J. BIOL. ENVIRON. SCI.,
2015, 9(27), 119-126

Original Research Article

Investigation of Barley Productivity Responses to Different Water Consumption by Using the CERES-Barley Model

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Received: 30.08.2014; Accepted: 23.03.2016; Published Online: 19.04.2016

ABSTRACT

Cropping system models have evolved over the last four decades in response to demand for modeling to address more complex questions, including issues on sustainable production, climate change and environmental impact. The present study is about dynamic mechanistic model (CERES (Crop Environment RE source Synthesis)-Barley that was validated by predicting growth and yield of barley (*Hordeum vulgare* L.) under different water management conditions. My objective was analysis of barley responses to different water consume for optimizing of biomass and yield productivity. Evaluation of analysis showed that performance of the model was reasonable as indicated by close correspondence of simulated crop phenology, biomass accumulation and grain yield versus measured data. Growth parameters of barley in CERES-Barley were calibrated through field experiments, Karaj (Iran) 2010-2011. Genotypic variables determined for 5 commonly cultivars grown in Karaj. The performance of the models was evaluated using simulated and observed data on anthesis and maturity date, in-season LAI, final yield and its components. Grain yields simulated by model were acceptable when compared with experimental results. The determination coefficient in historical series varied from 0.83 to 0.99 for evaluation of CERES- Barley under normal irrigation. The accuracy of model simulation in dry matter was optimum in based on correlation coefficient 0.91-0.98. Also model acted well for biomass simulation in treatments. As biomass measured data generally have 10-20% error and treatments widely varied in two irrigation system. The objective of this study was determine, whether CERES-Barley model could be forecast yield and biomass in maturity under growing season and ecological management in Karaj.

Keywords: **CERES-Barley, Simulation, Yield and Biomass, Drought stress**

CERES-Arpa Modeli Kullanılarak Arpa Verimliliğinin Farklı Su Tüketimlerine Tepkisi Üzerine Araştırmalar

İklim değişikliği, sürdürülebilir üretim çevresel etkiler ile ortaya çıkan karmaşık sorulara cevap bulabilmek için geçtiğimiz 40 yılda bitki sistem modelleri ortaya çıkmıştır. Bu çalışmada dinamik mekanik model (CERES (Crop Environment RE source Synthesis) kullanılarak farklı su yönetim şartları altında arpanın gelişmini ve verimini tahminleme amaçlanmıştır. Farklı su tüketimleri için arpanın biyokütlesi ve verimin optimizasyonu incelenmiştir. Analiz değerlendirilmesi yapılmış ve modelin performansı başarılı bulunmuştur. 2010-2011 yıllarında yapılan arazi çalışmaları ile CERES-Arpa modelinin gelişim parametreleri kalibre edilmiştir. Kerec'te gelişen 5 yaygın tür için genotip değişkenleri belirlenmiştir. Modelin performansı çiçeklenme ve olgunlaşma zamanı son verim ve bileşenlerin simulasyonları ve gözlenen verileri kullanılarak değerlendirilmiştir. Deneysel sonuçlara bakıldığında simule edilen tane verimi kabul edilebilir olarak belirlenmiştir. Normal sulama şartlarında determinasyon katsayısı 0.83 ile 0.99 arasında değişkenlik göstermiştir. Korelasyon katsayısına göre (0.91-0.98) modelin tutarlılığı optimum olmuştur. Buna ek olarak uygulamalardaki biyokütle simulasyonu için model çok iyi uyum sağlamıştır. Bu çalışmanın amacı CERES modelinin arpada verimin ve biyokütlenin önceden tahmin edilmesi konusunda kullanılabileceğini göstermek amacıyla gerçekleştirilmitşir.

Anahtar Kelimeler: CERES-Barley, Uyarı, Verim ve Biyokütle, Kuraklık Stresi

INTRODUCTION

Water shortage is the main reason for creating different of barley yield in many of agricultural land in world. Therefore, great efforts have been made over many years to show how yield is fluctuating by water stress (Jamienson *et al.*, 1998). Many researchers studied about the empirical models for determine of biomass production and evapotranspiration relationship. These studies provide a little information regards physiological mechanism of yield fluctuation (Hank and Rassmussen 1982). During the past few decades, the crop models based on physiological principles have the ability to simulate of dynamic factors effects on growth and yield, so they can simulate its traits under variable environmental conditions. Beside, the simulation model is able to analyze the different management strategies, as well as to choose the best efficient strategy. Thus, the models appear to have good potential in drought studies. Up to now, many studies have been conducted regarding the study of the production under drought conditions using models. Crop models are an important part of ecological models (Jorgensen 1997), because these models can predict the plant systems and increase our knowledge about

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their function (Sinclair and Seligman 2000). Models play an important role in making data and ideas and able to identify weaknesses in our knowledge. A model of plant growth is the mathematical description of our understanding of plant behavior, this behavior is should be at clear and specific stage due to the use of mathematical functions, and there is no place for chance or possibility. Need an equation, force us to consider the assumptions, and the model is constructed to test this hypothesis. If the model's predictions are not accurate of reality, it must accept that our understanding of the system is not perfect (Banayan 2002). These models have been used for various studies including selection of the appropriate crop and cultivar for planting, determination of the best crop management (Egli and Bruening 1992), policy for breeding varieties (Habekotte 1997), and anticipation the effects of climate change (Melkonian *et al.* 1997). DSSAT (The decision support system for agricultural technology) model is one of the most famous and most used crop simulation models (more than 20 different crops) (Soltani and Hoogenboom 2007). DSSAT model is derived from CERES- Barley CROPSIM-Barley (Jones *et al.* 2003). This software is distributed in over 90 countries and has been used by many researchers in the late 1980s (Jones *et al.* 2003). Jones *et al.* (2003) have listed more than 120 studies conducted by DSSAT models in the world, from North America to Africa, in these studies, DSSAT crop simulation models were used to determine the optimal operation management, fertilizer management, irrigation management, precision farming, pest management, biodiversity and climate change, environment pollution and education (Soltani and Hoogenboom 2007). Wheat plants and production has been evaluated under water stress using AFRCWHEAT2 (Jamienson *et al.* 1998); Sirius (Hunt *et al.* 1993); CERES-Wheat (Hundel and Kaur 1997); SUCROS2 (Hunt and Pararajasingham 1995) and SWHEAT (Jakson *et al.* 1996) models. These authors by the study of prediction functions of evapotranspiration in the different models and evaluation the advantages strategies associated with growth and yield, showed that except SWHEAT, other models have the ability to reasonably predict yield. In all cases, RMSE values was less than 10% the observation mean, these results together with the results of Banayan *et al.* (1999) used this model to predict winter wheat yield in the UK, shows good ability of CERES-Wheat model to simulate phenology stage and yield of wheat. Hundale and Kaur (1997) examined the applicability of the CERES-Wheat model using five-year climate data in the irrigated plains of the Indian Punjab. Evaluation analysis showed that performance of the model was reasonable as indicated by close correspondence of simulated crop grain yield, phenology, maturity and total dry matter with the filed-measured data. Further, evaluation of grain yield of five winter wheat varieties in Karaj weather condition in Full Irrigation (FI) and Stop Irrigation (SI) after flowering until final growth stage by Paknejad *et al.* (2012), indicated that CERES-Wheat model have appropriate accurate in simulation of seed yield. This is in contrast to deterministic models where the predicted values are computed without consideration of their variability. This context was carried out with the main objective of validation and performance evaluation of the detailed CERES-Barley model under drought stress and optimum irrigation condition.

MATERIALS AND METHODS

The present study was carried at the research farm of Islamic Azad university (35°43' N, 50°49' E, 1174.08 m above mean sea level), Karaj, Iran, during 2011, with moderate summer and cold winter. The soil type was sandy loam, and its physicochemical properties are given in Table 1. The average annual temperature is 13.9 ºC, and the coldest months of the year are during January and February with the average temperature 0.8 ºC. Climatic characteristics of the region of experimental site presented during growth season (Table 2). The experiment carries out in form of split plot factorial in based on randomized complete block design with four replicates. The treatment factors were two levels of irrigation system (Normal Irrigation (NI) and Stop Irrigation (SI) after heading) and five levels of cultivars (Kavir, Rayhan, Goharjo, Zarjo, Torkaman).

Table 1. The results of soil physicochemical properties

Depth (m)	EC (Dc/m)	pH	OC (%)	Total N (%)	P (ppm)	K (ppm)	Clay (%)	Silt (%)	Sand (%)	SP (%)	Tex
0-20	3.33	7.44	0.9	0.09	17	196.35	27	18	55	36	Clay loamy
20-40	3.75	7.86	0.63	0.06	11	147	26	17	57	36	Clay loamy
40-60	4.91	7.81	0.47	0.05	8.45	140.6	28	16	56	36	Clay loamy

Table 2. Climatic characteristics of experimental location (2010-2011).

Climatic parameters	November	December	January	February	March	April	May	June
Mean temperature (◦C)	12.9	9.8	1.9	2.4	6.4	17.7	18.6	24.9
Mean precipitation (mm)	31.5	4.1	41.5	28.9	67.7	79.1	34.9	1.6

Model Evaluation
After estimating of the CERES-Barley models coefficients for parameters, the simulated data compared to observed data (field experiments). Evaluation of traits simulation of model achieved in based on coefficient of performance model (d), coefficient of correlation (R^2), root mean square error (RMSE), and mean absolute error (MAE). Absolute RMSE and MAE (mean absolute error) are the best indexes for evaluate of model performance because they summarize the mean difference in the units of observed and predicted value. However, these two measures give only the estimates of average error not the relative size of the average difference and the nature of the differences. CV index (NRMSE) is defined as RMSE normalized to the mean of the observed values. A model reproduces experimental data perfectly when R^2 is 1, RMSE is 0 and D-index is 1.

$$MAE = \frac{\sum_{i=1}^{n} |Pi - Oi|}{n}$$

$$(CV) normalsied\ RMSE\ (\%) = \frac{absolute\ RMSE}{mean\ of\ the\ observerd}$$

$$RMSE = \sqrt{\sum_{i=1}^{n} \left(\frac{(Pi - Oi)^{2}}{n} \right)}$$

$$d = \frac{\sum_{i=1}^{n} (Pi - Oi)^2}{\sum(|Pi - O_{iavg}|) + (|Oi - O_{iavg}|)^2}$$

Where, p_i and o_i are the predicted and measured amounts respectively, n is the number of observations and o_{iavg} is the average of observed amounts, n is the number of cases. The d rate varies between 0 and 1. When the amount of d calculated by model is equal to 1 indicates that the model has shown climax of performance in simulation and model predicted system behavior 100 percent.

RESULTS

Simulation of seed yield
Predicting seed yield is one of the main objectives of crop simulation. In seed yield simulation RMSE index range (256.62-545.62 kg ha^{-1}) in normal-irrigation conditions (I1), which was <10% of the average of measured mounts, also RMSE range (146.48-1158.14 kg ha^{-1}) in stress conditions (I2), which was almost <20% of measured average (Table 3). The efficiency coefficient (d) range was 0.93 to 0.98 and 0.94 to 0.99 for I1 and I2, respectively (Table 3). According to grain yield simulation, Rayhan cultivar under I2 conditions with d=0.99, RMSE=146.48, normalized RMSE =4.9% and MAE= 306.8 was the best. In based on linear regression analysis between measured and simulated data of seed yield in the wheat varieties, coefficient of correlation (R^2) was 0.86 in normal- and stress conditions (Table 3). The deviation percent between measured and simulated for Zarjo, Kavir, Goharjo, Rayhan, Torkaman were 8, 11, 0.18, 1 and 1 (for I1) and 31, 44, 37, 39 and 18 (for I2), respectively (Table 3). In GY predicting accurate, model was less under I1 than I2 conditions. $RMSE_n$ dimension in normal and drought stress conditions were 5.2-9.8 % and 4.9-20 %, respectively (Table 3). According to Figure 1 correlation coefficient between varieties under normal and drought stress conditions was 0.99 and 0.95, respectively.

Table 3. Statistical indexes for evaluating of CERES-Barley performance in grain yield prediction (kg ha^{-1}).

Treatments	Name of the cultivars	RMSE	MAE	$RMSE_n$	n	P – O	O	P	R^2	d	Deviation between O, P (%)
I1	Zarjo	447.4	420.8	9.8	5	401	4744	5145	0.91	0.93	8
	Kavir	402.1	510	5.2	5	871	7781	8652	0.96	0.98	11
	Goharjo	256.6	191.8	9.6	5	5	2685	2690	0.93	0.93	0.18
	Rayhan	380.1	276.4	9.1	5	44	4162	4206	0.95	0.94	1
	Torkaman	545.9	350.8	9.2	5	41	5903	5944	0.95	0.93	1
I2	Zarjo	591.2	483	15.2	5	1229	3903	5132	0.87	0.95	31
	Kavir	1158.1	728.4	20	5	2509	5685	8194	0.95	0.94	44
	Goharjo	334.1	231	17	5	721	1962	2683	0.9	0.94	37
	Rayhan	146.5	306.8	4.9	5	1186	3011	4197	0.92	0.99	39
	Torkaman	664.3	499.3	15.1	5	784	4401	5185	0.86	0.96	18
Combined I1		406.49	350	8.6	5	272	5055	5327	0.86	0.94	
Combined I2		578.9	449.7	14.4	5	1286	3794	5078		0.96	

RMSE: absolute root mean square error, MAE: mean of absolute error, $RMSE_n$: normalized root mean square error, n: number of observation, P: predicted value, O: observed value, R^2: coefficient of determination, d: D-index, Deviation: Absolute percent deviation between observed and predicted.

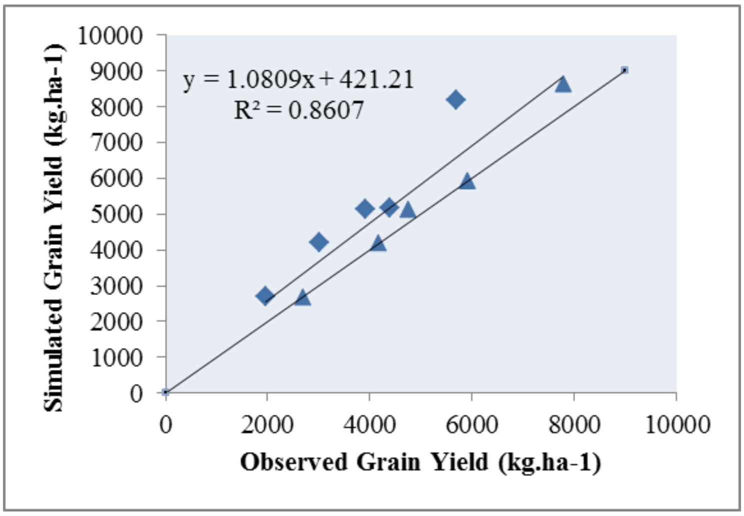

Figure 1. The regression relation of simulated and observed grain yield for five barley varieties in both normal (▲) and stress conditions (■).

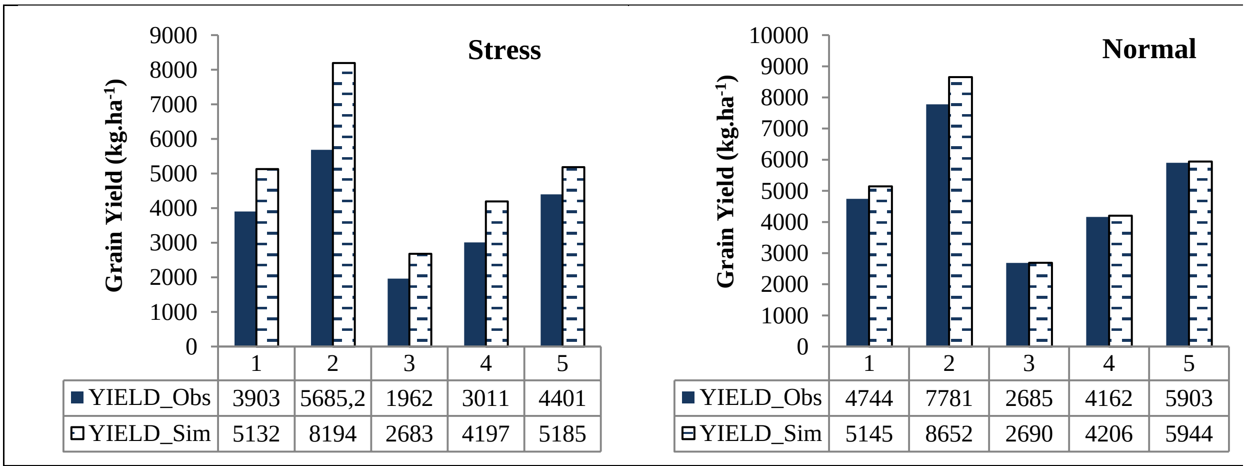

Figure 2. A comparison of simulated and observed grain yield for varieties of barley in both of normal and stress conditions.

Biomass simulation

The comparison of correlation of measured and simulated biomass in barley varieties under normal and drought stress conditions indicated that d value range in normal and drought stress conditions were 0.94-0.99 % and 0.88-0.96 %, respectively (Table 4). Analyzing of correlation coefficient (R^2) obtained from linear regression function for measured and simulated biomass in barley varieties, correlation coefficient range in normal and drought stress conditions were 0.88-0.97 and 0.94-0.99 %, respectively. According to the results $RMSE_n$ range in normal and drought stress conditions were 6.5-19.5 % and 15-28.9 %, respectively (Table 4). The best prediction of biomass in normal conditions was related to Kavir cv. (with d = 0.99, absolute RMSE = 1491, normalized RMSE = 6.5% and MAE= 884.8) (Table 4). Goharjo cv. under drought stress conditions with high R^2 had a lower d-index, indicating that the correlation between simulated and observed amounts was 0.96 % but biomass of simulated and observed amounts did not match with the model-simulated trend. Based on the correlation diagram between observed and simulated biomass in normal and stress conditions, R^2 was 0.85 % (Figure 3), which indicates the acceptable capability of the model for biomass simulation. The maximum difference between the observed and simulated biomass was related to Goharjo cv. under tress condition. In based on deviation simulated in comparison to observed showed that model in biomass simulation acted well under two irrigation conditions, except in Goharjo cv. (39%) under stress conditions (Table 4).

Table 4. Statistical indexes for evaluating of CERES-Barley performance in Biomass prediction (kg ha^{-1}).

Treatments	Name of the cultivars	RMSE	MAE	$RMSE_n$	n	P - O	O	P	R^2	d	Deviation between O, P (%)
I1	Zarjo	2064	1670	12	11	1855	16972	18827	0.97	0.97	11
	Kavir	1491	884.8	6.5	11	-190	22877	22687	0.97	0.99	1
	Goharjo	2901	2158	19.5	11	2044	14852	16896	0.88	0.94	14
	Rayhan	2187	1443	11	11	32	19642	19674	0.93	0.97	0.16
	Torkaman	2027	1553	11.8	11	953	17149	18102	0.97	0.97	6
I2	Zarjo	2195	1896	15	11	906	14604	15510	0.94	0.96	6
	Kavir	2299	1792.7	17	11	2441	13287	15728	0.98	0.95	18
	Goharjo	3561	2951.2	28.9	11	4569	11592	15901	0.96	0.88	39
	Rayhan	2266	1959.2	15.4	11	800	14749	15549	0.95	0.96	5
	Torkaman	2488	2123.2	15.1	11	282	15646	15928	0.94	0.95	2
Combined I1		2134	1541.8	12.2	11	938.8	18298	19237	0.85	0.97	
Combined I2		2562	2144.5	18.3	11	1799.6	13975	15723		0.94	

RMSE: absolute root mean square error, MAE: mean of absolute error, $RMSE_n$: normalized root mean square error, n: number of observation, P: predicted value, O: observed value, R^2: coefficient of determination, d: D-index, Deviation: Absolute percent deviation between observed and predicted.

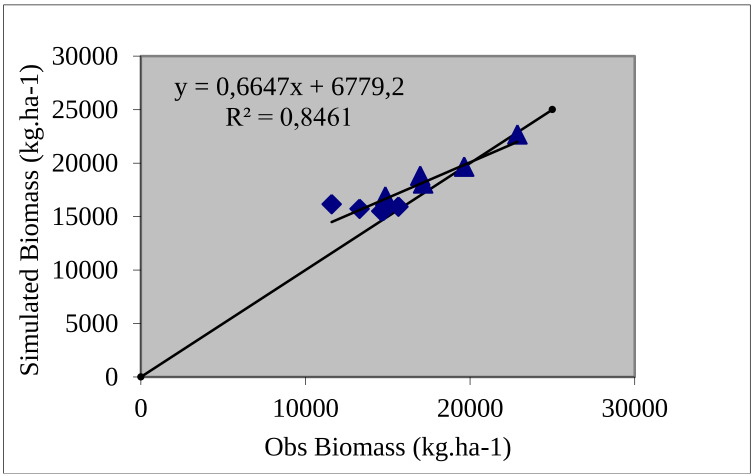

Figure 3. The regression relation of simulated and observed biomass for varieties of Barley in both of normal (▲) and stress (■) conditions.

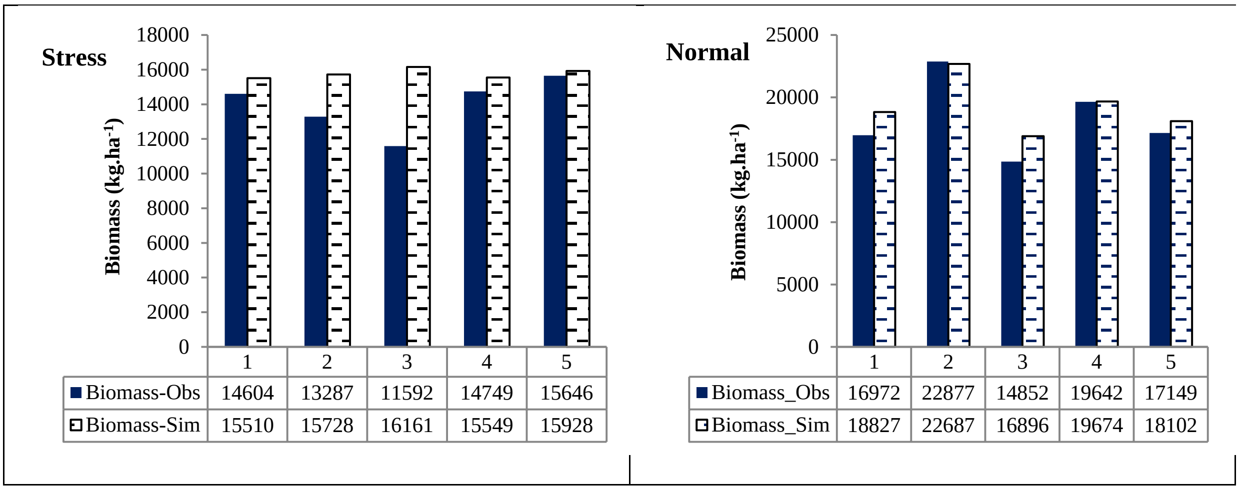

Figure 4. A comparison of simulated and observed biomass for varieties of Barley in both of normal and stress conditions.

Simulation of leaf area index (LAI)

Results demonstrated that the accuracy of the model for simulation of LAI was lower than that of biomass and grain yield, so that $RMSE_n$ rate in normal and stress conditions was 27 % and 26 %, respectively (Table 5). Under normal irrigation, the lowest $RMSE_n$ was detected in Zarji cv. ($RMSE_n$ = 21 %). Our results were agreement with Arora *et al.* (2007) in simulation of LAI during wheat growing season (with absolute RMSE=0.5, normalized RMSE= 25-35 % and R^2= 0.88). The coefficient of determination (R^2) of LAI for whole barley varieties was 0.87 and 0.9 under normal and drought stress, respectively. The RMSE of LAI range calculated was 0.688-0.972 m^2/m^2 and 0.518-1.126 m^2/m^2 for I1 and I2, respectively. The best prediction of LAI was detected in Zarjo with RMSE=0.518, d=0.98, MAE= 0.38 and $RMSE_n$=19 % under drought stress conditions. The smallest difference between simulated and observed LAI was obtained for Zarjo cv. under I2 conditions (with difference of 0.02m^2/m^2) (Table 5). According to the bar charts (Figure 5), LAI values obtained by model for all of varieties were greater than the observed data in both normal and stress conditions. The minimum coefficient of determination belong to Kavir and Torkaman under I1 condition.

Table 5. Statistical indexes for evaluating the performance of CERES-Barley in predicting LAI.

Treatments	Name of the cultivars	RMSE	MAE	$RMSE_n$	n	$P_{mean} - O_{mean}$	O_{mean}	P_{mean}	R^2	d
I1	Zarjo	0.686	0.36	21	10	-0.4	3.21	2.81	0.92	0.97
	Kavir	0.823	0.59	26	10	0.11	3.12	3.21	0.83	0.94
	Goharjo	0.86	0.68	23	10	-0.36	3.62	3.26	0.9	0.96
	Rayhan	0.967	0.68	33	10	0.56	2.88	3.43	0.88	0.94
	Torkaman	0.972	0.62	33	10	0.28	2.94	3.22	0.83	0.94
I2	Zarjo	0.518	0.38	19	10	0.02	2.73	2.75	0.94	0.98
	Kavir	0.839	0.56	28	10	0.14	2.91	3.06	0.86	0.95
	Goharjo	1.126	0.82	31	10	0.64	3.53	3.17	0.87	0.9
	Rayhan	0.729	0.45	24	10	0.33	2.99	3.32	0.93	0.97
	Torkaman	0.748	0.4	26	10	0.34	2.79	3.13	0.91	0.96
Combined I1		0.86	0.95	27.2	10	0.038	3.15	3.19	0.87	0.96
Combined I2		0.79	0.52	25.6	10	0.29	2.99	3.08	0.9	0.95

RMSE: absolute root mean square error, MAE: mean of absolute error, $RMSE_n$: normalized root mean square error, n: number of observation, P_{mean}: mean of predicted value, O_{mean}: mean of observed value, R^2: coefficient of determination, d: D-index.

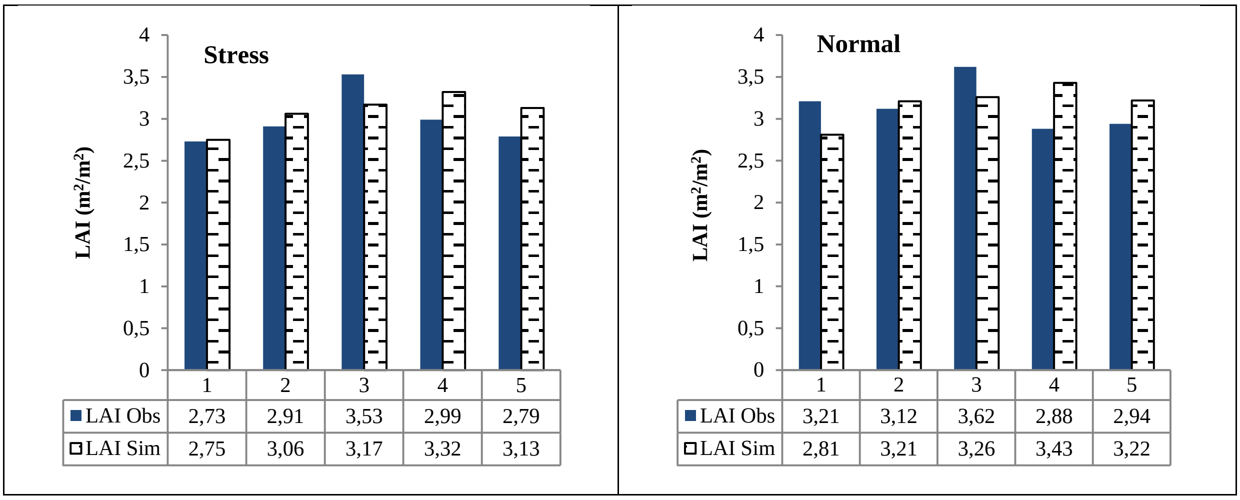

Figure 5. A comparison of simulated and observed LAI mounts for five barley varieties in both normal and stress conditions.

DISCUSSION

According to Table 3 difference between the measured and predicted yields was lower in normal irrigation conditions than discontinuing the irrigation which indicates the model acted well for seed yield simulation under normal irrigation. The seed yield simulated for barley varieties under discontinuing irrigation were underestimated (Figure1 and 2). This means that seed yield simulation by CERES-Barley model have not response to discontinuing irrigation (I2). However, high values of R^2 between simulated and observed mounts in both irrigations indicate that model was satisfactory in grain yield prediction. In addition CERES-Barley model with RMSE = 406.49 kg ha^{-1} and RMSE=578.9 kg ha^{-1} had good performance in grain yield prediction, under I1 and I2, respectively. Bannayan *et al*. (2003) with prediction of the final yield of wheat during the growing season (three-to four-leaf stage, tip of flag leaf appearance and milk stage), claimed that the mounts of RMSE for simulated and observed biomass was 0.95 t ha^{-1} for the first forecast date and 0.68 t ha^{-1} for the final forecast date, and they also reported that CERES-Wheat model had appropriate accurate in simulation of final yield during the barley growing stages. Paknejad *et al*. (2012) by evaluation of CERES-Wheat model on five varieties of winter wheat in Karaj weather condition found that R^2 for grain yield was 0.81 and 0.81-0.95% under normal and stress conditions, respectively. Relatively good agreement between observed and simulated mounts for both grain yield and biomass using CERES-Wheat was reported by Heng *et al.* (2001). In the experiment by Chipanshi *et al.* (1997) the simulated grain yield via CERES-Wheat model during wheat growing season showed <10 % difference than the real amounts of field. Using CERES- Wheat model, Ghaffari *et al.* (2001) predicted the potential yield of six wheat varieties during various years, with 8985 to 9884 kg ha^{-1} range depend on region. As observed in Figure 4 under stress irrigation, the simulated biomass was more than the real amounts of the field, indicating that failed to show watering restrictions. The low coefficient of correlation (R^2) resulted from the analysis of simulated and observed biomass can be attributed to large differences between simulated and observed biomass in Goharjo cultivar (Figure 3). This cultivar was likely to be sensitive to the end season stress, but model failed to show well in Goharjo cultivar. However, the simulated biomass by model was satisfactory in both conditions of irrigations. Simulation of dry matter is probably the central portion of each crop simulation model affecting by modeling of phenological development and leaf area changes. Simulation of dry matter distribution is important because its highlights grain yield (Soltani *et al.* 2005). With CERES-Wheat model for simulation of biomass under different regimes of fertilizer and irrigation, Singh *et al.* (2008) reported the RMSE of the real and simulated was 1940 kg ha^{-1} during maturity stage.

Figure 5 showed that in most varieties simulated amounts LAI was greater than the observed amounts. This can be due to a limitation on the farm that has not been introduced into the model and in the early stages of growth the observed LAI was more than simulated LAI. Also, the error occurrence in the simulation can be attributed the lack of precision in the measurement of leaf area by researcher in the laboratory, because leaves may be yellow or folded causing light transmission from the edges of the leaves. Predictability changes in leaf area are also important in crop models. The LAI prediction is required to estimate the amount of radiation received and the production of dry matter and its prediction in determination of the ratio of evaporation to evapotranspiration is important (Soltani *et al*. 2006). Furthermore, increasing of the growth and leaves number on the main stem and tillers, and the other hand destruction of leaves and tillers influence on the leaves development, since all of this processes are simulated in the model by the time–temperature, and with regard to close relationship temperature with phyllochron, it seems for accurate simulation of leaf area index, which is a critical factor in the simulation and their total of the photosynthetic production. Field experiments should be conducted to identify of leaf expansion rate in different cultivars, consequently, we can calibrate the model for this intention (Paknejad *et al*. 2012).

Overall, the results of CERES-barley model assessment in this research indicated that model had acceptable potential and accurate for quantifying the developmental processes and dry matter accumulation in different organs of the plant. But we should be known that the model will have not been the best estimation of dry matter production, grain yield and LAI in all of the circumstances. Therefore, we required to the more experiments under regional multi-level to identification of this model ability.

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