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Using the PILOTE Model to Improve Water Productivity for Rice in Rasht, North of Iran

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Abstract

In order to calibrate and validate the PILOTE model for rice in a humid climate, this study was carried in a randomized complete block design with three replications on a popular local variety, Hashemi, during 2001, 2002, 2005, 2006 and 2007 crop seasons. This research was done at the Rice Research Institute of Rasht, Iran. Evaluation of simulated and measured grain yield and dry matter values was done using Nash-Sutcliffe efficiency (EF), Root Mean Square Errors (RMSE) and normalized root mean square errors (NRMSE) indices. The results revealed that RMSE for validation and calibration were 0.69 and 0.72 Mgha^{-1}, respectively. NRMSE for calibration was 9.5 % and for validation was 14.1 %. NRMSE for grain yield and dry matter were 8.74 and 13.37 %, respectively. EF values were between 0.84 and 0.98. The results showed that the PILOTE model can be used to manage properly rice irrigation in different regimes. Scenario analysis showed that the best irrigation regime was intermittent irrigation with 8-day interval.

Keywords:
Hashemi variety, irrigation management, Rasht, simulation

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INTRODUCTION

Water is an important factor for agricultural production in Iran. However Guilan province has an annual rainfall equal to 1200 mm (1960-2010) that regularly takes place in fall and winter that are out of rice cultivation seasons; accordingly, the rice can not be irrigated by rainfall. In addition, Sefidroud River, which is the main source of irrigation water of Guilan province, is taking water from upstream provinces, and because of dams built on the upstreams of this river, water allocation has reduced on Sefidroud irrigation network. The water statistics of Guilan Regional Water Authority showed that river discharge have reduced to half in the past decade than the three decades before it. The solution to this problem is to increase the irrigation water productivity in agricultural section. Rice is the main product in this region that is cultivated in vast areas and needs a lot of water. As such, improving water productivity is the main priority in this region. Alternatively, sustainability of agriculture will be in danger. Alternative irrigation can be a suitable substitute for flooding irrigation in this region;however, before this change, it is crucial to test different option. Similar research studies conducted so far are of two major types: field experiments and simulation models. Field experiments are expensive and time consuming. If these models were calibrated and validated satisfactorily, the problem would be solved. After this stage, different management scenarios can be tested without any cost, and the best choice can be selected at the lowest possible time. As lack of water is a pretending problem in this area, water-crop models are suitable to test water saving managements. Many models of this kind have been developed by some researchers. Some of these models are ORYZA 2000 (Bouman et al., 2001), WOFOST (Bouman & Tuong, 2001), SWAP (Van Dam, 1977) and CropSyst (Stokle et al., 1992). Amiri et al. (2011a) have evaluated rice yield in the different irrigation management using ORYZA 2000. Grain yield was simulated by RMSE equal to 150-182 kg ha^{-1} and NRMSE equal to 6 %. Saadati et al. (2011) evaluated WOFOST plant growth model for irrigation management of rice with two varieties i.e. Binam and Hassani varieties. NRMSEs of yield simulation were 7.94 and 13.71 % for Binam and Hassani varieties, respectively.

Saadati (2011) evaluated rice yield with two varieties called Binam and Hassani in a humid climate using CropSyst model. The yield NRMSE of Binam variety was between 0.81 to 12.58 % in calibration year. The NRMSE of Hassani variety was between 2.4 to 19.42 %. The NRMSE of Binam was between 0.83 and 16.4 % and the NRMSE of Hassani was between 2.82 and 21.27 %, in validation year.

The PILOTE model is a water-yield model that requires a few inputs and is based on LAI simulation. This model simulates the balance of water and yield at day time steps. This model was developed for sorghum and sunflower by Mailhol et al. (1997). Later, this model was completed for corn and durum wheat for tillage and no tillage systems by Khaledian et al. (2009). They used it to improve water productivity (Khaledian et al., 2011, 2013). The PILOTE model was used in combination with HYDRUS-2D model to improve subsurface drip irrigation performance and irrigation program for corn by Mailhol et al. (2011). This model, as all other models, should be calibrated and validated, and then it can be used to study different irrigation management scenarios to improve water productivity. Due to lack of water availability in rice cultivation season, irrigation specialists are looking for a way to increase irrigation water productivity. The PILOTE model is a suitable tool to study different irrigation management because of fewer input data compared with other water-yield models. The PILOTE model, thanks to its simple structure, can be easily calibrated for other crops, maintaining its robustness. The goal of this study was to calibrate and validate the PILOTE model to estimate Hashemi rice yield in Rasht under different irrigation regimes. Following validation, the model was used to find relevant irrigation regime in the region by the help of a scenario analysis during a long climatic series of 20 years.

MATERIALS AND METHODS

In this study, two experiments were carried out in the research field of the National Rice

Table 1
Physical and Chemical Properties of Soil (0-0.35 m) at Rice Research Institute of Iran (n=3)

Soil texture	Available potasium mg/kg	Extractable phosphoros mg/kg	Total nitrogen%	pH	Saturation percentage
Silty clay	242(±22.61)*	18.73(±6.00)	0.162(±0.01)	7.27(±0.12)	75(±0.0)

Research Institute, Rasht at 37˚12´ North latitude, 49˚38´East longitude, and 24.6 meters above the sea level. Climate data consist of rainfall, sunshine hours, wind speed, temperature, humidity, and radiation taken from the local climate station. In this study, evapotranspiration (ET_0) is calculated by ET_0 calculator software, which is based on Penman-Monteith equation (Allen et al, 1998).

Soil samples have been sent to the lab for chemical analysis: N, P, and K were determined according to Kjeldahl method for N, Olsen-sodium Bicarbonate Extractant Method for extractable P and Ammonium Acetate Extractant Method for available K (Page, 1982). The results of this analysis are summarized in Table 1. According to this table, the soil has the minimum essential nutrients for rice cultivation. Water chemical analysis results and meteorological data are shown in Tables 2 and 3, respectively. Water quality and climate conditions do not limit normal plant growth.

The soil samples were classified as a silty clay soil. In order to evaluate the PILOTE model performance on the Hashemi rice variety in Guilan province, two field experiments were done in a complete randomized block design with three replications: The first one, which was carried out in irrigation treatments including four levels, consisted of permanent flooding irrigation (I_1: usual irrigation regime in the region) and five (I_2), eight (I_3) and 11 (I_4) days irrigation interval in 2001 and 2002 crop seasons in the experimental plots of 3 meters ×5 meters. The second experiment was carried out under irrigation treatments including three levels (I_1, I_2 and I_3) in 2005, 2006 and 2007 crop seasons. In order to prevent losses of water and fertilizer from plot walls, plot boundaries were covered by nylon. Ten days after seedling, irrigation treatments were applied. This time was considered for better establishment of seedling. After physiological maturity, plant samples were taken from the center of each plot. The samples were dried in the oven and the yield values were estimated in each unit.

Table 2
Chemical Properties of Irrigation Water at the Rice Research Institute in Rasht, Iran

Na^+	Mg^{2+}	Ca^{2+}	SO_4^{2-}	Cl^-	HCO^{3-}	CO_3^{2-}	TDS	pH	EC	SAR
meq lit^{-1}							mg lit^{-1}	-	dS m^{-1}	-
3.1	1.2	3.8	2.2	2.6	3.2	0.8	600	8	0.8	1.96

Table 3
Weather Parameters During Rice Growth Season in Rasht (April-August), Iran

Weather parameters	Crop seasons				
	2001	2002	2005	2006	2007
Precipitation (mm)	144.7	248.2	160.9	135	129.9
Average of maximum daily temperature (˚C)	32	31.2	23.6	23.7	23.6
Average of minimum daily temperature (˚C)	11.8	13.0	18.9	18.5	18.8
Average of maximum relative humidity (%)	100	98.4	98.0	96.7	97.3
Average of minimum relative humidity (%)	30.8	32.2	60.0	55.8	58.8

Model description

The PILOTE is a soil water balance and crop yield model assuming that just the water is limiting crop growth. In the PILOTE model, the soil module consists of three water reservoirs from soil surface to the maximum root depth. The shallow reservoir R_1 with a depth of 0.10 m manages water balance, where soil evaporation is ruled by LAI which acts on the partitioning coefficient between soil evaporation and transpiration. The capacity of second reservoir R_2 enlarges with root growth. The next reservoir represents the left part before the maximum root depth is completely taken by R_2. Water first is captured from R_1 till transpiration and soil evaporation completely deplete the R_1 and following that water is obtained from R_2 only by transpiration. Water Stress Index (WSI) is calculated as the ratio of actual transpiration to the maximum transpiration (actual transpiration/ the maximum transpiration) using actual and Maximum Evapotranspiration (MET). The later is calculated as $MET=K_c \times ET_0$, where Kc is the crop coefficient as a function of LAI, and ET_0 is the reference evapotranspiration (Allen et al., 1998). Actual evapotranspiration diminishes linearly from MET with the depletion of R_2 under water stress condition. Therefore, WSI could be calculated and was then exported to the crop module. Crop module is based on the LAI simulation and its response to WSI. The simulation involves the temperature sum corresponding to the maximum LAI and two shape parameters. Biomass yield is calculated according to Beer´s law (Mailhol, 2005). Grain yield is the product of biomass yield and harvest index. The later is set to a potential value if average LAI from grain filling stage to pasty grain stage is greater than a threshold value, if not it linearly declines (Khaledian et al., 2009; Mailhol et al., 1997).

In order to evaluate model statistically, the simulated and observed values of the grain and biomass yields were determined. Three statistical indices including Root Means Square Error (RMSE), Nash-Sutcliffe efficiency (EF), as well as Normalized Root Mean Square Error (NRMSE) were calculated as below:

$$RMSE=\left(\frac{\sum(P_i-O_i)^2}{n}\right)^{0.5} \qquad (1)$$

$$NRMSE=\frac{100\left(\frac{\sum(P_i-O_i)^2}{n}\right)^{0.5}}{O_{mean}} \qquad (2)$$

$$EF=1-\sum(P_i-O_i)^2 \,/\, \sum(P_i-O_{mean})^2 \qquad (3)$$

In these formulas, P_i is the simulated value, Oi is the observed value, n is the number of estimated values and O_{mean} is the mean of the observed values.

The best value for RMSE and EF are zero and one, respectively. Indeed, NRMSE showed relative difference (percentage of mean value) between simulated and observed values. If the evaluated result (NRMSE) is less than 10 %, it will show an excellent relative difference. If NRMSE is more than 10 % and less than 20 %, it will show good relative difference. If NRMSE is more than 20 % and less than 30 %, it will show the fair relative difference. If NRMSE is more than 30 %, it will show poor relative difference (Bannayan & Hoogenboom, 2009; Jamieson et al., 1991).

The PILOTE model has four input parts: The first part is the soil physical properties such as field capacity, permanent wilting point, soil moisture preliminary reserve, and so on, which is shown in Table 4.

The second part consists of meteorological data that include daily mean temperature, radiation, rainfall, and evapotranspiration. The third part is about plant properties that involve root depth, root growth rate, maximum LAI, plant density, required degree-day for different growth stages, and the fourth part includes an irrigation schedule where date and depth of irrigation are introduced to the model. Required soil information was measured by soil sampling. Meteorological data were provided by National Rice Research Institute of Iran. Some plant information was taken from references (Amiri et al., 2011a; Rezaei & Nahvi, 2007; Saadati et al., 2011), some others were resulted by model calibration, and finally, some were provided by direct field measurements. Irrigation schedule during the study were determined by field taken and recorded irrigation data. Irrigation water depth was determined by a volumetric contour.

Sensitivity analysis

Sensitivity analysis is a useful technique for determining the parameters that have a significant effect on the model outputs, and doing sensitivity analysis is necessary before calibration to recognize sensitive parameters. These parameters were selected from measured or calibrated parameters. Sensitivity is conceptualized as the rate of change in the output resulting from a change of that input parameter (Wohling, 2005). The sensitivity index, SI, proposed by Ng and Loomis (1984) is defined as:

$$sl = \frac{(\frac{100}{N})\sum_{i=1}^{N}(Xin-Xci)Xci}{\Delta} \tag{4}$$

where X_{in} is the new value of the ith data with a changed value of the input parameter, X_{ci}: the value of output for the ith point in the control simulation run, N: the number of point and Δ: is the absolute change in the input parameter. SI in the given form is a measure of the percentage change in the output from that in the control simulation resulting from one percent change in the value of the input parameter. According to the results of sensitivity analysis, model calibration was started from the most sensitive parameter having a higher SI. Primary input parameters were introduced to the model by five percent changing process. In order to find relevant input parameters, model results versus measured data were compared in each calibration stage according to statistical indices. This procedure was applied for next sensitive parameters. Crop season of 2006 was used for model calibration and crop seasons of 2001, 2002, 2005 and 2007 for model validation.

A calibrated and validated model can be used as a reliable tool to analyze different irrigation scenario on a long climatic dataset to consider all dry and wet years in a region and to find the best irrigation regime. The main goal in an irrigation program can be maximizing water productivity (WP) while maintaining crop production level.

Table 4
Soil Properties Used in the PILOTE Model

Parameter	value
field capacity (FC)	40 %
permanent wilting point (PWP)	23 %
initial soil water reserve (0-0.35 m)	140 mm

Scenario analysis to improve water productivity

According to Viets (1962) WP is defined as:

$$WP= yield/water\ use \tag{5}$$

To discriminate the role of irrigation in crop production, WP relation can be modified as (Rodrigues & Pereira, 2009):

$$WP= grain\ yield/irrigation\ water\ depth \tag{6}$$

where WP is in kg ha^{-1} mm^{-1}, grain yield is in kg ha^{-1} and irrigation water depth is in mm. The PILOTE model was employed to compare the irrigation depth and yield production in different irrigation treatments, that is, permanent flooding irrigation as traditional irrigation method in the region and intermittent irrigation method such as 5, 8, and 11 days intervals. The simulation was performed on a long climatic series, which was available in the region (20 years in 1982-2012 period). In some years climatic data were not recorded completely and five years were considered for model calibration and validation.

SPSS 15 was used to do statistical analysis including analysis of variance and Duncan multiple range test for mean comparison.

RESULTS AND DISCUSSION

Experimental results

Results showed that there was no significant difference between permanent flooding irrigation and intermittent irrigation (Table 5) in all the years studied. Furthermore, the table of mean comparison (Table 6) showed that applied irrigation treatments had no statistically significant effects on the measured yield except the intermittent irrigation with 11-day interval as compared to flooding irrigation in 2001. Reviewing Table 6 showed that performing intermittent irrigation

Table 5
Analysis of Variance

S.O.V.	df	Year		df	Year		
		2001	2002		2005	2006	2007
replications	2	154000	616000	2	162136	779959	177700
irrigation	3	758000^{ns}	60000^{ns}	2	21186^{ns}	207332^{ns}	33369^{ns}
error	6	197000	58000	4	70592	77993	278562
CV (%)		13.6	7.8		7	9	9

S.O.V.: source of variation, ns: represent no statistically significant differences, the numbers in the table except of CV represent mean squares

Table 6
Analysis of Mean Comparison of Rice Grain Yield under Different Irrigation Regimes (kg ha^{-1})

Irrigation Treatments	Crop season				
	2001	2002	2006	2006	2007
Flooding	3845.8^{a}	3148^{a}	4043^{abc}	5290^{a}	4575^{abc}
5-day interval	2955.6^{ab}	2942^{a}	3892^{abc}	4871^{abc}	4637^{abc}
8-day interval	3508.3^{ab}	3271^{a}	3720^{c}	4863^{abc}	4755^{ab}
11-day interval	2750.0^{b}	3038^{a}	-	-	-

Same letters means no difference at 95% by Duncan multiple range test

sometimes caused a minor yield increase or decrease, a finding that has been approved by other researchers in the region (Rezaei & Nahvi, 2007; Rezaei et al., 2013). Belder et al. (2004) reported that intermittent irrigation did not decrease rice yield as compared to permanent flooding irrigation. Our findings highlight the potential of intermittent irrigation as compared with flooding irrigation to reduce water consumption, while maintaining crop production, or in other words, this technique can improve WP. Yet, in all types of regions, climate can change over years. accordingly, it would be difficult to generalize the results to all years unless this method tests for all types of year in the region. To do that, a simple water-yield model can be helpful to test this scenario on a long climatic series including all types of year, that is, from wet to dry years. Yet, before using a model, it should be calibrated and validated. That is why, the PILOTE model was calibrated and validated in this study.

Model calibration and validation

Sensitivity analysis of the PILOTE model was determined by 25 % reduction and increase in input parameters and controlling the changed in model outputs. This difference for field parameters was determined by10% difference from the reference. Initial SWR was a sensitive factor in the PILOTE model (Mailhol et al., 1997).

The results of sensitivity analysis showed that simulation of grain yield is highly sensitive to the field capacity, maximum plant efficiency, maturity degree-day, Harvest Index (HI), and radiation use efficiency; accordingly, these values should be determined carefully. Confalonieri et al. (2009) evaluated WARM model in comparison to CropSyst and WOFOST models in Italy. As shown by the findings of the present study, WARM model was sensitive to 30 % of input model parameters against less than 10 % and 20 % with CropSyst and WOFOST models, respectively. The PILOTE model is sensitive to 16% of input model parameters, and the WARM and CropSyst models are more and less sensitive, respectively.

Table 7 shows input parameters and their corresponding values in the PILOTE model. They derived from literature, field measurements, and model calibration. Table 8 shows the result of calibration and validation of the PILOTE model. In this table the simulated values of the grain and biomass yields are compared to the observed values in 2006. Two data sets were used by val-

Table 7

Plant Parameters Used in the PILOTE Model

Parameter	Value	Unit	Identification method
Maximum root depth	0.35	meter	field observation
Root growth rate	0.01	m day^{-1}	field observation
Installation period of root	10	day	field observation
Plant coefficient	1.05	-	field observation
Evaporation coefficient	0.3	-	field observation
Sensitive coefficient to water stress	1.75	-	calibration
Real planting density	25	plant m^{-2}	field observation
Optimum planting density	25	plant m^{-2}	Amiri et al (2011a)
Grain humidity	14	percentage	Measurement
Radiation coefficient change to biomass	0.9	-	calibration
Harvest index, HI	0.5	-	field observation
Water stress threshold	3	m^2 m^{-2}	calibration
Reduction coefficient of harvest index	0.15		Rezaei and Nahvi (2007)
Floration degree-day	1200	degree-day	Rezaei and Nahvi (2007)
Maturity degree-day	1500	degree-day	Rezaei and Nahvi (2007)
Germination degree-day	0	degree-day	Rezaei and Nahvi (2007)
Base temperature	10	^{0}C	Saadati et al (2011)
Maximum LAI	3		field observation
α	6		calibration
β	1.5		calibration
γ	4		calibration

idation years. RMSEs for calibration of biomass and grain yield were 0.94 and 0.18 Mg ha-1 and for validation of biomass and grain yield were 0.96 and 0.36 Mg ha^{-1}. NRMSEs for calibration of biomass and grain yield were 9.9 and 3.5% and for validation of biomass and grain yield were 14.4 and 10.1%.

According to Table 7, the RMSE of calibration (for both biomass and grain yields) was equal to 0.69 Mg ha^{-1} and in this model the RMSE of validation (for both biomass and grain yields) was equal to 0.72 Mg ha^{-1}. The RMSE value of biomass was equal to 0.96 Mg ha^{-1} and grain yield RMSE value was equal to 0.33 Mg ha^{-1} indicating that model has simulated yield satisfactorily. Amiri et al. (2013) evaluated ORYZA 2000 and the RMSE of grain yield was equal to 0.15 – 0.182 Mg ha^{-1}. In addition, they tested WOFOST, and the RMSE of biomass yield was equal to 0.389-0.553 Mg ha^{-1}.

NRMSE value is 14.12 % in the validation years. According to Jamieson et al. (1991), relative difference was categorized in the good class as being between 10-20%. This value is 9.51 % in the calibration year showing an excellent performance (according to Jamieson et al. (1991)). Moreover, biomass yield was categorized in the good class and NRMSE is equal to 13.37 % showing a good relative difference. Saadti et al. (2011) evaluated WOFOST model to simulate yield of Binam and Hassani rice varieties and NRMSE was 8 and 14% being in the good to excellent classes, showing that WOFOST model simulated the yield of Binnam similar to the PILOTE model, but with Hashemi variety. In addition, the results of the study by Amiri et al. (2011a) indicated that WOFOST model could estimate biomass similar to the PILOTE model, and the NRMSE (relative difference) was in the good class. Amiri et al. (2013) evaluated the CERES-Rice model under irrigation and N application managements in Iran. RMSE of this research for grain yield was equal to 0.297 Mgha^{-1} and RMSE of biomass was equal to 0.862 Mgha^{-1}; Furthermore NRMSE of grain yield was equal to 8 %; therefore, according to Jamieson et al. (1991), it was in the excellent class and NRMSE of biomass was equal to 10 %, being in the good class. The results show that CERES-Rice model and the PILOTE model are in the same class.

Comparing WOFOST model to the PILOTE model showed a negligible difference. According to Table 8, EF for grain and biomass yields,

Table 8

Model Statistical Evaluation with Root Mean Square Error (RMSE, Mg.ha^{-1}), Normalized Root Mean Square Error (NRMSE, %) and Nash-Sutcliffe Efficiency (EF)

Parameter	Validation	Calibration	Biomass yield	Grain yield
RMSE	0.72	0.69	0.96	0.33
NRMSE	14.12	9.51	13.37	8.74
EF	0.87	0.98	0.84	0.98

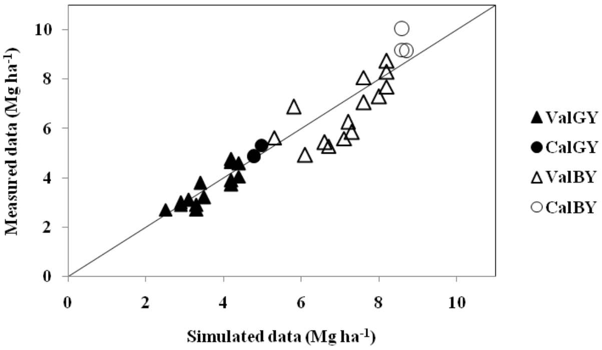

Figure 1. The 1:1 line for comparing field records and model outputs. Biomass yield and grain yield (Mg ha^{-1}) of rice simulated by the PILOTE model versus biomass yield and grain yield in different treatments of irrigation at Rice Reasearch Institute (Val: validation, Cal: calibration, GY: grain yield, BY: biomass yield, EF=0.91, NRMSE=13% and RMSE=0.71 Mgha^{-1}).

calibration and validation years were 0.98, 0.84, 0.98 and 0.87, respectively. In the research of Confalonieri et al. (2009) on three models i.e. WARM, CropSyst and WOFOST in Italy, modelling efficiency (EF) was similar to the PILOTE in the calibration year, but a little bit (0.03) higher in validation years.

The other method to compare observed and simulated values is to use a graph with a 45° slope line. Figure 1 shows the graph of simulated and observed values of grain and biomass yields in the selected field. If observed and simulated grain yields were compared to each other, it would be observed that the model was calibrated well in 2006. Confalonieri and Boechi (2005) evaluated CropSyst model and NRMSE was equal to 11-29 % in the calibration year for rice in the North of Italy. These values are categorized in good and fair classes. Yet, the result of the PILOTE model and NRMSE was different in this study; NRMSE was 9.51 %, categorized in the excellent class. Because of the calibration test stage proved to have been successful, the model was evaluated with two data sets (2001-2002) in addition to the last data set (2005, 2006 and 2007). It showed that the model have simulated grain yield better than biomass yield. This problem could be because of clear cutting, unsuitable drying, and leaf senescence that caused the field data to be weak. The biomass yield was in the inferior; accordingly, the model is able to simulate the economic yield very well. As such, the difference in simulated yield and observed yield is not considerable. Hsiao et al. (2009) evaluated AquaCrop model. The result was similar to the PILOTE model. Singh et al. (2013) worked on CropSyst model, the RMSE of biomass, and grain yields were 0.7 and 0.33 Mg ha^{-1}, respectively which is similar to the PILOTE model. On the other hand, CropSyst reaction with a lot of input parameters was the same as the PILOTE model with a fewer input parameters. Xiong et al. (2008) evaluated CERES-Rice model in China. Results showed that CERES-Rice model was able to simulate rice yield with a RMSE equal to 991 kg ha^{-1} and NRMSE equal to 14.9 %.

PILOTE model application to evaluation of water productivity

According to calibration and validation results, the PILOTE simulates satisfactorily the yield with NRMSE of 13 % and EF of 0.91. therefore, the model can be used as a proper tool for evaluation of different irrigation scenarios on a long climatic series regarding water productivity. Figure 2 demonstrates the results of the PILOTE simulations on the climatic series. WP was found to increase from 3.2 with flooding irrigation to 7.2 kg ha^{-1} mm^{-1} with 11-day interval irrigation in this region. Irrigation interval of 8 days results in a WP of 7.7 kg mm^{-1}. It can be said that in average a water application depth of 600 mm was saved with 8-day compared with flooding irrigation.

Table 9
Comparing Mean of Water Productivity in Different Irrigation Treatments During Climatic Series of 20 Years Using t-test

Irrigation treatments		p-value	Statistical test result
flooding	5-day interval	0.00	**
flooding	8-day interval	0.00	**
flooding	11-day interval	0.00	**
5-day interval	8-day interval	0.00	**
5-day interval	11-day interval	0.00	**
8-day interval	11-day interval	0.037	*

*p<0.05, **p<0.01

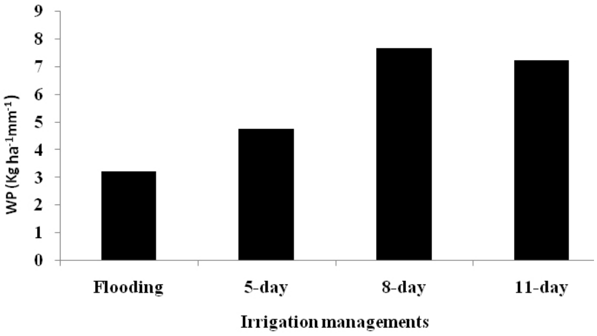

Figure 2. Mean water productivity (kg ha^{-1} mm^{-1}) as affected by different irrigation managements

Regarding statistical analysis (see Table 9), the best irrigation treatment was intermittent irrigation with 8-day time interval. The grain yield under this treatment condition was not different from that of others (see Table 6); accordingly, this treatment can be recommended because of both the highest water productivity and equal crop production. This irrigation is very interesting regarding water deficiency in the region.

CONCLUSION

According to the result of statistical evaluation, the PILOTE model was shown to provide an acceptable level of accuracy in the simulation of rice yield. Despite the fact that the PILOTE model has less input parameters than other models and is easy to use, it can simulate yield with high accuracy. After calibration and validation of the model, it was used to assess different irrigation management scenarios. Using intermittent irrigation, instead of flooding irrigation, could produce equivalent grain yield with a higher level of water productivity, which is very attractive in a region with limited water resources for rice production. As is the case with the region, the problem of water scarcity is highlighted; therefore, using this model for managing irrigation properly, can address this issue.

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