CALIBRATION AND EVALUATION OF CERES-RICE MODEL UNDER DIFFERENT DENSITY AND WATER MANAGEMENTS

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Abstract. The objective of this study was the evaluation of the Ceres-Rice model under different density and water management options in Semi-Mediterranean climate condition. An experiment was conducted in a randomized complete block design (RCBD) with three replications in north of Iran during cropping seasons of 2014 and 2015. There were 5 levels of irrigation treatments in this research including: I_1: Flood irrigation, I_2: Saturation, I_3: Irrigation with 8 days alternative before anthesis, I_4: Irrigation with 8 days alternative after anthesis, I_5: Irrigation with 8 days alternative whole growth season) and there were three plant spacing including: $D_1 = 15 \times 15$, $D_2 = 20 \times 20$, $D_3 = 25 \times 25$cm. Evaluation simulated and measured grain yield, total crop biomass, and crop biomass by adjusted coefficient of correlation and by absolute and normalized root mean square errors (RMSE). Grain yield of D_2 was predicted the most accurate than other density treatments (RMSE = 439 and RMSEn = 11%). Biomass of D_2 was predicted the most accurate than other density treatments (RMSE = 873 and RMSEn = 9%). Observed and predicted planting densities by rice showed good agreement in both calibration and evaluation steps. The Ceres-Rice model can be applied to research purposes (irrigation and planting densities) under northern Iranian conditions.
Keywords: *Semi-Mediterranean, Ceres-Rice, Irrigation, Crop Model, Water Productivity*

Introduction

Rice is a main food for majority of the world's population, raised on about 146.5 million ha of the agricultural fields of the world. So it is necessary to optimize usage of available resources due to shortage of water resources in rice fields (Thakur et al., 2014; Gill et al., 2014; Murumkar et al., 2014). Water necessity is more for this plant than other grains and the amount of it is affected by the rice cultivar, stage of growth, length of growth stage, plant density and even method of cultivation and weather conditions. Iran is an area with an annual rainfall of 240 mm and 0.57 million ha paddy field. Most rainfalls occur out of rice growth stages. Water allocation is not sufficient for low efficient irrigation in Iran, and surface water storage will be increased by construction of dams (Amiri et al., 2011).

Agricultural water productivity directly affects crop production; therefore, various water saving techniques and managements have been developed for rice producers to minimize water use and maintain optimum yield (Pascual, 2016). For instance, observed yield and simulated water balance, the calculated average WP_{ET} was significantly lower than the average WP_T: 37%. The average WP_I, WP_{ET}, WP_T and WP_{ETQ} were 1.01, 0.89, 1.41 and 0.65 kgm^{-3} (Amiri and Rezaei, 2013).

Severe drought stress at mid-tillering delayed flowering, and caused substantial yield losses by large percentage of unfilled grains (Davatgar et al., 2009). This finding has been confirmed by Pirdashti et al. (2009) who pointed out that water shortage in the vegetative growth stage extended the number of days for flowering in different rice cultivars. It has been documented that dry matter is more affected under vegetative stage stress whereas severe effects on sink size (spikelet fertility, 1000 grain weight and seed yield) under reproductive stage stress would be resulted (Guan et al., 2010).

Roderick et al. (2011) concluded in a research that alternate wet and drying irrigation deficit method has reduced about 38% of irrigation water usage, with the same yields and farmers profits.

High densities of rice cultivation reduce plant yield and yield components (Chamara et al., 2016). Some researchers have reported increased yield per unit area as a result of increasing density per unit area (Clerget et al., 2016). Other researchers have also reported declined yield and biomass per unit area due to increasing density (Awan et al., 2014). In addition, high densities are recommended to suppress weeds and increase yield in rice (Chauhan et al., 2011).

In order to detect the effect of planting density on the water productivity of rice product, an experiment was conducted in a split plot design with three plant-distance (20 × 20, 15 × 15, 20 × 10 cm) as a sub plots and four different irrigation regimes (permanent flooding treatment as a control group and 100%, 75% and 50% evaporation from the pan) as the main factors. The best yield in irrigation was reported for 75% evaporation from the pan and the plant-density of (20 × 20 cm) (Amiri et al., 2011).

In recent years, there has been an increasing amount of literature on simulation and modeling application on rice production (Amiri et al., 2014; Vijayalaxmi et al., 2016)

Until now, the most conducted researches have been about the method of irrigation management based on fixed round of irrigation from the first to the end of growing season. Fewer researches have been conducted about the method of irrigation management regarding cultivation density. At present, information required for the rice production improvement with suitable management practices is a need of hour. The generation of new data through agronomic research methods is insufficient and time consuming to meet these needs. So crop simulation models are considered as potentially useful tools in agricultural decision making. The major objectives of this study were to investigate: (i) Modeling response of Hashemi rice variety to change in planting densities and irrigation managements (ii) Calibrate and validate the DSSAT v 4.5. model based on experimental data; (iii) To explore on-farm strategies which result in higher economic gains and water productivity.

Materials and methods

Experimental design, crop establishment, and crop management

The experiment was conducted as split plot based on randomized complete block design with three replications on rice Hashemi cultivar during growing season of 2014 and 2015 in Koosal-Lahijan region located in north of Iran. The height of the site is 3 m from the sea level and it is located at 14"3'37° of north latitude and14"1'50° of east length. Irrigation treatments were at five levels: full irrigation = I_1 saturated = I_2 irrigation with 8 days alternative until anthesis = I_3, irrigation with 8 days alternative after anthesis = I_4, irrigation with 8 days alternative during the whole period of growth = I_5 and density was at 3 levels: 15 × 15 = D_1, 20 × 20 = D_2, 25 × 25 = D_3 cm

(444000, 250000, 160000 plants per hectare, respectively). Each experimental plot was 9.2 m long and 3 m wide. After transplanting the markers to the main land, the plots were kept for 10 days in permanent flooding until the markers were settled. After that, irrigation management was applied in the plots based on the program. I_1 was often flooding and I_2 was often saturated. I_3 was irrigated every 8 days before anthesis and then was flooded. The treatments I_4 was irrigated every two to three days before anthesis and then irrigated every 8 days. I_5 was completely irrigated every 8 days. It should be noted that the management of irrigation with frequency of 8 days (Amiri and Rezaei, 2013) was performed based on the alternation according to the growth of rice, using optimal water management in drought stress condition and in order to cope with damages caused by water stress on Hashemi cultivar.

According to the *Table 1,* soil of the experiment site is suitable for rice. *Table 2* also shows crop information and *Figures 1* and *2* shows the meteorological characteristics of the site. The first 20 days were irrigated by flooding. Urea, potassium and phosphate fertilizers were each used at baseline of 60 kg.ha^{-1}. 60 kg urea fertilizer was also consumed one month after the baseline stage. Graining was carried out at the end of April in the treasury environment and transplantation of the treatments was done at the end of May. After handling and harvesting, the clusters were placed in an oven for drying for 72 h at 70 °C.

Table 1. Soil physical and chemical characteristics of the experimental site before sowing the rice crop

Soil characteristics	Depth (cm)				40–50
	0–10	10–20	20–30	30–40	
Texture					
Sand (%)	18	14	17	9	11
Silt (%)	39	39	39	44	42
Clay (%)	47	47	44	47	47
Bulk density (g cm^{-3})	1.45	1.4	1.4	1.42	1.41
Water content at saturation	0.392	0.392	0.39	0.39	0.39
Water content at FC (0.01 MPa)	0.204	0.204	0.209	0.209	0.209
Water content at PWP (1.5 MPa)	0.34	0.34	0.345	0.345	0.345
KSAT (cm day^{-1})	57.54	57.54	30.79	0.40	11.79
pH	7.05	7.15	7.23	7.26	7.08
CEC (meq 100 g^{-1})	33	33	32	31	31
Organic carbon (%)	2.30	2.72	2.54	2.25	2.76
Total N (%)	0.19	0.16	0.14	0.074	0.074
Extractable P (ppm)	8.7	10.1	7.3	5.2	3.2
Extractable K (ppm)	225	195	176	185	161

Table 2. Crop information in two different years of experiment

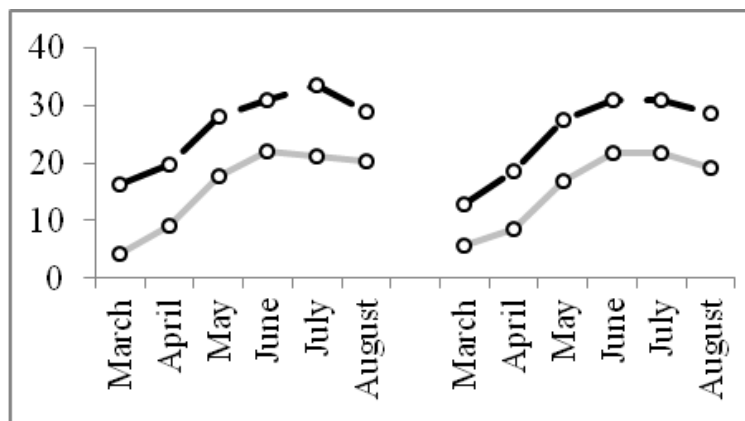| Crop year	Date of plowing	Date of plotting	Date of fertilizing	Date of transplantation	Date of anthesis	Date of excess fertilizing	Date of harvesting	Total period of growth-day
2014	27 May	30 May	4 Jun.	2 Jun.	5 Aug.	6 Jul.	5 Sep.	95
2015	27 May	31 May	4 Jun.	3 Jun.	6 Aug.	6 Jul.	10 Sep.	99

Figure 1. Monthly minimum and maximum air temperatures (°C) during the growing periods of rice in 2014 and 2015 growing seasons (left to right, respectively)
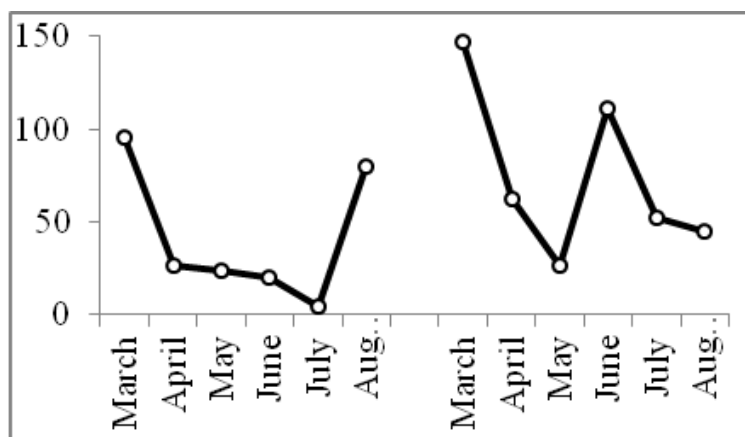

Figure 2. Monthly rainfall during the growing periods of rice in 2014 and 2015 growing seasons (left to right, respectively)

Ceres-Rice description

Ceres-Rice model was selected as a tool for simulating growth and yield of rice under different environment and management strategies. The Ceres-Rice model simulates rice crop growth and development from either planting or transplanting to physiological maturity and is based on the physiological processes that describe the response of rice to local soil and weather conditions. Potential growth is mainly dependent upon photosynthetically active radiation (PAR), light interception and the light conversion efficiency, while actual growth is a constraint of crop management, soil and weather interactions.

The input data required to run the DSSAT models include daily weather data, i.e. maximum and minimum temperature, rainfall, and solar radiation; soil characterization data, genetic coefficients and crop management information, such as date of planting, age of seedlings, row and plant spacing, rates and dates and amount of fertilizer and irrigation applied. Input data files of Ceres-Rice model are as per IBSNAT standard input/output formats and file structure described in DSSAT v 4.5 (Hoogenboom et al., 2003).

Model inputs

The DSSAT models require the minimum data set for model operation. They encompass data on the site where the model is to be operated, on the daily weather data, on the soil properties, and on the all aspects management of the crop growth. Important crop management factors include planting date, planting depth, row spacing and direction, plant population, fertilization, irrigation, inoculation, residue applications, tillage, and harvest date.

Calibration of Ceres-Rice model

The calibration of the Ceres-Rice model was based on data from measured data of grain yield, total biomass in 2014-2015 field experiment. The genetic coefficients of the rice cv. Hashemi that affect the occurrence of phonological stages in the Ceres-Rice models were derived using the GLUE Estimator of DSSAT v 4.6. This program estimates the coefficients for a genotype by iteratively running the crop model with an approximate value of the coefficients concerned.

One would expect to have, for good model performance, values of RMSE as close as possible to 0. A model produces experimental data perfectly when α is close to 1, β is close to 0, R^2 is close to 1, RMSEa is similar to the SD of measured values, and RMSEn is similar to the coefficient of variation (CV) of measured values.

Model evaluation

Summary measures used in the present study were the mean of measured and simulated values, the standard deviations (SD) of the observations and simulations, the slope α, intercept β, and coefficient of determination (R^2) of the linear regression line between simulated and measured values. The different measures were based on the analysis of residual errors, that is, the difference between simulated and measured values. We computed the absolute and normalized root mean square errors (RMSE and RMSEn, respectively). Also, based on the measured data and relationship data and statistical estimation of the model were done through the root mean square error (RMSE), normalized root mean square error (RMSEn), relative error of the model (ME). When the RMSE and RMSEn values are closer to zero, it indicates that the prediction has been done better by relations (*Eqs. 1–3*).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \qquad (Eq.1)$$

$$RMSE_n = 100 \; (\sum_{i=1}^{n}(P_i - O_i)^2 / n)^{0.5}) \Big/ \overline{O} \qquad (Eq.2)$$

$$RMSE = 100 \; (\frac{P_i - O_i}{O_i}) \qquad (Eq.3)$$

In the first two relations (*Eq. 1* and *2*), S_i and O_i are respectively the values of relative and observed performance equations. $\overline{O}$ is the mean of observed values and n is the number of observations (Amiri et al., 2011).

Water balance components

The water balance of lowland rice model includes (*Eq. 4*):

$$dW = I + R + C - E - T - S - Q - D \tag{Eq.4}$$

where dW is the change in stored water, I is irrigation supply, R is rainfall, C is capillary rise, E is evaporation, T is transpiration, S is seepage, Q is percolation, and D is surface drainage/runoff (all units are mm) (Bouman et al., 2001).

Water productivity

WP indices express the profit derived from the consumption of water and can be used for assessing the impact of on-farm strategies under water scarce situations. They provide a proper vision of where and when water could be conserved. The following equations (*Eqs. 5–9*) were used to calculate the water productivity components (Singh et al., 2006).

$$WP_T = \frac{Y_g}{T} \tag{Eq.5}$$

$$WP_{ET} = \frac{Y_g}{E+T} \tag{Eq.6}$$

$$WP_I = \frac{Y_g}{I} \tag{Eq.7}$$

$$WP_{I+R} = \frac{Y_g}{I+R} \tag{Eq.8}$$

$$WP_{ETQ} = \frac{Y_g}{E+T+Q} \tag{Eq.9}$$

where Yg (Kg) is the crop grain yield, T (mm) is the actual transpiration, E (mm) is the actual soil evaporation, I (mm) is irrigation, R (mm) is rainfall and Q (mm) is the percolation. WP_I (kg/m^3), WP_{I+R} (kg/m^3), WP_{ET} (kg/m^3), WP_T (kg/m^3) and WP_{ETQ} (kg/m^3) are expressed in crop grain yield (Yg) per unit amount of I, I+R, ET, T and ETQ respectively.

Results and discussion

Model calibration

The calibrated genetic coefficients (cv. Hashemi) as derived by Gencalc for Ceres-Rice are given in *Table 3*.

Table 4 shows the goodness-of-fit parameters for grain yield and aboveground biomass at harvest of the whole data set. The model simulated aboveground biomass

and Grain yield quite well, with the absolute and normalized RMSE values greater than the error in the measured value (*Table 4*). For biomass, the slope was close to 1, and the intercept ß was high, indicating general overestimation of simulated values. Almost the same pattern was observed for grain yield. The model simulated grain yield and biomass generally good. The slope in validation was a little bit greater than that of calibration while the intercept ß was less than that of calibration. The relatively high R^2 reflects the low spread of the data. The error value in validation step has decreased, which is a reason to accept the results of the model. Also, the mean square error should be less than the standard deviation of the actual values that the results of the evaluation of Ceres-Rice model accuracy in irrigation management and different crop distances indicate that.

Table 3. *Genetic coefficients of the rice cv. Hashemi as derived by GENCALC of DSSAT model*

Genetic parameters	Description	Coefficient for Hashemi
P1	Time period (expressed as growing degree days (GDD) in °C above a base temperature of 9 °C from seedling emergence during which the rice plant is not responsive to changes in photoperiod	320.0
P20	Critical photoperiod or the longest day length (in h) at which the development occurs at a maximum rate	5.0
P2R	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P20	13.5
P5	Time period in GDD °C) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9 °C	240.0
G1	Potential spikelet number coefficient as estimated from the number of spikelets per g of main culm dry weight (less lead blades and sheaths plus spikes) at anthesis	55.2
G2	Single grain weight (g) under ideal growing conditions, i.e., nonlimiting light, water, and nutrients and absence of pests and diseases	0.0200
G3	Tillering coefficient (scaler value) relative to IR64 cultivar under ideal conditions	1.00
G4	Temperature tolerance coefficient. Usually 1.0 for varieties grown in normal environments	1.00

Model evaluation

Grain yield the graphical comparison between simulated and measured grain yield is presented in *Figure 3*. The Ceres-Rice model simulated grain yield in 2015 quite well. Grain yield of D_2 was predicted the most accurate than other density treatments ($R^2 = 0.85$).

The graphical performance of the Ceres-Rice model in simulating total crop biomass at harvest is presented in *Figure 4*. Similar to the simulation results of the grain yield, the best performance of the model in simulating total crop biomass was obtained in

2015. Biomass of D_2 was predicted the most accurate than other density treatments ($R^2 = 0.89$).

Table 4. *Evaluation results for Ceres-Rice simulations of final aboveground biomass and yield, for the calibration and validation conditions*

Year	Crop variables		N	X_{obs}	X_{sim}	Sd_{obs}	α	ß	R^2	RMSE (kg.ha^1)	RMSEn (%)
2014 Calibration	D_1	Biomass (kg.ha^{-1})	5	9648	10027	2254	0.40	6168	0.72	1363	14.13
		Yield (kg.ha^{-1})	5	3736	4042	919	0.79	1093	0.78	491	13.15
	D_2	Biomass (kg.ha^{-1})	5	9944	9930	2069	052	4719	0.87	955	9.60
		Yield (kg.ha^{-1})	5	3818	3971	1212	070.	1314	0.83	499	13.06
	D_3	Biomass (kg.ha^{-1})	5	9379	9720	1449	0.54	4682	0.57	917	9.78
		Yield (kg.ha^{-1})	5	3741	3907	874	0.77	1045	0.63	521	13.92
2015 Validation	D_1	Biomass (kg.ha^{-1})	5	9093	9638	1678	0.58	4364	0.77	958	10.53
		Yield (kg.ha^{-1})	5	3837	4188	814	0.81	1082	0.81	473	12.32
	D_2	Biomass (kg.ha^{-1})	5	9858	9563	1783	0.59	3750	0.89	790	8.02
		Yield (kg.ha^{-1})	5	3926	4095	937	0.74	1191	0.85	379	9.66
	D_3	Biomass (kg.ha^{-1})	5	9269	9343	1098	0.55	4231	0.64	872	9.41
		Yield (kg.ha^{-1})	5	3842	4000	852	0.76	1073	0.69	457	11.90

N: number of treatments, X_{obs}: mean of observed value; X_{sim}: mean of simulated value; Sd_{obs}: standard deviation of observed value; α: slope of linear relation between simulated and measured values; ß: intercept of linear relation between simulated and measured values; R^2: adjusted linear correlation coefficient between simulated and measured values; RMSEn: normalized root mean square error (%); RMSE: absolute, absolute root mean square error
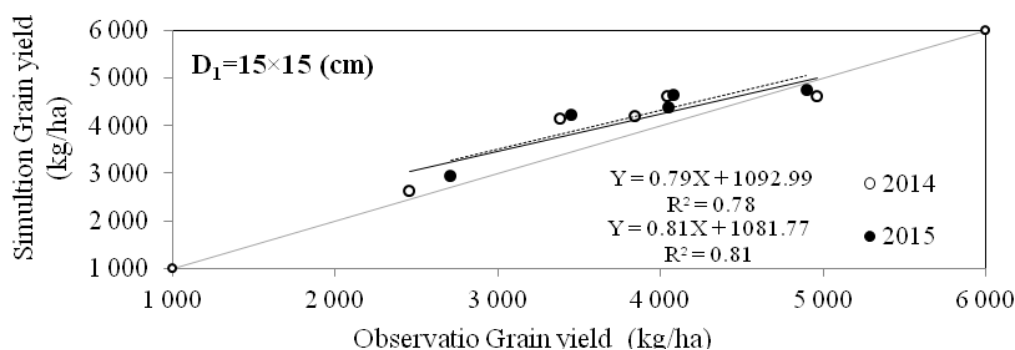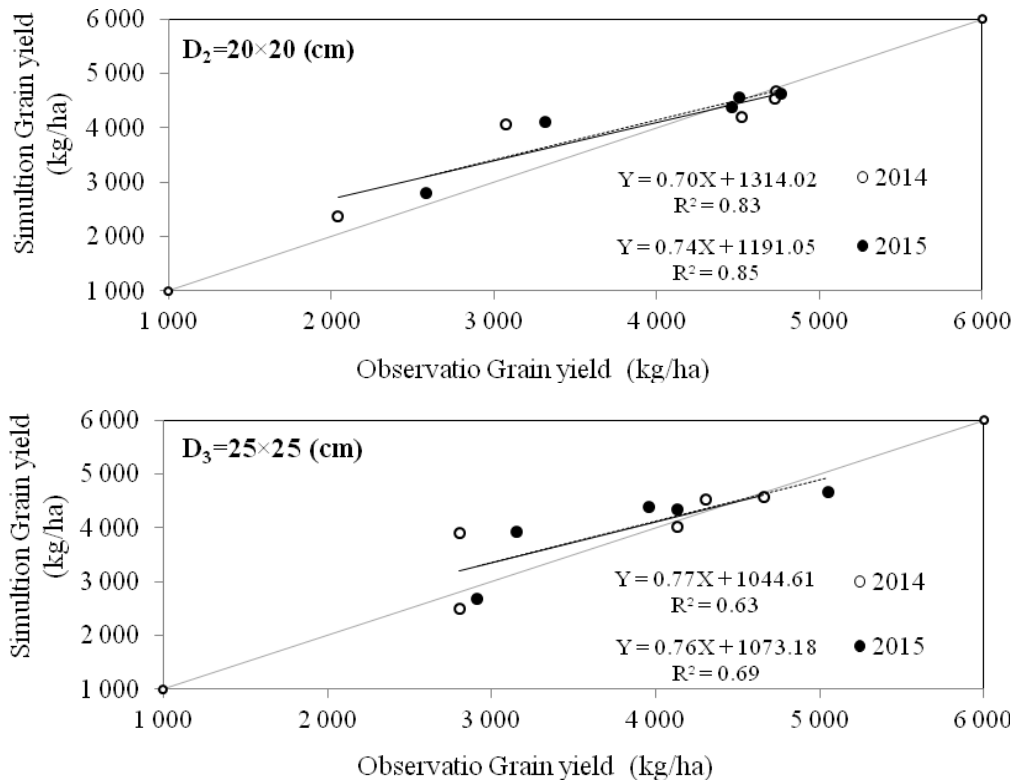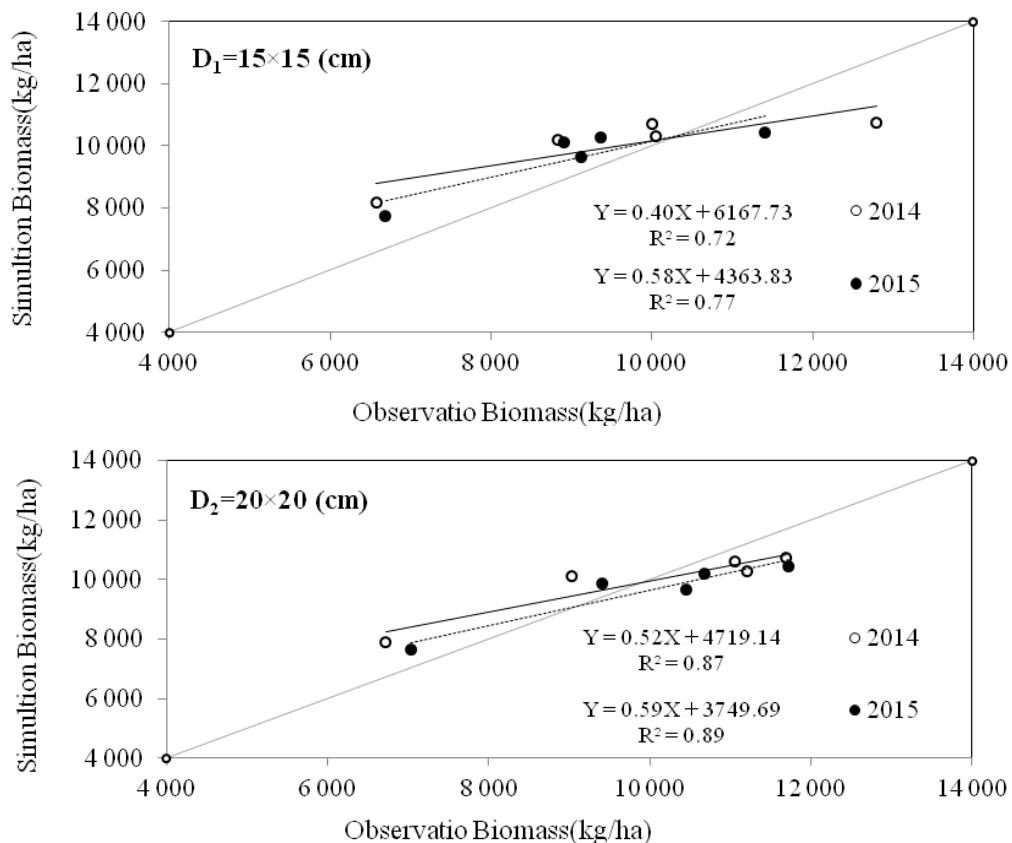
Figure 3. Evaluation of Ceres-Rice model for grain yield under different density and water management
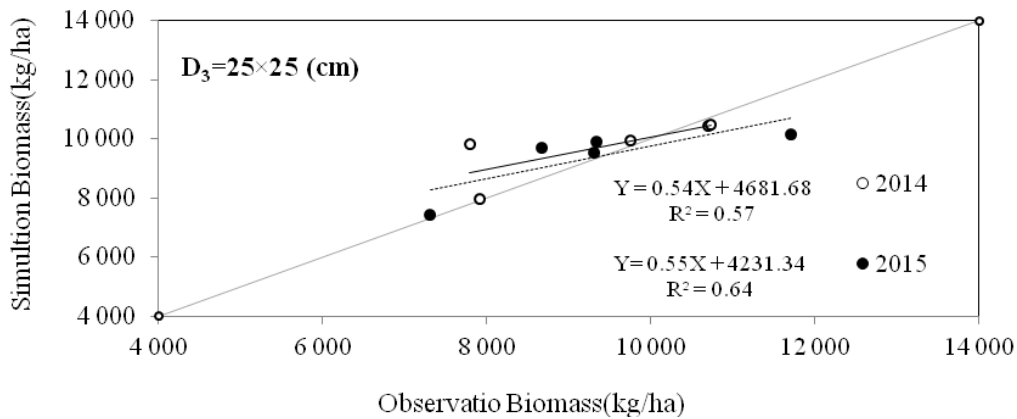
Figure 4. Evaluation of Ceres-Rice model for final above ground biomass under different density and water management

The use of Ceres-Rice model in different years to simulate rice yield in irrigation management and different densities is shown in *Figure 5*. The ability of the Ceres-Rice model to simulate the total biomass of rice in different years under irrigation management and different densities is shown in *Figure 6*. In the second year, the plant was exposed to warmer days and the rice plant was subjected to more severe drought stress, which caused the plant to close its stomata more than the first year, and the yield and total biomass decreased compared to the first year.
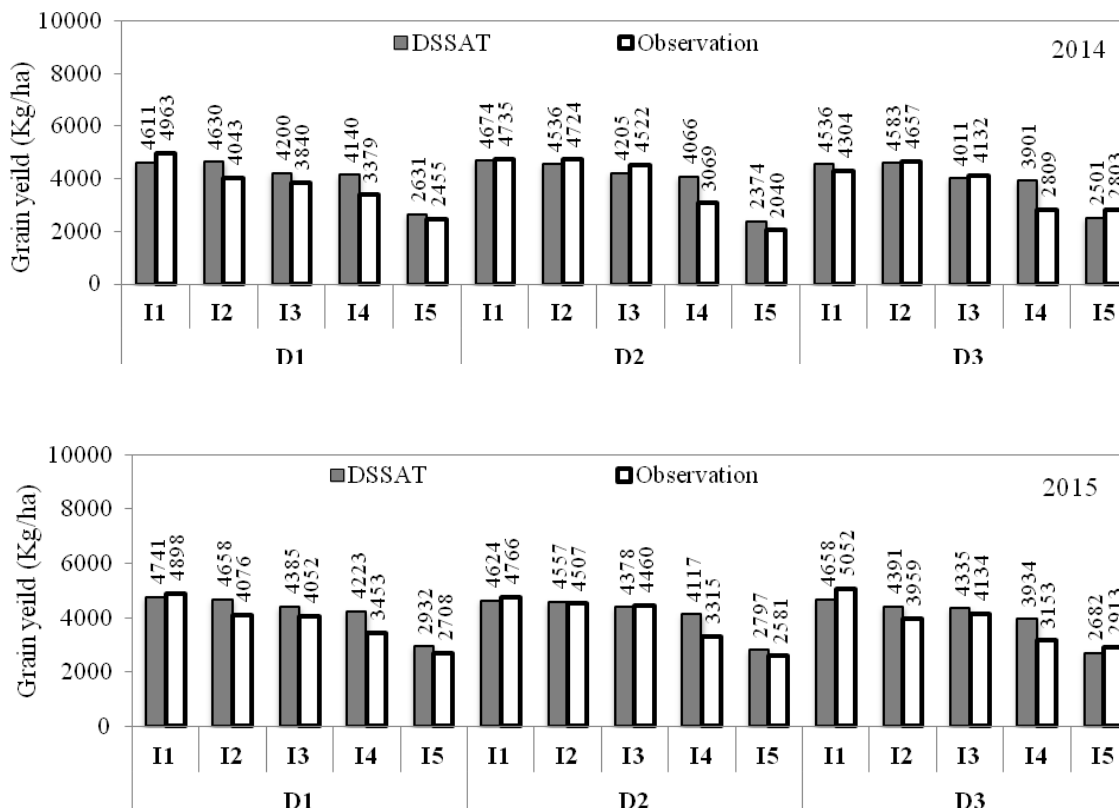

Figure 5. Performance of Ceres-Rice model for simulating grain Yield of rice under water management and plant density situations (15 × 15 = D₁, 20 × 20 = D₂, 25 × 25 = D₃ cm)
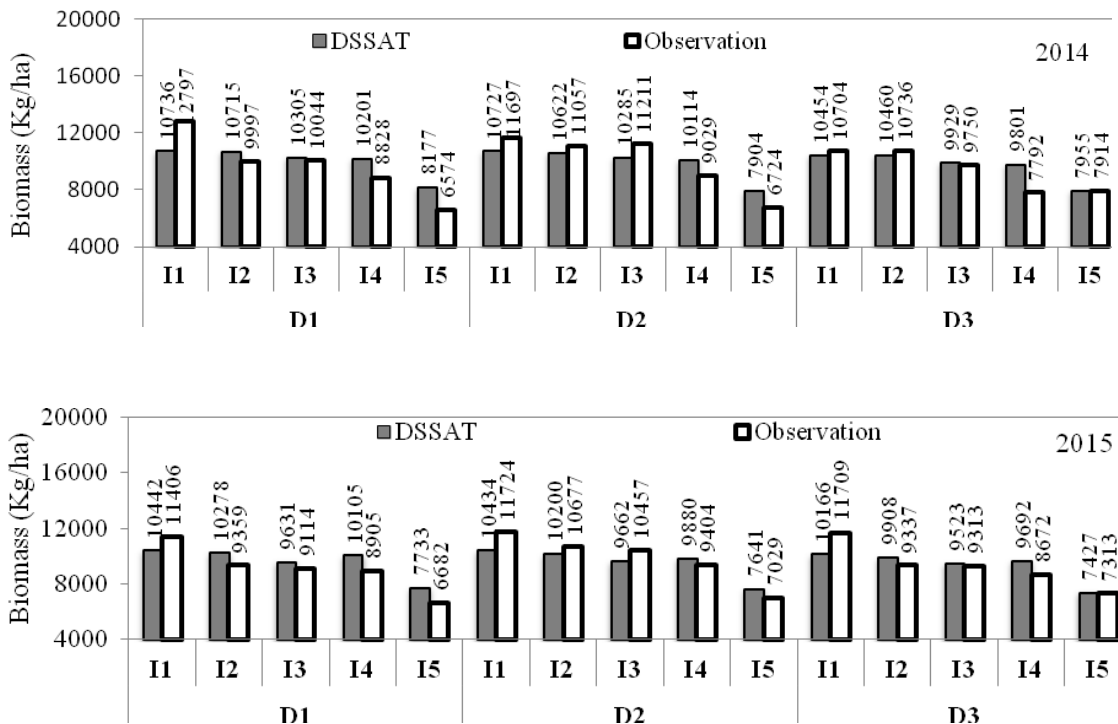
Figure 6. Performance of Ceres-Rice model for simulating Biomass of rice water management and plant density situations (15 × 15 = D₁, 20 × 20 = D₂, 25 × 25 = D₃ cm)

Water balance components

An examination of simulated components of water balance under different density and water management reveals interesting facts (*Fig. 7*).
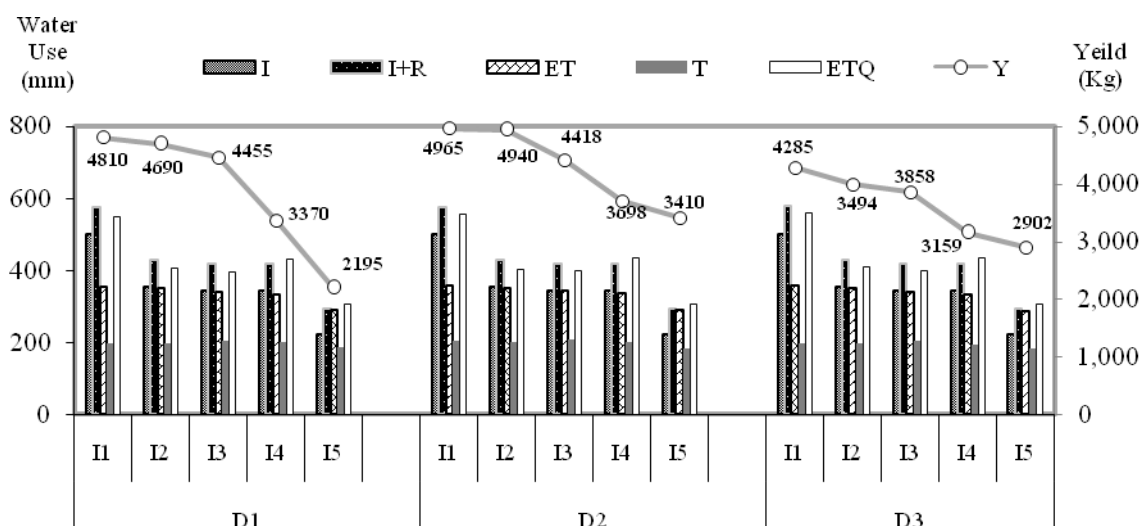

Figure 7. Water productivity values at different irrigation and crop distance treatments

The seasonal evaporation varied from 103 to 159 mm and showed a significant reduction with a decrease in plant spacing and applied water amount. The results of the

model showed that the amount of evaporation (E) is 36-44% of evapotranspiration (ET). The variability of physiological function of rice plant in irrigation management and different intervals of cultivation and changing environmental conditions leads to different transpirational requirements and consequently the amount of transpiration (T) in the plant. Changing the irrigation method from floodwaters to non-floodwaters results in increased transpiration (T). Investigation of transpiration amount in irrigation management and planting distance showed that transpiration values varied in the range of 187-217 mm; the highest transpiration (T) was observed in I_3: Irrigation with 8 days alternative before anthesis for irrigation and crop distance $D_2 = 20 \times 20$ cm was observed at 209 mm. Estimation of depth of penetration (ETQ) in irrigation and planting intervals showed that depth of penetration (ETQ) varies in the range of 534-295 mm; the results of deep penetration in the study period showed that the maximum amount of water loss Through deep penetration (ETQ) was observed in flood management. Amounts of rainfall from transplanting to harvest stage were 38 mm for 2014 and 169 mm for 2015. The amount of irrigation water applied varied between 221 mm to 502 mm. As the spacing increased, the depth of penetration (ETQ) increased. Irrigation with 8 days alternative before anthesis with only 4% reduction in yield (Y) compared to the usual method of flooding reduced water consumption and savings of 16% in irrigation water + precipitation (I + R).

Water productivity components

The water productivity for rice was analyzed using the Ceres-Ricesimulation model. We calculated the water productivity rates using the simulated water balance components of T and ET by Ceres-Rice and the actual (observed) grain yield (*Table 5*).

Table 5. *Water productivity values at different irrigation and crop distance treatments*

Treatment		Year									
		2014					2015				
		WP_I	WP_{I+R}	WP_{ET}	WP_T	WP_{ETQ}	WP_I	WP_{I+R}	WP_{ET}	WP_T	WP_{ETQ}
D_1	I_1	0.92	0.86	1.30	2.30	0.86	0.94	0.77	1.34	2.40	0.85
	I_2	1.31	1.19	1.30	2.33	1.18	1.32	1.00	1.36	2.35	1.12
	I_3	1.22	1.11	1.20	1.97	1.09	1.27	0.96	1.33	2.22	1.08
	I_4	1.20	1.09	1.24	2.08	0.99	1.23	0.92	1.26	2.11	0.95
	I_5	1.19	1.03	0.90	1.39	0.89	1.33	0.87	1.03	1.59	0.92
D_2	I_1	0.93	0.87	1.28	2.23	0.85	0.92	0.75	1.32	2.32	0.83
	I_2	1.28	1.17	1.28	2.26	1.16	1.29	0.97	1.32	2.27	1.09
	I_3	1.22	1.11	1.19	1.93	1.08	1.27	0.96	1.32	2.19	1.07
	I_4	1.18	1.08	1.21	2.01	0.96	1.20	0.90	1.23	2.06	0.93
	I_5	1.07	0.93	0.81	1.26	0.81	1.26	0.83	0.98	1.53	0.87
D_3	I_1	0.90	0.85	1.25	2.24	0.83	0.93	0.76	1.32	2.39	0.82
	I_2	1.30	1.18	1.26	2.27	1.14	1.24	0.94	1.29	2.27	1.05
	I_3	1.17	1.06	1.14	1.90	1.03	1.26	0.95	1.32	2.18	1.06
	I_4	1.13	1.03	1.17	1.99	0.93	1.14	0.86	1.19	2.02	0.88
	I_5	1.13	0.98	0.86	1.34	0.85	1.21	0.80	0.95	1.50	0.84

Table 5 shows the WP values at different irrigation and crop distance treatments in the experiment. Water productivity values for irrigation management and different densities are shown in *Table 5*. Water productivity is based on the amount of mechanism secretion in the plant and depends on the type of plant. As a result, WP_T for a rice plant is a measurable variable that depends on eco-hydrological conditions. The results of this study indicate that the WP_T value varies between 1.6 and 2.46 kg/cm^3. Water productivity is discussed based on the amount of evapotranspiration on soil and plant matter and shading, depending on the type of soil and climate and plant. The inevitable water shortage due to evaporation from the surface water and saturated soil (E) leads to a reduction in water productivity from WP_T to WP_{ET}; on average, WP_{ET} is 41% lower than WP_T. By changing the irrigation management from flood to non-waterlogging, water productivity (WP_I) increases, so that the lowest water productivity (WP_I) in flood treatment is $I_1 = 0.92$ kg/m^3 and The highest water productivity (WP_I) was observed in saturated treatment of $I_2 = 1.27$ kg/m^3. The average amount of water-based components of irrigation, evapotranspiration, transpiration and total evapotranspiration and deep penetration (WP_I, $WP_{I + R}$, WP_{ET}, WP_T and WP_{ETQ}) were 1.13, 0.94, 16.1, 1.97 and 0.49 kg/m^3 respectively. In general, I_3D_3 treatment has reduced water consumption while maintaining optimum performance and water productivity. Continuously surface water flooded method result in high soil evaporation in Hashemi rice planting. Reducing water allocation from continuous flooded methods to soil saturation or alternative irrigation methods will slightly decrease the rice yields but will substantially increase the water productivity (Amiri and Rezaei, 2013).

Conclusion

The results from this study showed that the Ceres-Rice model generally predicted biomass and grain yield, fairly satisfactorily across a range of data sets covering varying levels of water- and density management during 2 years. Results showed that predicted grain yields agreed well with observed yields (RMSEa = 382 and RMSEn = 10%). Also total biomass also were simulated well (RMSEa = 975 and RMSEn = 10%). High evaporation rate at initial stages of crop growth due to traditional irrigation method, has decreased WP_{ET} by 41% compared to WP_T. The results showed that I_3: Irrigation with 8 days alternative before anthesis and $D_2 = 20 \times 20$ cm plant density is the optimum irrigation method and crop density management. The Ceres-Rice model is calibrated and validated using field experimental data, and can be used to predict the experimental results of irrigation and different densities conditions in northern Iran, thus helping to identify target domains and irrigation and density management recommendations for farmers.

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