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