Journal of Agricultural Science; Vol. 5, No. 3; 2013
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Evaluation and Improvement of Crop Production Functions for Simulation Winter Wheat Yields with Two Types of Yield Response Factors

Arash Tafteh[1], Hossein Babazadeh[2], Niaz Ali EbrahimiPak[3] & Feridon Kaveh[4]

[1] PhD candidate, Department of Water Sciences and Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran

[2] Assistant Professor, Department of Water Sciences and Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran

[3] Assistant Professor, Department of Irrigation and Soil Physics, Soil and water research institute, Karaj. Iran

[4] Associate Professor, Department of Water Sciences and Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran

Correspondence: Arash Tafteh, Department of Water Sciences and Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran. E-mail: Arash_tafteh@yahoo.com

Received: December 5, 2012 Accepted: February 4, 2013 Online Published: February 5, 2013

doi:10.5539/jas.v5n3p111 URL: http://dx.doi.org/10.5539/jas.v5n3p111

Abstract

Water is an important item of crop production and Irrigation water is limiting for crop production in arid and semi-arid areas. On the other hand, considering the population growth and increasing the water and food needs and also limited resources of water, the optimization of water consumption, especially in section of agriculture is important. For this purpose, in first step, the production function of expected products in any region should be obtained acceptably, because in this case, the models are totally dependent on the production function. Thus, finding the optimal production function has the lowest error in the estimation of risk-taking and decision-making power in the future will be important. So this study was conducted in Esmaeil Abad in Qazvin plain in Iran in the growing season of 2009-2012. Deficit Irrigations applied on different growth stages of winter wheat. The maximum evapotranspiration 641 mm and maximum attainable yield 5847 kg/ha was determined. After that the different production functions were studied and these methods have been tried to improve a new method with the least error. On the other hand yield response factor (K_y) per month was defined as either one of the standard values by FAO and the other using correction values by Najarchi et al. (2011). The result showed that the new model in this study is normalized with yield response factors of Najarchi et al. (2011) with 5% normal root mean square (NRMSE) has the lowest error. Therefore this technique for estimating water deficits of winter wheat in the Qazvin Plain was suggested.

Keywords: production function, yield response factor (K_y), winter wheat

1. Introduction

The important limit for agriculture in Iran is water, especially in Qazvin plain. So paying attention to the management of water consumption in agricultural sector as the main consumer of water is necessary. The rapid increase of the population and the corresponding demand for extra water by sectors such as industries and municipals, forces the agricultural sector to use its irrigation water more efficiently. Also planning and management of available water resources in the agricultural sector are to become a national and global priority (Smith, 2000). One important thing is to discuss in agricultural land is water shortage in under irrigation lands. There are different strategies to confront with this problem on farm land which are divided into six parts including: 1) Increasing soil water storage at the time of cultivation; 2) Increase water usage by plant in soil; 3) To decrease the evaporation from soil surface; 4) optimization model for water consumption; 5) improving plant tolerance to water stress and tensions; 6) irrigation at critical growth periods (Debaeke & Aboudrare, 2004). Apart from field experiments, a robust simulation model with which specific situations can be simulated would be very useful for the proper design of deficit irrigation strategies. The mechanistic models however generally require a huge set of input data which is often not readily available outside research stations. Since they also demand an extensive site-specific calibration before they can be applied, this type of model might not be very useful for developing irrigation strategies under practical conditions (Raes et al., 2006). In this context, By means of a mechanistic crop growth model, the expected yield for several growing conditions can be estimated (Penning de Vries & Van Laar, 1982; Spitters et al., 1989; Ritchie, 1990; Goudriaan & van Laar, 1994; Bouman et al., 1996; Boote & Jones, 1998; Soltani et al., 1999 ; Robertson et al., 2001; Batchelor et al., 2002; Stockle et al., 2003; Wang et al., 2003; Ziaei & Sepaskhah, 2003; Yang et al., 2004). Also we don't have enough data to run and to calibrate these models in each region of Iran especially in Qazvin plain. So using of these models is difficult. We need sample models to estimate crop yield in practical conditions. For this purpose, we try to find monthly sample method for estimating crop yield. In this study, the sample models, Doorenbos and Kassam (1979), Allen (1994), Stewart et al. (1977) and Raes (2004) are used to find best simple model. In the other hand, yield response factor (K_y) is very important to all of the models. So In the case of Qazvin Plain, we use yield response factor (K_y) that produce by Najarchi et al. (2011). Therefore, we should see that the impact of this correction factors is how much Influence on the production functions. Considering the importance of winter wheat as one of important products to supply the food needed in Iran and deficit irrigation method, the present study was to investigate the production functions with correction factor Najarchi et al. (2011) was conducted to estimate winter wheat yield to show that production function can be used and which functions will provide better answers.

2. Method and Materials

2.1 Experimental Site

This study was conducted in Esmaeil Abad in Qazvin province, Iran in the growing season of 2009-2012.This experiment was performed on a land area of 600 square meters in Esmaeil Abad Research Station (49º 52' N, 36º 15' E, 1285 MSL). There was no salinity and sodium hazard by using the irrigation water. In this experiment 200 kg/ha Nitrogen and 45 kg/ha phosphate fertilizer with 5 million plants per hectare density was applied. Randomized complete block design with 5 treatments and 3 replications was used. In each crop year and after preparing the ground with dimensions of 6m long, 4m wide, for each plot (24 m) were classified. Soil physical and chemical properties are given in Tables 1 and 2 respectively. In order to cultivate the seed of Alvand was used. Deficit Irrigations applied in during the Germination, Tillering, Stem elongation, flowering, Milky and dough and ripening stages. The evapotranspiration and crop yield in each method shown in Tables 3, 4 and 5. To ensure of significant difference between treatments in per year, Duncan test was applied, and the results were added to the tables.

Table 1. Some physical properties of the experimental soil

Depth	Clay	Silt	Sand	Bulk density	Field capacity	Permanent wilting point
cm	%	%	%	g cm^{-3}	cm^3 cm^{-3}	cm^3 cm^{-3}
0-25	51	34	15	1.44	0.21	0.11
25-50	35	50	15	1.42	0.2	0.1
50-75	47	38	15	1.47	0.23	0.12
75-100	39	54	7	1.53	0.23	0.12
100-125	37	54	9	1.55	0.23	0.13
125-150	39	42	19	1.6	0.24	0.13

Table 2. Some chemical properties of the experimental soil

Depth	pH	EC	$N0_3$	K	P	Ca	Na	Mg
cm		dS/m	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l
0-50	7.3	0.86	0.7	5.7	0.25	1.8	0.27	0.48
50-100	7.5	1.1	1.2	6.1	0.32	2.1	0.31	0.52

2.2 Measurement and Methodologies

The amount of irrigation water, in the basis of soil moisture in depths of 25, 75, 100, and 125 cm was measured, and amount of water demand in each layer in the region of plant's root relation was obtained by Equation 1.

$$d_n = \sum_{i=1}^{n}(\theta_{fci} - \theta_i)\Delta_z \quad (1)$$

Where d_n is the net irrigation depth (m), θ_{fci} and θ_i are the volumetric soil water contents in layer i at field capacity and before irrigation, respectively ($m^3\ m^{-3}$), Δ_z is the soil layer thickness (m) and n is the number of soil layers. Using Equation given by Borg and Grimes (1986) root growth during the growing season was calculated as follows:

$$Z_r = R_{DM}\left[0.5 + 0.5\ \mathrm{SIN}\left(\frac{3.03D_{AS}}{D_{TM}} - 1.47\right)\right] \quad (2)$$

Where z_r is the root depth, R_{DM} is maximum rooting depth, D_{TM} is the number of days required to reach the maximum depth, D_{AS} is the number of days after they are planted, The maximum depth of the root is 1 meter for winter wheat was placed 160 days after planting (Hosseini, 2005).

After calculating the amount of irrigation water needed due to the type of treatment applied, the soil water balance Equation for each treatment was calculated as the winter wheat evapotranspiration (Jensen, 1973).

$$ET = I + P - D \pm \left(\sum(\theta_1 - \theta_2)\Delta S_i\right) \quad (3)$$

where I is the irrigation amount (mm), P is the precipitation (mm), D is the deep percolation (mm) at the bottom of the root zone, n is the number of layers, ΔS is the thickness of each soil layer (mm) and θ_1 and θ_2 are the volumetric soil water contents ($cm^3\ cm^{-3}$) before two consecutive irrigations. These values are presented in Table 3, 4, and 5. In this test, the farming field capacity and bulk density during test was assumed constant. At the time of growth season, necessary cares like weeding, spraying against pests and plant diseases were performed and harvesting was done by hand. Then the product was dried and next the seeds were separated from the Straw and yields were measured for each treatment.

2.3 Yield Production Functions

According to information obtained (Table 3, 4, and 5), different production functions used. These functions for were as follows:

Doorenbos and Kassam (1979) have presented the relationship between relative yields, relative evapotranspiration, and crop coefficients were as follows:

$$1 - \frac{y_a}{y_m} = K_y\left(1 - \frac{ET_a}{ET_m}\right) \quad (4)$$

Where y_a is the actual harvested yield (kg/ha), y_m is the maximum attainable yield (kg/ha), K_y is the yield response factor (non-dimensional), and ET_a and ET_m are the actual evapotranspiration (mm) and maximum evapotranspiration (mm), respectively, during the growing period. Y_{max} and K_y are crop-related coefficients, which must be known.

This Equation acts as simple and general. So it is usable for total growth period and other methods based on this method have been written. In order to use this model, using yield response factor of product recommended by FAO and once again using yield response factor of product recommended by Najarchi et al. (2012) was applied.

Table 3. Monthly evapotranspiration rates of winter wheat in different irrigation treatments

year/month	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	∑ mm	yield Kg/ha
2010	39.8	13.3	14.7	11.3	10.4	67.2	87.1	151.5	176.4	571.7	5000^{g*}
	23.9	10.1	14.7	11.3	10.4	67.2	91.7	151.1	176.4	556.8	5100^{f}
	46.9	24.2	14.7	11.3	10.4	67.2	91.7	151.5	176.4	594.3	5170^{ef}
	20.2	0.0	14.7	11.3	10.4	67.2	75.2	151.5	176.4	526.9	5250^{e}
	38.9	20.3	14.7	11.3	10.4	67.2	91.7	151.1	176.4	582.0	5450^{d}
	46.9	24.2	14.7	11.3	10.4	67.2	91.7	151.1	176.4	593.9	5400^{d}
	32.4	9.9	14.7	11.3	10.4	67.2	83.4	151.5	176.4	557.2	5550^{c}
	26.2	4.7	14.7	11.3	10.4	67.2	79.7	151.5	176.4	542.1	5700^{b}
	18.8	0.0	14.7	11.3	10.4	67.2	91.7	151.1	176.4	541.6	5800^{a}
	30.1	15.7	14.7	11.3	10.4	67.2	91.7	151.1	176.4	568.6	5850^{a}
Testifier	46.4	24	14.6	11.2	10.3	76.5	108.8	158.3	184.3	634.4	5884^{a}

*Means followed by the same letters in each parameter are not significantly different at 5% level of probability

Table 4. Monthly evapotranspiration rates of winter wheat in different irrigation treatments

year/month	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	∑ mm	yield Kg/ha
2011	46.9	24.2	14.7	11.3	10.4	67.2	91.7	151.5	76.4	494.3	4500^{g*}
	43.2	22.5	14.7	11.3	10.4	67.2	17.4	130.3	169.3	486.3	4500^{g}
	39.4	20.9	14.7	11.3	10.4	67.2	66.0	34.0	176.4	440.3	4600^{f}
	39.4	20.8	14.7	11.3	10.4	67.2	0.0	106.1	162.3	432.2	4600^{f}
	45.0	23.4	14.7	11.3	10.4	67.2	76.0	36.0	176.4	460.4	5050^{e}
	46.9	24.2	14.7	11.3	10.4	67.2	91.7	151.0	176.4	593.8	5250^{d}
	46.9	24.2	14.7	11.3	10.4	67.2	87.0	118.0	176.4	556.1	5250^{d}
	46.9	23.7	14.7	11.3	10.4	67.2	66.0	145.4	174.6	560.2	5500^{c}
	45.0	23.2	14.7	11.3	10.4	67.2	41.3	140.9	172.9	526.9	5630^{b}
	46.9	24.2	14.7	11.3	10.4	67.2	81.0	91.0	176.4	523.1	5900^{a}
Testifier	46.9	24.2	16.7	12.3	10.4	67.5	121.7	159.5	181.7	640.9	5800^{a}

*Means followed by the same letters in each parameter are not significantly different at 5% level of probability

Table 5. Monthly evapotranspiration rates of winter wheat in different irrigation treatments

year/month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	∑ mm	yield Kg/ha
2012	39.9	24.2	14.7	11.3	10.4	67.2	91.7	74.2	72.0	405.6	4700^{f*}
	46.9	24.2	14.7	11.3	10.4	67.2	88.9	150.0	56.4	470.0	4750^{ef}
	46.9	24.2	14.7	11.3	10.4	67.2	91.7	151.5	176.4	594.3	4800^{e}
	46.9	24.2	14.7	11.3	10.4	67.2	91.7	98.5	98.0	462.9	4950^{d}
	46.9	24.2	14.7	11.3	10.4	67.2	88.9	150.0	134.0	547.6	5000^{d}
	46.9	24.2	14.7	11.3	10.4	67.2	91.7	151.5	176.4	594.3	5100^{c}
	46.9	24.2	14.7	11.3	10.4	67.2	88.9	150.0	93.5	507.1	5150^{c}
	46.9	24.2	14.7	11.3	10.4	67.2	91.7	115.0	119.0	500.4	5150^{c}
	46.9	24.2	14.7	11.3	10.4	67.2	88.9	130.0	30.0	423.6	5700^{b}
	46.9	24.2	14.7	11.3	10.4	67.2	91.7	134.1	149.0	549.5	6000^{a}
Testifier	47.4	26.5	15.8	13.4	12.5	77.9	102.6	173	178.2	647.3	5857^{a}

*Means followed by the same letters in each parameter are not significantly different at 5% level of probability

Minimum product loss is another method which was expressed by Allen (1994) and different growth period was considered:

$$\frac{Y_a}{Y_P} = \mathrm{Min}\left\{\frac{Y_{a1}}{Y_{P1}}, \frac{Y_{a2}}{Y_{P2}}, \dots, \frac{Y_{ai}}{Y_{Pi}}\right\} \quad (5)$$

Where Y_a is the actual harvested yield (kg/ha), Y_p is the maximum attainable yield, Y_{ai}/Y_{pi} are expected relative yield as result of water stress in growth stage i. The expected yield is estimated by the sum of the right hand terms of Equation 1 determined for each period.

In this study, instead of taking minimum, the Average of product reduction was considered, as the Equation can be written as follows;

$$\frac{Y_a}{Y_P} = \frac{1}{n}\sum_{i=1}^{n}\left\{\frac{Y_{a1}}{Y_{P1}}, \frac{Y_{a2}}{Y_{P2}}, \dots, \frac{Y_{ai}}{Y_{Pi}}\right\} \quad (6)$$

Where Y_a is the actual harvested yield (kg/ha), Y_p is the maximum attainable yield, Y_{ai}/Y_{pi} are expected relative yield as result of water stress in growth stage i. The expected yield is estimated by the sum of the right hand terms of Equation 1 determined for each period.

Another productive method of generating functions is that Stewart et al. (1977) presented the following Equation for the stress at different growth stages:

$$\frac{y_a}{y_m} = \prod_{i=1}^{n}\left(1 - K_{yi}\left(1 - \frac{ET_{ai}}{ET_{mi}}\right)\right) \quad (7)$$

Where y_a is the actual harvested yield (kg/ha), y_m is the maximum attainable yield, ET_{ai} is the actual evapotranspiration in each period (mm), ET_{mi} is the maximum evapotranspiration in each period (mm), K_{yi} is the yield response factor (non-dimensional) at any stage of growth, i is the stage of development, and n is the number of stages of growth.

Therefore, according to Equation 7, reduction rate in one-month period was determined. So that the final product can be gotten, as this method, one time with yield response factor of FAO and another time with yield response factor of Najarchi et al. (2011) were performed.

To improve and increase the accuracy of the Equation 7, Raes (2004) in the water and solute balance model (BUDGET), the following Equation was used where the different stages are divided into a number of smaller periods:

$$1 - K_{yi}\left(1 - \frac{ET_{a,i}}{ET_{m,i}}\right) = \prod_{j=1}^{M}\left(1 - K_{yi}\left(1 - \frac{ET_{a,j}}{ET_{m,j}}\right)\right)^{\frac{\Delta t_j}{L_i}} \quad (8)$$

Where $\prod$ stands for the product of the M functions between square brackets, M for the number of time steps with length Δt_j (day), during the growth stages i, L_i for the total length of the stages(day), and $ET_{a,j}$ and $ET_{m,j}$ for respectively the actual and maximum evapotranspiration during the time step j. In this study length of period (Δt_j) is 30 days, and Equation 8 was used with monthly intervals, and range of ($\Delta t_j/L_i$) is given in Table 6.

So, using the table of values and evapotranspiration values in each interval, yields were estimated by this method. In this way, the yield response factors of the two types of plants were used.

To improve and increase the accuracy of the Equation 8 and to increase the accuracy of production function, it has been tried, the weighting of length of periods with yield response factor is replaced and the new Equation is as follows:

$$\frac{Y_a}{Y_P} = \prod_{i=1}^{n}\left(1 - K_{yi}\left(1 - \frac{ET_{a,j}}{ET_{m,j}}\right)\right)^{\frac{K_{yi}}{\sum_{i=1}^{n} K_{yi}}} \quad (9)$$

Where Y_a is the Actual yield (Kg/ha), Y_p is the maximum attainable yield (kg/ha), $ET_{a,j}$ is the actual evapotranspiration (mm) in each period, and $ET_{m,j}$ is the maximum evapotranspiration (mm) in each period, K_{yi} is the yield response factor (non-dimensional) at any stage of growth, i:stage development, and n is the number of stages.

The computed values for new coefficients are given in Table 6. According to the values obtained the new method was launched.

Table 6. Monthly coefficients of the Raes (2004) and the new method

Month	∑	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.
Δ_{tj}	-	15	31	30	31	31	30	31	30	15
$\Delta tj / Li$	-	0.04	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.06
K_{yFAO}	5	0.20	0.50	0.60	0.60	0.60	0.60	0.60	0.50	0.40
$\frac{K_{yi}}{\sum_{i=1}^{n} K_{yi}}$	-	0.04	0.1	0.12	0.12	0.12	0.12	0.12	0.1	0.08
K_{yNaj}	6.1	0.31	0.61	0.71	0.71	0.71	0.71	0.71	0.61	0.51
$\frac{K_{yi}}{\sum_{i=1}^{n} K_{yi}}$	-	0.05	0.1	0.12	0.12	0.12	0.12	0.12	0.1	0.08

2.4 Analyses Method

Simulation yield were compared with the measurement values. The goodness of fit of the simulations was assessed with the help of three statistical estimators:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - Y_i)^2} \tag{10}$$

Where RMSE is the Root Mean square error, n is number of data, X_i is the Data Measurement and Y_i is data estimated by the model.

$$NRMSE = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - Y_i)^2}}{\bar{X}} \tag{11}$$

Where NRMSE is the Normal Root Mean square error, n is the number of data, X_i is the measured data, Y_i is the data estimated by the model, and $\bar{X}$ is the average of measured data.

$$d = 1 - \left[\frac{\sum_{i=1}^{n}(x_i - y_i)^2}{\sum_{i=1}^{n}(|x_i - \bar{X}| + |y_i - \bar{Y}|)^2}\right] \tag{12}$$

Where d is Agreement index, n is the number of data, x_i is the measured data, y_i is the data estimated by the model, $\bar{X}$ is the average of measured data, and $\bar{Y}$ is the average of estimated data.

3. Results and Discussion

According the measured values and different functions of production which were used in this study, the yield of winter wheat was estimated in any method with separation of yield response factor are given in Tables 7, 8 and 9.

Table 7. Prediction yield by difference production functions (2010)

	Predict Method(kg/ha)											
Measured (Kg/ha)	Eq.(4) K_{FAO}	Eq.(4) K_{Naj}	Eq.(5) K_{FAO}	Eq.(5) K_{Naj}	Eq.(6) K_{FAO}	Eq.(6) K_{Naj}	Eq.(7) K_{FAO}	Eq.(7) K_{Naj}	Eq.(8) K_{FAO}	Eq.(8) K_{Naj}	Eq.(9) K_{FAO}	Eq.(9) K_{Naj}
5000	5246	5463	3404	2898	5374	5200	2855	1871	5302	5120	5340	5170
5100	5319	5557	4039	3674	5476	5324	3631	2562	5451	5318	5483	5356
5170	5170	5365	2850	2223	5288	5063	2249	1220	5170	4911	5220	4978
5250	5243	5459	2850	2223	5345	5141	2500	1403	5235	4999	5290	5069
5450	5503	5795	5690	5683	5698	5697	5681	5670	5699	5698	5698	5897
5400	5444	5719	5241	5107	5633	5582	5045	4581	5634	5598	5643	5608
5550	5321	5560	4016	3645	5464	5340	3557	2717	5426	5308	5452	5342
5700	5393	5653	4416	4134	5536	5464	4145	3576	5510	5440	5528	5463
5800	5505	5798	5690	5683	5699	5698	5688	5680	5699	5699	5699	5698
5850	5377	5633	4699	4455	5557	5450	4348	3482	5553	5470	5573	5493

Table 8. Prediction yield by difference production functions (2011)

	Predict Method(kg/ha)											
Measured (Kg/ha)	Eq.(4) K_{FAO}	Eq.(4) K_{Naj}	Eq.(5) K_{FAO}	Eq.(5) K_{Naj}	Eq.(6) K_{FAO}	Eq.(6) K_{Naj}	Eq.(7) K_{FAO}	Eq.(7) K_{Naj}	Eq.(8) K_{FAO}	Eq.(8) K_{Naj}	Eq.(9) K_{FAO}	Eq.(9) K_{Naj}
4500	4968	5104	2929	1677	5344	5174	2541	1340	5000	4842	5195	4851
4500	4699	4757	2280	735	5195	4950	1686	455	4966	4290	4968	4311
4600	4840	4938	3527	2741	5409	5292	3082	2222	5314	5124	5351	5181
4600	4740	4809	3490	2689	5325	5155	2614	1677	5223	4984	5264	5047
5050	5170	5365	3820	2971	5470	5362	3547	2646	5401	5228	5396	5232
5250	5315	5553	5070	4842	5618	5587	4905	4612	5603	5564	5612	5577
5250	5151	5341	4562	4150	5545	5485	4235	3717	5509	5428	5525	5452
5500	5336	5579	4742	4309	5583	5532	4571	4096	5558	5489	5556	5491
5630	5503	5795	5690	5683	5698	5697	5681	5670	5699	5698	5698	5697
5900	5505	5798	5690	5683	5699	5698	5690	5683	5700	5699	5699	5700

Table 9. Prediction yield by difference production functions (2012)

	Predict Method (kg/ha)											
Measured (Kg/ha)	Eq.(4) K_{FAO}	Eq.(4) K_{Naj}	Eq.(5) K_{FAO}	Eq.(5) K_{Naj}	Eq.(6) K_{FAO}	Eq.(6) K_{Naj}	Eq.(7) K_{FAO}	Eq.(7) K_{Naj}	Eq.(8) K_{FAO}	Eq.(8) K_{Naj}	Eq.(9) K_{FAO}	Eq.(9) K_{Naj}
4700	4426	4403	3420	1767	5232	4910	2084	664	5283	4877	5247	4877
4750	4746	4816	4643	3877	5393	5207	3150	2048	5410	5222	5415	5222
4800	4703	4761	3875	2552	5349	5099	2755	1309	5403	5124	5373	5124
4950	4416	4391	4203	3117	5253	4959	2318	1094	4873	4970	5279	4970
5000	4911	5030	4105	2949	5420	5221	3256	1926	5483	5297	5446	5297
5100	4962	5096	4937	4383	5481	5347	3777	2841	5498	5370	5501	5370
5150	5246	5463	5328	5059	5595	5530	4710	4163	5606	5549	5607	5549
5150	5135	5319	4330	3337	5495	5350	3823	2691	5562	5452	5516	5452
5700	5505	5798	5690	5683	5699	5698	5690	5683	5700	5699	5699	5699
6000	5506	5799	5700	5700	5700	5700	5700	5700	5700	5700	5700	5700

For better results, first, we explain the review of results of the production function of Doorenbos and Kassam (1979). For this work, the estimated parameters measured using the index of sensitive plants FAO in Figure 1a and the coefficients of yield response factor of Najarchi et al. (2011) in Figure 1b, compared to the one by one line along with the values of RMSE, NRMSE and d is presented. As, it's clear, this production function the index of sensitive plants FAO can act better and amount of normal risk is 6% and this is while with the index of sensitive plants of Najarchi et al. (2011), the amount of error reaches to 5%, thus, in the case of using this production function, coefficients of Najarchi et al. (2011) are proposed.

Second function of production, which has been examined, is a minimization method, as amount of estimated values with this method is brought using FAO plant yield response factors in Figure 2a and yield response factor Najarchi et al. (2011) in Figure 2b relate to a line, one by one and together with values of RMSE, NRMSE and d is presented. Considering the results obtained, this method with two aforesaid yield response factors didn't work and only based on the extremist tension can make decision, thus, its results are not imputable and has normal error of 21-34%, as it was not suggested.

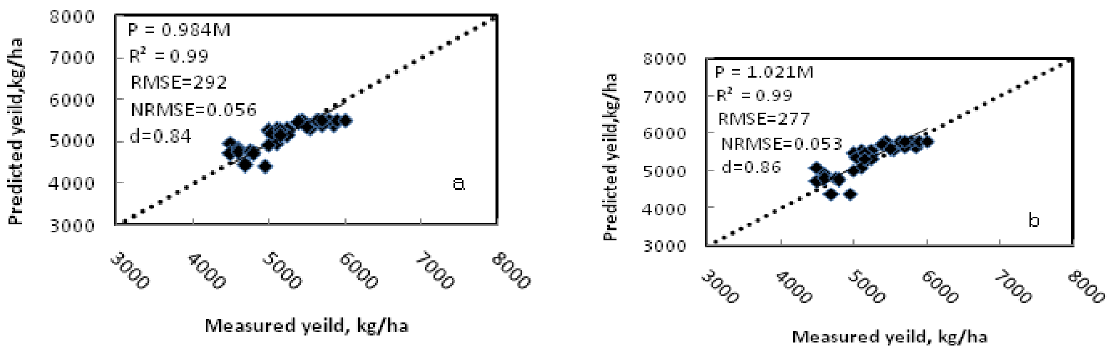

Figure 1. Relationship between amount of measured and yield was estimated by Equation. (4) with:
a) FAO plant yield response factors. b) Plant yield response factors of Najarchi et al. (2011)

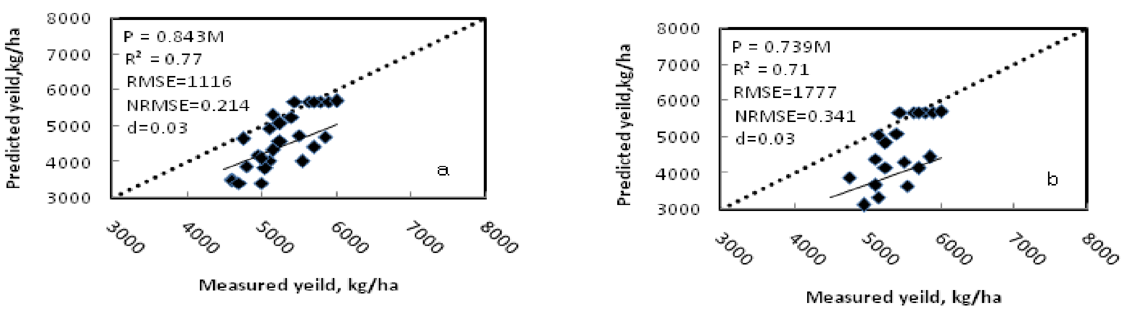

Figure 2. Relationship between amount of measured and yield was estimated by Eq. (5) with:
a) FAO plant yield response factors. b) Plant yield response factors of Najarchi et al. (2011)

The third function is the averaging method of production was investigated in this study, this method was used to correct for the minimal approach. Values estimated by this method using the FAO crop yield response factor in Figure 3a and Najarchi et al. (2011) plant yield response factor in Figure 3b compared to the one by one line along with the values of RMSE, NRMSE and d are presented. Considering the results obtained this method Najarchi et al. (2011) yield response factor work better and based on the averaging of imposed tensions estimates the amount of crop. Thus, results of this method are acceptable and using Correction Coefficient (Najarchi et al., 2011) its Normal Error reduces from 8 to 6 percent. So, this method can increase the accuracy of estimate and comparing to method of minimum offers more reasonable answers.

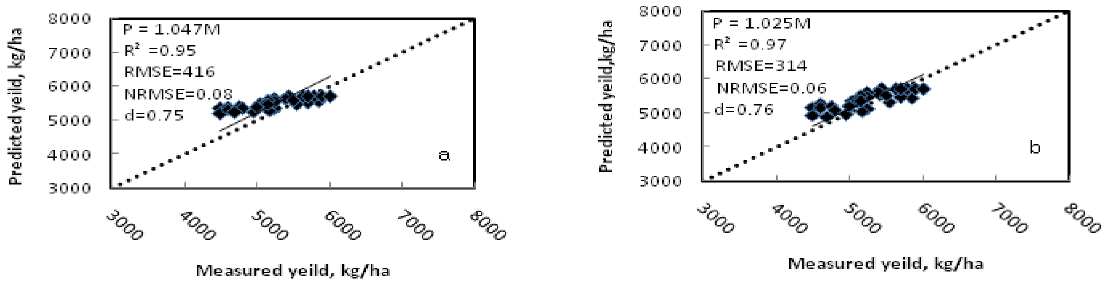

Figure 3. Relationship between amount of measured and yield was estimated by Equation. (6) with:
a) FAO plant yield response factors. b) Plant yield response factors of Najarchi et al. (2011)

Next function of production, which has been examined, is a simple multiplication method, as in this method, water tension in each cycle, have influence on each other as multiplying and decrease the crop in this function. Amount of estimated values with this method is brought using FAO plant yield response factor in Figure 4a and yield response factor Najarchi et al. (2011) in Figure 4b relate to a line, one by one and together with values of RMSE, NRMSE and d is presented. Considering the results obtained, this method with two aforesaid yield response factors didn't work and only based on the extremist tension can make decision, thus, its results are not imputable and has normal error of 32-48%, as it was not acceptable and is not suggested.

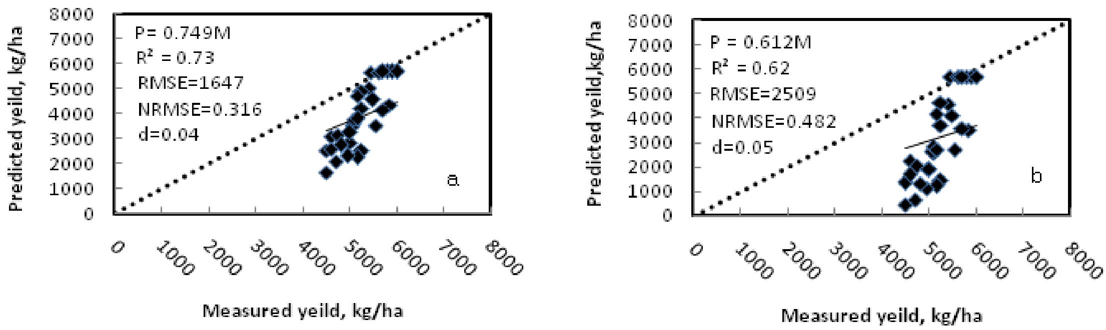

Figure 4. Relationship between amount of measured and yield was estimated by Equation. 7 with:
a) FAO plant yield response factors. b) Plant yield response factors of Najarchi et al. (2011)

Raes (2004) in order to improved simple multiplication method, the multiplying function of production with coefficients were defined to the length of each period were corrected. As in this method, water tension in each cycle, have influence on each other as multiplying and decrease the crop. Amount of estimated values with this method is brought using FAO plant yield response factorin Figure 5a and yield response factor Najarchi et al. (2011) in Figure 5b relate to a line, one by one and together with values of RMSE, NRMSE and d is presented. Considering the results obtained this method Najarchi et al. (2011) Plant yield response factor work better. Thus, results of this method are acceptable and using Correction Coefficient its Normal Error reduces from 8 to 6 percent. So, this method can accurately increase the accuracy of estimate and comparing to method of simple multiplication offers more reasonable answers.

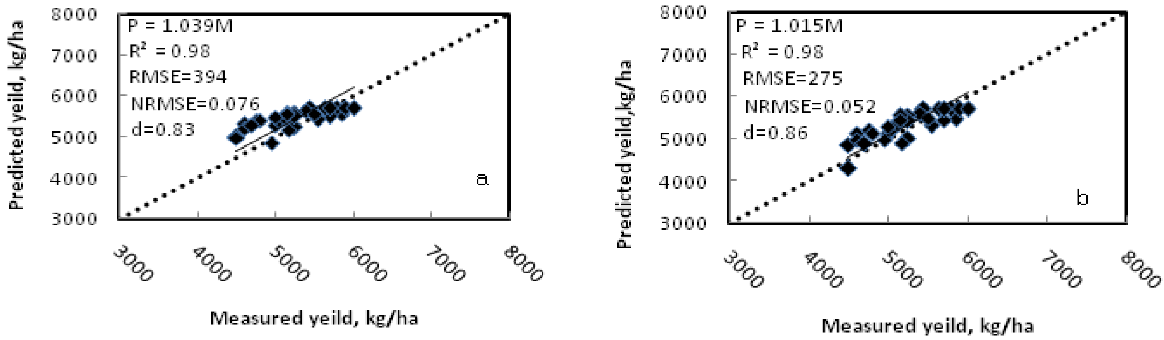

Figure 5. Relationship between amount of measured and yield was estimated by Equation 8 with:
a) FAO yield response factors. b) Plant yield response factors of Najarchi et al. (2011)

Raes (2004) multiplication method defined multiplication function with strength coefficients, which is dependant to the proportion of length of each time period, but, the important thing is sensitivity of plant during each period. Thus, in this study, these coefficients are distributed according to yield response factor of each period so that it can be observed that this strength proportion is much dependent to the length of period or rate of yield response factor of each period. And the severity of crop reduction in each period can be controlled with these new coefficients. Amount of estimated values with this method is brought using FAO plant yield response factor in Figure 6a and yield response factor Najarchi et al. (2011) in Figure 6b relate to a line, one by one and together with values of RMSE, NRMSE and d is presented. Considering the results obtained this method Najarchi et al. (2011) Plant yield response factor work better. Thus, results of this method are acceptable and using Correction Coefficient its Normal Error reduces from 8 to 5 percent. So, this method can accurately increase the accuracy of estimate and comparing to method of Raes (2004) offers more reasonable answers.

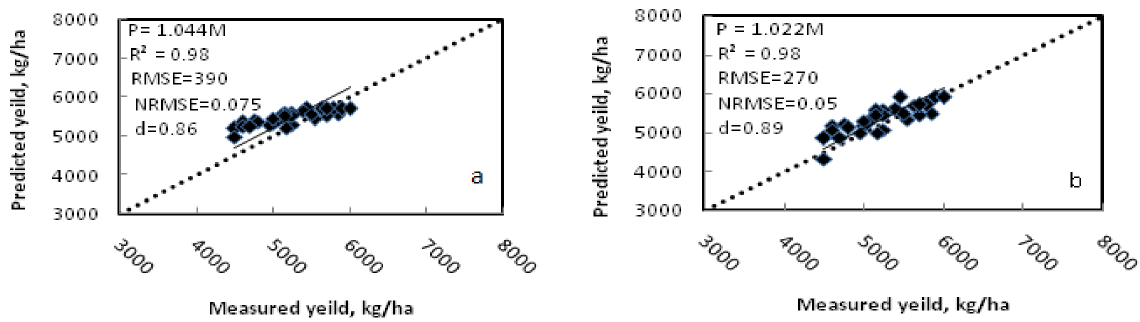

Figure 6. Relationship between Amount of measured and yield was estimated by Equation 9 with:
a) FAO yield response factors b) Plant yield response factors of Najarchi et al. (2011).

4. Conclusions

Considering functions of planned production in this study, it's needed that results which are obtained should be collected in a table so that we can get an appropriate conclusion. Therefore, a summary of statistical results are given in Table 10. The values obtained in the method of Doorenbos and Kassam (1979), the yield response factors of Najarchi et al. (2011) are recommended. However, this method is general and does not feature a monthly breakdown. In the Average method, the normal error rate is reduced to 8 percent. And with the use of Najarchi et al. (2011) yield response factors, this error can be reduced to 6 percent.

Table 10. Values of RMSE, NRMSE and d for production functions

Method	Ky	RMSE	NRMSE	d
Doorenbos	FAO	292	0.056	0.84
Doorenbos	Naj	277	0.053	0.86
min	FAO	1116	0.214	0.03
min	Naj	1777	0.341	0.03
AVE	FAO	416	0.080	0.75
AVE	Naj	314	0.060	0.76
multi	FAO	1647	0.316	0.04
multi	Naj	2509	0.482	0.05
Raes	FAO	394	0.076	0.83
Raes	Naj	295	0.056	0.86
New	FAO	390	0.075	0.86
New	Naj	270	0.050	0.89

In simple multiplication method and minimum method, we see high error as in these methods. Therefore, these methods with error of 21% and 31% are not recommended to estimate the crop of Winter wheat. The method of Raes (2004) with monthly stage cause a suitable weighting is done and the normal error rate is reduced to 8 percent. Therefore, with this method, we can reach satisfactory answers and it can act better than the average method. Also, the normal error rate is reduced to 6 percent by using corrective coefficients of Najarchi et al. (2011). In this new method that the weighing power is connected to the coefficient of sensitivity, the normal error rate is reduced to 7.5 percent and in the case of corrective coefficients of Najarchi et al. (2011), the normal error rate is reduced to 5 percent. So, what is the more effective on weighting is not length of course of plant sensitivity. Thus, the new method can provide a more acceptable solution. Therefore, among aforesaid methods, the new method works better than others and is proposed as a suitable method. Finally, in order to increase the accuracy of plant yield in Qazvin Plain response factor of Najarchi et al. (2011) is proposed.

Acknowledgement

This study supported by the Soil and Water Research Institute (SWRI) of Iran and Department of Water Engineering, Science and Research branch of Tehran, Islamic Azad University of Iran.

References

Allen, R. G. (1994). Memorandum on application of FAO-33 yield functions. Department of Biological and Irrigation Engineering, Utah State University, Logan, Utah.

Batchelor, W. D., Basso, B., & Paz, J. O. (2002). Examples of strategies to analyze spatial and temporal yield variability using crop models. *European Journal of Agronomy, 18*, 141-158. http://dx.doi.org/10.1016/S1161-0301(02)00101-6

Boote, K. J., & Jones, J. W. (1998). Simulation of crop growth: CROPGRO model. In R. M. Curry (Ed.), *Agricultural Systems Modeling and Simulation*. Marcel Dekker, Inc.

Borg, H., & Grimes, D. W. (1986). Depth development of roots with time: An empirical description. *Trans of the ASAE., 29*, 194-197.

Bouman, B. A. M., van Keulen, H., van Laar, H. H., & Rabbing, R. (1996). The 'School of de Wit' Crop Growth Simulation Models: a pedigree and historical overview. *Agricultural System, 52*, 171-198. http://dx.doi.org/10.1016/0308-521X(96)00011-X

Debaeke, P., & Aboudrare, A. (2004). *Adaptation of crop management to water-limited environmental*. *European Journal of Agronomy, 21*, 433-446.

Doorenbos, J., & Kassam, A. H. (1979). *Yield response to Water*. irrigation and drainage. paper No. 33, Food and Agricultural Organization. Rome. Italy.

FAO (1992). CROPWAT, a computer program for irrigation planning and management by M. Smith. FAO Irrigation and Drainage paper No. 26. Rome.

Goudriaan, J., & van Laar, H. H. (1994). Modelling potential Crop Growth Processes. *Current Issues in Production Ecology,* 2. Dordrecht, the Netherlands: Kluwer Academic Press Publishers.

Hosseini, S. (2005). *Effects between alternate furrow irrigation and different levels of nitrogen on winter wheat in Bajgah and kooshkak*. M.Sc. Thesis. Irrigation department, Shiraz University.

Jensen, M. E. (1973). *Consumptive Use of Water and Irrigation Water Requirements* (p. 215). ASCE.

Najarchi, M., Kaveh, F., Babazadeh, H., & Manshouri, M. (2011). Determination of the yield response factor for field crop deficit irrigation. *African Journal of Agricultural Research, 6*(16), 3700-3705.

Penning de Vries, F. W. T., & Van Laar, H. H. (1982). *Simulation of plant growth and crop production*. Wagening, the Netherlands: Center for Agricultural Publishing and Documentation.

Raes, D. (2004). Budjet: a soil water and salt balance model. Reference Manual. Version 6.0 (http://www.iupware.be) and select downloads and next software. last updated June 2004. http://dx.doi.org/10.1016/j.agwat.2005.04.006

Raes, D., Geerts, S., Kipkorir, E., Wellens, J., & Sahli, A. (2006). Simulation of yield decline as a result of water stress with robust soil water balance model. *Agricultural Water Management, 81*, 335-357.

Ritchie, J. T. (1990). Specifications of the ideal model for predicting crop yields. In C. Russell, & J. Muchow, A. Bellamy (Eds.), *Climatic risk in crop production, Brisbane* (pp. 97-123). Australia.

Robertson, M. J., Carberry, P. S., Chauhan, Y. S., Ranganathan, R., O'Leary, G. J. (2001). Predicting growth and development of pigeonpea: a simulation model. *Field Crops Res., 71*, 195-210. http://dx.doi.org/10.1016/S0378-4290(01)00160-5

Smith, M. (2000). The application of climatic data for planning and management of sustainable rain fed and irrigated crop production. *Agriculture Forest Meteorology, 103*, 99-108. http://dx.doi.org/10.1016/S0168-1923(00)00121-0

Soltani, A., Ghassemi-Golezani, K., Khooie, F. R., & Moghaddam, M. (1999). A simple model for chickpea growth and yield. *Field Crops Res., 62*, 213-224. http://dx.doi.org/10.1016/S0378-4290(99)00017-9

Spitters, C. J., Van Keulen, H., & Van Kraalingen, D. W. G. (1989). A simple and universal crop growth simulator: SUCROS87. In: R. Rabbinge, S. A. Ward, H. H. va n Laar (Eds.), *Simulation and Systems Management in Crop Protection, Simulation Monographs 32*. Wageningen.

Stewart, J., Cuenca, R. H., Pruitt, W. O., Hagan, R. M., & Tosso, J. (1977). *Determination and Utilization of water production functions for principal California Crops*. In: W-67 California Contribution Project Report. Univercity of California, Davis.

Stockle, C. O., Donatelli, M., & Nelson, R. (2003). Cropsyst, a cropping system simulation model. *European journal of agronomy, 18*, 289-307. http://dx.doi.org/10.1016/S1161-0301(02)00109-0

Wang, F., Fraisse, C. W., Kitchen, N. R., & Sudduth, K. A. (2003). Site-specific evaluation of the CROPGRO-soybean model on Missouri claypan soils. *Agric. Syst., 76*, 985-1005. http://dx.doi.org/10.1016/S0308-521X(02)00029-X

Yang, H. S., Dobermann, A., Lindquist, J. L., Walters, D. T., Arkebauer, T. J., & Cassman, K. G. (2004). Hybrid-maize-a maize simulation model that combines two crop modeling approaches. *Field Crops Res., 88*, 131-154. http://dx.doi.org/10.1016/j.fcr.2003.10.003

Ziaei, A. N., & Sepaskhah, A. R. (2003). Model for simulation of winter wheat yield under dryland and irrigated conditions. *Agriculture Water Management, 58*, 1-17. http://dx.doi.org/10.1016/S0378-3774(02)00080-X