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Simulation of rice yield under different irrigation and nitrogen application managements by CropSyst model

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ABSTRACT

The aim of this study was the calibration and validation of CropSyst model for rice in the city of Rasht. The necessary data were extracted from a field experiment which was carried out during 2005-2007 in a split-plot design. The main plots were irrigation regimes including continuous flooding irrigation and 5-day irrigation intervals. The subplots consisted of four nitrogen levels: zero N application, 45, 60 and 75 kg N ha^{-1}. Normalized Root Mean Squared Error (nRMSE) and Residual Mass Coefficient (Crm) in calibration years were 9.3% and 0.06, respectively. In validation year, nRMSE and Crm were 9.7% and 0.11, respectively. According to other indices to assess irrigation regimes and fertilizer levels, the most suitable treatments regarding environmental aspect were 5-day irrigation regime and 45 kg N ha^{-1}.

Key words: crop model, irrigation, fertilization, rice

IZVLEČEK

SIMULACIJA PRIDELKA RIŽA S CROPSYST MODELOM PRI RAZLIČNIH REŽIMIH NAMAKANJA IN GNOJENJA

Namen te raziskave sta bili kalibracija in validacija CropSyst modela za pridelovanje riža v Rashtu (Iran). Podatki za obdelavo izvirajo iz poljskega split-plot poskusa, ki je potekal v letih 2005-2007. Glavne ploskve so bile namakane, vključno z neprekinjenim poplavnim namakanjem v petdnevnih intervalih. Podploskve so imele štiri režime gnojenja z dušikom in sicer: 0 N –brez dušika, 45, 60 in 75 kg N ha^{-1}. Normalizirana vrednost korena povprečnih kvadriranih napak (Normalized Root Mean Squared Error;nRMSE) in koeficient mase ostankov (Coefficient of Residual Mass; Crm) sta v kalibracijskih letih sta znašala 9.3 % in 0.06 %. V validacijskem letu sta omenjena parametra znašala (nRMSE in Crm) 9.7 % in 0.11 %. Glede na druge kazalnike ocenjevanja namakanja in gnojenja je bil tudi okoljsko najprimernejši tretma petdnevno namakanje in gnojenje s 45 kg N ha^{-1}.

Ključne besede: pridelovalni model, namakanje, gnojenje, riž

1 INTRODUCTION

Nowadays agriculture sector requires production systems with high water productivity. The issue of water scarcity is an important issue from the economical aspect of it due to high irrigation water requirement in the production of rice. Development of new water saving systems is one of increasing rice yield choice with limited water resource. Therefore, multiple ways were approved (Pirmoradian et al. 2004; Kato et al. 2006). The production of rice without constant use of water head above soil surface which is referred to as none-constant-submerging or its alternative intermittent-irrigation is one of those optimum methods. In Asia researchers try to enhance yield under water saving irrigation by using genetic improvement e.g. development of varieties that are resistant to dry condition (Nemoto et al. 1998). Irrigation under limited supply of water decreases photosynthesis, claws, leaf area, biomass, number

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of grain per an ear, thousand kernel weight and grain yield (Zubaer et al. 2007).

Guilan Province with 200 thousands hectares of rice cultivation is one of the important zones of rice production in Iran. Water requirement for agricultural activities is being supplied by Sepidroud dam and its widespread irrigation network. Recently, the decrease of fresh water resources has made a great concern on rice production in Guilan province. Climate changes, degrading of water resources and continuous drought has influenced agriculture in general and farmers' incomes specifically (Rezaei et al. 2013). Besides, local varieties of Iran are resistant to intermittent irrigation conditions (Razavipour et al., 2000). Also, experimental data requires a lot of expenditure and is time consuming in order to receive research aims. Therefore, crop models are offered to save money and time. These models can lead to other advantageous e.g. examining different management scenarios.

The aim of CropSyst development was to simulate cropping systems and crop rotation. So, this model was developed from the early 1990s. CropSyst model is a perfect sample of simulation model that ever used in the world. CropSyst simulates crop system with daily time step that can be in multi-year and multi-crop conditions. In this model, effects of different elements like climate, soil, management and crop characteristics on crop systems and environment has been examined. The significant feature of CropSyst is that it can connect to GIS software. Plant growth is simulated by the model based on arriving time to each phenology stage according to accumulation temperature. CropSyst simulates soil-plant nitrogen balance, crop canopy and crop development, root growth, dry matter production, yield, residue production and decomposition and erosion by water and salinity (Stöckle et al. 1994; Stöckle et al. 2003).

CropSyst model has been applied to estimate soil water balance in rainfed and fallow land and irrigated farm in Southern Africa (Abraha and Savage 2008). Results, showed that the model accuracy was higher in simulation of dry rather than wet soil water balance. This model was evaluated to simulate growth, water- and N-uptake of irrigated winter wheat (*Triticum aestivum* 'Kupava') in Khorezm, in the dry lands of Northwest Uzbekistan, Central Asia (Djumaniyazova et al. 2010).

CropSyst was calibrated and validated by using field experiments. Results of 2005/06 and 2006/07 seasons were used for model calibration and 2007/08 season was used for model validation. The results of modeling were studied while nRMSE of aboveground biomass and grain yield in 2007/08 was 11%.

On first two cropping season and 749 and 869 mm irrigated water, N-leaching was high and ranged from 63 to 106 kg ha^{-1} and was low (7-15 kg ha^{-1}) by 148-395 mm irrigation during 2007/08. In another study, biomass growth of alfalfa (*Medicago sativa* L.) and its influence on soil water dynamic were analyzed under different irrigation treatment in Austria. Simulation results showed satisfactory application by suitable value of RMSE of biomass growth (0.58-3.52 t ha^{-1}) and water content in the soil profile (20.9-50.6 mm) (Raza et al. 2013).

The effect of alternative management options (nitrogen application and soil water content) on maize (*Zea mais* L.) crop was evaluated by CropSyst model at Pisa, Central Italy. Experimental and simulation results were compared. Modeling efficiency (EF) were 0.82 and 0.75 for biomass and soil water content, respectively (Bellocchi et al. 2002). Another study in Southern Italy was done on sorghum and sunflower during 1986-1993. Obtained results based on nRMSE (11 and 25% for simulated yield of sorghum and sunflower, respectively) showed that CropSyst is a suitable model (Ventrella and Rinaldi 1999).

Because of drought in recent years, deficit of water resources and constructing several dams upstream of Sefidroud watershed, the agriculture of Guilan province faced to water deficit (Rezaei 2007). According to water deficit and degrading available water in considered region, more field research as well as introducing suitable tools such as crop models is necessary to test different management scenarios and improving water productivity. So, CropSyst model was calibrated and validated on rice ('Hashemi' variety, a local and a popular variety) under different irrigation and nitrogen managements to predict yield of this crop under the weather conditions of Rasht.

2 MATERIALS AND METHODS

2.1 Experimental data

This study was conducted at the rice research institute (37˚12′19″N, 49˚38′28″E, 24.6 m a.s.l.) of Iran, located in Rasht, Guilan province. The field experiments were carried out on a silty-clay soil (13% sand, 41% silt, 46% clay). The climate of Rasht was determined to be so humid, based on Köppen method according to 50-year climatic data (1956-2005). Annual mean temperatures range between 13.3 and 17.2 ˚C with an average of 15.9 ˚C; relative humidity: 75 to 87% with an average of 81 %; and mean annual rainfall is 1359 mm. Experimental data were collected during 2005-2007. Some weather and soil characteristics are presented in Table 1 and Table 2. This soil has been always a paddy soil for a long time. About 90% of rainfall in the region falls in autumn and winter. Soil 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. N content in plant (stem and grain) was measured using Kjeldahl method.

Table 1. Weather parameters during rice growth season in Rasht (April-August)

	(crop season of rice)		
Weather parameters	2005	2006	2007
precipitation (mm)	160.9	135	129.9
Average of maximum daily temperature (˚C)	28.3	28.8	28.4
Average of minimum daily temperature (˚C)	18.9	18.5	18.8
Short length radiation (MJ m^{-2} d^{-1})	19.57	20.22	19.87
Average of maximum relative humidity (%)	98.02	96.7	97.28
Average of minimum relative humidity (%)	60.04	55.82	58.84
Average of wind speed (m s^{-1})	3.6	4.57	4.62

Table 2. Some soil characteristics

Saturated water content %	Soil electrical conductivity dS m^{-1}	pH	Total nitrogen mg kg^{-1}	Absorbable phosphorus mg kg^{-1}	Absorbable potash mg kg^{-1}
75	1.12	7.4	1890	17.8	280

The rice variety was 'Hashemi' so popular in Guilan province. The research was carried out in a split plot design in a complete randomized block under different regimes of irrigation and nitrogen applications at the Rice Research Institute of Iran, Rasht. There were three blocks as replication. Each block was divided into two main plots and each main plot was divided to four subplots. The main plots consisted of two plots; I_1: continuous submergence irrigation (with 30-50 mm standing water throughout crop growth); and I_2: 5-day irrigation interval.

Subplots with 15 m^2 areas included four levels of nitrogen applications: N_1: zero N application; N_2: total N rate of 45 kg ha^{-1} (applied at basal); N_3: total N rate of 60 kg ha^{-1}; and N_4: total N rate of 75 kg ha^{-1}. To reduce N leaching, half of N_3 and N_4 were applied at basal and the residual of N fertilizer was applied at maximum tillering as a top dressing. The boundaries of plots were covered with nylon to prevent transportation of water, fertilizer and herbicide. For 10 days after transplanting, all plots were under continuous submergence condition. Then irrigation treatments were applied based on their scheduled time. After plant maturity, the yield in different treatment was determined according to harvested samples in a 5 m^2 of middle of each plots.

2.2 Simulation model

To introduce processes of CropSyst simulation, some equations are more important in this study so they are presented here. Crop transpiration-dependent biomass production (Bpt) and LAI are effective on output of CropSyst based on calibration results. Third equation is yield that was one of main evaluated outputs. Therefore, those three equations were presented in this paper, more information can be found in Stockle et al. (1994) and Stöckle et al. (2003).

There is a relationship between crop transpiration and biomass production that is based on carbon and vapor exchange in leaves. So the potential daily biomass production can be calculated as (Tanner and Sinclair 1983):

$$B_{PT} = \frac{K_{BT} T_P}{VPD} \qquad (1)$$

where B_{PT} is the crop transpiration-dependent biomass production (kg m^{-2} day^{-1}), T_P is crop potential transpiration (kg m^{-2} day^{-1}), VPD is the daytime mean atmospheric vapor pressure deficit (kPa) and K_{BT} is a biomass-transpiration coefficient (((kg m^{-2}) kPa) m^{-1}).

The increase of leaf area during the vegetative period, expressed as leaf area per unit soil area (leaf area index (LAI)) is calculated as a function of biomass accumulation:

$$LAI = \frac{SLAB}{1+p^{B}} \qquad (2)$$

where LAI is in m^2 m^{-2}, B is accumulated aboveground biomass (kg m^{-2}), SLA is the specific leaf area (m^2 kg^{-1}) and *p* is a partition coefficient (m^2 kg^{-1}) controlling the fraction of biomass to leaves (a value of zero apportion all biomass to leaves) (Stockle et al. 2003).

Yield simulation depends on total biomass accumulated at physiological maturity (B_{PM}) and the harvest index (HI= harvestable yield/aboveground biomass):

$$Y = B_{PM}\,HI \qquad (3)$$

where Y is yield (kg m^{-2}) and B_{PM} is also in kg m^{-2}.

In this study CropSyst ver. 4.13.09 was used. Model inputs are entered in database and scenario sectors. Water and fertilizer managements, climate, soil and plant conditions are inputs that are entered in the database which is an important part of the model. Finally running the model is done in scenario sector. In this part some parameters are determined like simulation period, initial features and suitable way of evapotranspiration. The model let user to determine produced outputs while he or she could choose daily or yearly output.

Sensitivity analysis is done by using of different methods like Morris and regression-based method (Confalonieri et al. 2010). In this study Ng and Loomis method was used to calculate sensitivity index (Ng and Loomis 1984):

$$SI = \frac{(\frac{100}{N}) \times \sum_{i=1}^{N} (Xni - Xci)/Xci}{\Delta} \qquad (4)$$

where Xni is the new value of the i^{th} data point with a changed value of the input parameter; Xci: the value of output for the i^{th} point in the control simulation run; N: the number of point; Δ is the absolute change in the point parameter; SI in the given form is a measure of the percentage change in the output from that in the control simulation results from a percent change in the value of the point parameter.

2.3 Calibration and validation

After sensitivity analysis, the model should be calibrated. The purpose of calibration is describing experimental station conditions for the model. The inputs include of literature value, measurements and default quantities. Measured values should be used if some sensitive parameters were consisting of them.

Calibration was started from more sensitive parameters that had higher SI. Model primary values were entered by 5 % changing process. To determine the suitable input, simulated and measured values were compared in each stage by statistical indices. In this study three statistical indices were used i.e. Crm, RMSE and nRMSE:

$$\text{Crm} = 1 - \frac{\sum_{i=1}^{n}(P_i)}{\sum_{i=1}^{n}(O_i)} \quad (5)$$

$$\text{RMSE} = \sqrt{\sum_{i=1}^{n}(P_i - O_i)^2/n} \quad (6)$$

$$\text{nRMSE} = \sqrt{\sum_{i=1}^{n}(P_i - O_i)^2/n} \times \frac{100}{\sigma} \quad (7)$$

where O_i is observed yield; P_i: simulated yield and n: number of treatments in each year.

If Crm and RMSE are close to zero, then simulations and observations have closer values. nRMSE gives a measure of the relative difference of simulated versus observed data. The simulation is considered excellent with nRMSE less than 10 %, good if nRMSE is greater than 10 and less than 20 %, fair if nRMSE is greater than 20 % and less than 30 % and poor if nRMSE is greater than 30 % (Jamieson et al. 1991; Bannayan and Hoogenboom 2009).

Another issue has been assessed about irrigation water and nitrogen uptake by crop (different simulated parameters by model) with some indices was done. Rice is a sensitive crop to nitrogen so physiological nitrogen use efficiency (PNUE) is defined to analyze the amount of nitrogen uptake (simulated by the model) that is fraction of grain yield (kg ha^{-1}) to nitrogen uptake (kg ha^{-1}) (Montemurro et al. 2006):

$$\text{PNUE} = \frac{\text{grain yield}}{\text{N uptake}} \quad (8)$$

Both grain yield and N uptake in equation 8 were simulated by the model. Treatment consisted of different irrigations; therefore, an assessment should be done about the amount of irrigated water. Consequently, irrigation water use efficiency (IWUE) was used (Shahnazari et al. 2007). IWUE is the fraction of grain yield (kg ha^{-1}) simulated by the model to irrigation water (m^3 ha^{-1}):

$$\text{IWUE} = \frac{\text{grain Yield}}{\text{irrigatin water}} \quad (9)$$

Nitrogen harvest index (NHI) was used according to the portion of grain N content (kg ha^{-1}) to N uptake (kg ha^{-1}) simulated by the model (Montemurro et al. 2006) that can be analyzed completely under this study:

$$\text{NHI} = \frac{\text{grain N content}}{\text{N uptake}} \times 100 \quad (10)$$

CropSyst did not simulate grain N content, so observed values were used in NHI because of no significant difference between observed and simulated grain yield and plant N uptake values.

3 RESULTS AND DISCUSSION

3.1 Experimental results

Data of 2005 and 2006 were used for model calibration and 2007 data were considered for model validation. According to measurements and observations during research period, it was determined that maximum daily temperature in all days was lower than cutoff temperature likewise comparison of minimum daily temperature in all days with base temperature showed that only one day in 2007 had lower temperature than base temperature. So air temperature had reasonable fluctuation in the period of three years. Crop parameters that were used are shown in Table 3. Harvest index in 2005, 2006 and 2007 were respectively 0.4, 0.49 and 0.46.

Table 3: Rice crop parameter and references of information

Crop parameter	Crop season			
	2005	2006	Determination method [*]	Units
Canopy extinction coefficient for total solar radiation		0.5	D	-
ETc		1.05	C	-
Leaf water potential at the onset of stomatal closure		-700	D	J kg^{-1}
Wilting leaf water potential		-1600	D	J kg^{-1}
Maximum water uptake		13	L	mm day^{-1}
Above ground biomass transpiration coefficient (K) for annuals		6	C	kPa kg m^{-3}
Maximum radiation use efficiency		0.003	D	kg MJ^{-1}
Mean daily temperature that limits early growth		11	D	° C
Specific leaf area at optimum temperature		23.1	C	m^2 kg^{-1}
Stem/leaf partition coefficient (SLP)		1.85	C	-
Leaf water potential that begins reduction of canopy expansion		-800	D	J kg^{-1}
Leaf water potential that stops canopy expansion		-1200	D	J kg^{-1}
Emergence	80	80	M	° C-days
Maximum root depth	970	970	M	° C-days
End of vegetative growth	970	970	M	°C-days
Begin flowering	850	850	M	° C-days
Begin filling	900	900	M	° C-days
Physiological maturity	1530	1530	M	° C-days
Leaf area duration	800	800	D	° C-days
Maximum rooting depth		0.35	M	m
Harvest index	0.4	0.49	M	-
Nitrogen demand adjustment	1	0.8	C	-
Base temperature		10	M	° C
Cutoff temperature		42	M	° C

[*] D: default; M: measured; C: calibrated parameter; L: literature (Saadati 2012)

3.2 Model results

Calibrated and validated values of biomass and yield in three years are shown in Table 4. These two parameters were evaluated by using statistical indices. According to calculated statistical indices (Table 5), Crm and nRMSE in calibration years (2005 & 2006) for biomass and yield were 0.01, 8.3%, 0.06 and 9.3%, respectively. In validation year (2007) nRMSE for biomass and yield were 9.6 and 9.7% and Crm for these parameters were 0.03 and 0.11, respectively. The results of the statistical indices showed that CropSyst is a suitable model for simulating rice yield. A research about rice was done in Northern Italy between 1991 and 2002. Calibration results of CropSyst have shown that nRMSE for biomass ranged from 11 to 29% (Confalonieri and Bocchi 2005). Because of similar climate in Italy and the study zone, it can be said that this model had a better performance in Rasht.

In Figure 1, 1:1 line was drawn between observed and simulated values of biomass and grain yield in calibration and validation years that is consisted of 48 points. Values of nRMSE and Crm were 9.8% and 0.04, respectively. According to Figure 1, the points are distributed properly around the 1:1 line. On the other hand, the points are inclined to underneath of the line so, it shows that the model had slightly underestimated.

Table 4 Observed and simulated values (kg ha^{-1}) in calibration and validation years

	Year	Crop parameter	Number	Observed value	Simulated value
Calibration years	2005	biomass	8	8195	7954
		yield	8	3243	3149
	2006	biomass	8	7793	7153
		yield	8	3857	3538
Validation year	2007	biomass	8	7510	7259
		yield	8	3479	3360

Table 5. Indices of agreement between observed and simulated values

	Crm	RMSE (kg ha^{-1})	nRMSE (%)
Calibration (2005 & 2006)			
Final biomass	0.01	659	8.3
Grain yield	0.06	331	9.3
Validation (2007)			
Final biomass	0.03	722	9.6
Grain yield	0.11	336	9.7

Values of PNUE were determined for N_1, N_2, N_3, N_4 and different irrigation treatments (Figure 2) using simulated values. By comparison of PNUE values in different irrigation it was found that this parameter was higher in continuous submergence than 5-day irrigation intervals. Based on the analysis of variance results (lack of space, results not shown here), grain yield in different irrigation levels had no significant difference thus high value of PNUE in continuous submergence was due to low N crop uptake in 2005 and 2006. But in 2007, it was different, while the difference between PNUE values in all these years were not significant in two treatments. In fact, different N application rates caused a change in the balance of grain yield and N uptake. Therefore, the result had no changing. 5-day irrigation intervals in comparison to continuous submergence caused degradation of PNUE (in 2005 and 2006) but not significant ($p>0.05$). So, according to PNUE index, 5-day irrigation intervals is recommended as pertinent alternative of continuous submergence to save water.

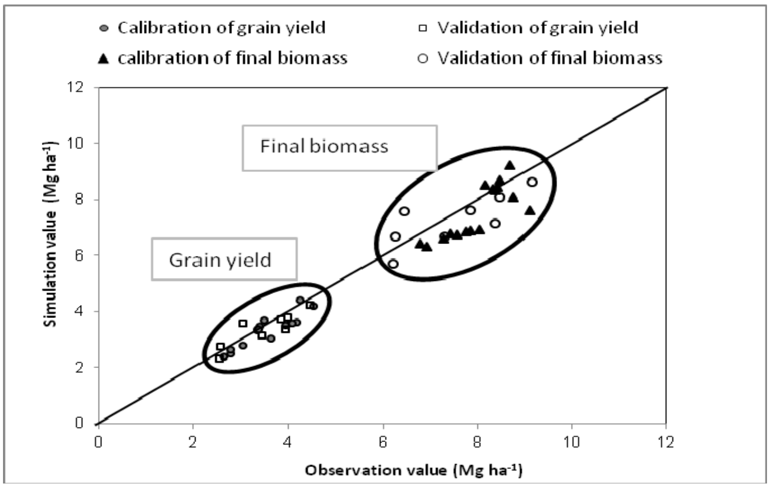

Figure 1: Comparison between observed and simulated value by 1:1 line

According to Figure 3, values of IWUE for 5-day irrigation intervals were the highest in all years, while it was predictable based on less water use in this treatment. IWUE had an ascendant trend from N_1 to N_4. The IWUE value of N_1 had significant difference by others but N_2, N_3 and N_4 did not have significant difference with each other ($P>0.05$) except of 2007. As a result, the 45 kg N ha^{-1} is recommended based on IWUE.

Irrigation treatments had similar effect on NHI index (Figure 4). By comparison of NHI in three N application treatments (N_2, N_3, N_4) did not see any significant difference, but in $N_1$was so different. By considering all the indices, as the results of N_2, N_3 and N_4 treatments were similar. So, N_2 (45 kg N ha^{-1}) can be recommended based on economical and environmental considerations.

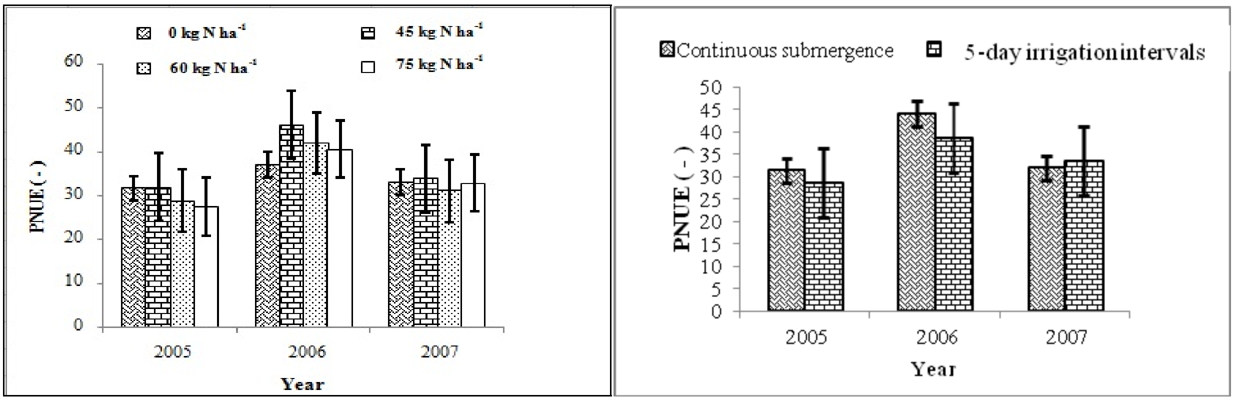

Figure 2: PNUE value in different years under irrigation and N application treatments (error bars represent standard deviation)

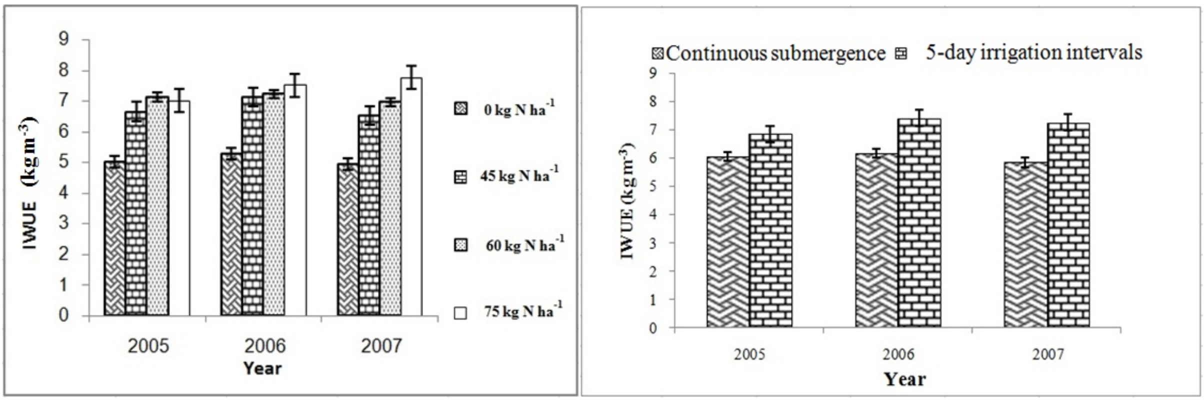

Figure 3. IWUE value in different years under irrigation and N application treatments (kg m^{-3}, error bars represent standard deviation)

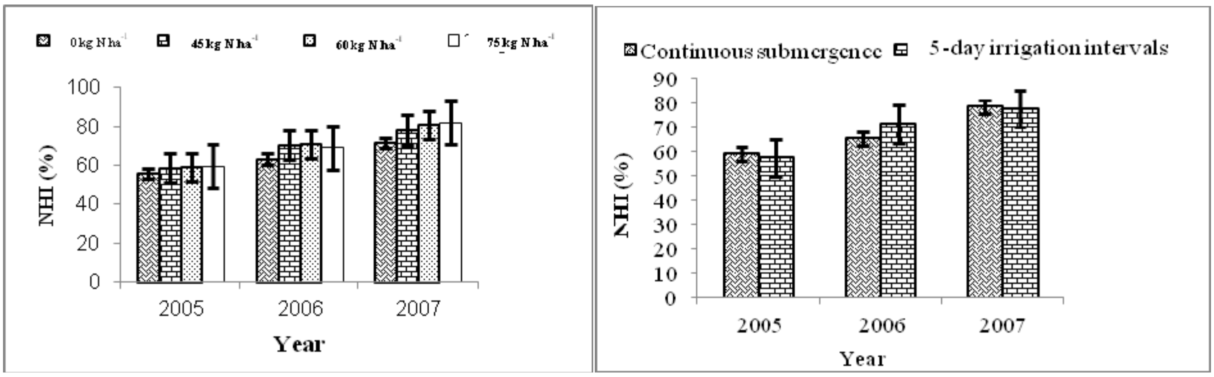

Figure 4. NHI value in different years under irrigation and N application treatments (error bars represent standard deviation)

4 CONCLUSIONS

According to the statistical indices (nRMSE = 9.8% and Crm = 0.04), CropSyst had suitable performance for rice yield simulation in Rasht. Apart from rice, the model could be calibrated and validated for other crops. Because of the importance of water in this region, along with the high cost of N fertilizers and possibility of fertilizer leaching, different management scenarios should be evaluated by crop model, and then optimum management should be recommended to the user regarding economical and environmental aspects. If research studies have been done in a wider scale by connection of CropSyst to GIS, it could be possible to recommend the suitable scenario regarding economical and environmental aspects e.g. whole Guilan province or a wide paddy region.

5 REFERENCES

Abraha M.G., Savage M.J. 2008. The soil water balance of rainfed and irrigated oats, Italian rye grass and rye using the CropSyst model. Irrigation Science, 26, 3: 203-212. DOI: 10.1007/s00271-007-0086-8

Bannayan M., Hoogenboom G. 2009. Using pattern recognition for estimating cultivar coefficients of a crop simulation model. Field Crops Research, 111, 3: 290-302. DOI: 10.1016/j.fcr.2009.01.007

Bellocchi G., Silvestri N., Mazzoncini M., Menini S. 2002. Using the CropSyst model in continuous rainfed maize (Zea mais L.) under alternative management options. Italian Journal of Agronomy, 6, 1: 43-56

Confalonieri R., Bellocchi G., Bregaglio S., Donatelli M., Acutis M. 2010. Comparison of sensitivity analysis techniques: a case study with the rice model WARM. Ecological Modelling, 221, 16: 1897-1906. DOI: 10.1016/j.ecolmodel.2010.04.021

Confalonieri R., Bocchi S. 2005. Evaluation of CropSyst for simulating the yield of flooded rice in northern Italy. European journal of agronomy, 23, 4: 315-326. DOI: 10.1016/j.eja.2004.12.002

Djumaniyazova Y., Sommer R., Ibragimov N., Ruzimov J. 2010. Simulating water use and N response of winter wheat in the irrigated floodplains of Northwest Uzbekistan. Field Crops Research, 116: 239-251. DOI: 10.1016/j.fcr.2010.01.001

Jamieson P., Porter J., Wilson D. 1991. A test of the computer simulation model ARC-WHEAT1 on wheat crops grown in New Zealand. Field Crops Research, 27: 337-350. DOI: 10.1016/0378-4290(91)90040-3

Kato Y., Kamoshita A., Yamagishi J., Abe J. 2006. Growth of Three Rice (Oryza sativa L.) Cultivars under Upland Conditions with Different Levels of Water Supply. Plant Production Science, 9, 4: 422-434. DOI: 10.1626/pps.9.422

Montemurro F., Maiorana M., Ferri D., Convertini G. 2006. Nitrogen indicators, uptake and utilization efficiency in a maize and barley rotation cropped at different levels and sources of N fertilization. Field Crops Research, 99, 2: 114-124. DOI: 10.1016/j.fcr.2006.04.001

Nemoto H., Suga R., Ishihara M., Okutsu Y. 1998. Deep rooted rice varieties detected through the observation of root characteristics using the trench method. Breeding Science, 48, 3: 321-324

Ng N., Loomis R.S. 1984. Simulation of growth and yield of the potato crop. Simulation Monographs. Pudoc (Center for Agricultural Publishing and Documentation). Wageningen, 147 pp.

Pirmoradian N., Sepaskhah A.R., Maftoun M. 2004. Effects of water-saving irrigation and nitrogen fertilization on yield and yield components of rice (Oryza sativa L.). Plant Production Science, 7, 3: 337-346. DOI: 10.1626/pps.7.337

Raza A., Friedel J.K., Moghaddam A., Ardakani M.R., Loiskandl W., Himmelbauer M., Bodner G. 2013. Modeling growth of different lucerne cultivars and their effect on soil water dynamics. Agricultural Water Management, 119: 100-110. DOI: 10.1016/j.agwat.2012.12.006

Razavipour T., Yazdani M., Kavosi M. 2000. The effects of water stress in different growing stage on rice yield. Presented in the 6th national conference on soil science . 26-28 Jun. 2007. Tehran. Pp 613-614.

Rezaei M. 2007. Environment protection using irrigation and herbicide management in paddy field. Presented in the 10th national conference on irrigation and drainage . 26-28 Jun. 2007. Tehran

Rezaei M., Davatgar N., Khaledian M., Pirmoradian N. 2013. Effect of intermittent irrigation with saline water on rice yield in Rasht, Iran/Učinek periodičnega namakanja s slano vodo na pridelek riža v provinci Guilan, Rasht, Iran. Acta agriculturae Slovenica, 101, 1: 49-57. DOI: 10.2478/acas-2013-0006

Saadati Z. 2012. Assessment of AquaCrop, CropSyst and WOFOST models in yield simulating of two rice varieties, Binam and Hasani, under different irrigation regimes. Dissertation, University of Iran

Shahnazari A., Liu F., Andersen M.N., Jacobsen S.E., Jensen C.R. 2007. Effects of partial root-zone drying on yield, tuber size and water use efficiency in potato under field conditions. Field Crops Research, 100, 1: 117-124. DOI: 10.1016/j.fcr.2006.05.010

Stöckle C.O., Donatelli M., Nelson R. 2003. CropSyst, a cropping systems simulation model. European Journal of Agronomy, 18, 3: 289-307. DOI: 10.1016/S1161-0301(02)00109-0

Stockle C.O., Martin S.A., Campbell G.S. 1994. CropSyst, a cropping systems simulation model: water/nitrogen budgets and crop yield. Agricultural Systems, 46, 3: 335-359. DOI: 10.1016/0308-521X(94)90006-2

Tanner C., Sinclair T. 1983. Efficient water use in crop production: research or re-search? In: Limitations to efficient water use in crop production. Madison: American Society of Agronomy: 1-27.

Ventrella D., Rinaldi M. 1999. Comparison between two simulation models to evaluate cropping systems in Southern Italy. Yield response and soil water dynamics. Agricoltura Mediterranea, 129, 2/3: 99-110

Zubaer M., Chowdhury A., Islam M., Ahmed T., Hasan M. 2007. Effects of water stress on growth and yield attributes of Aman rice genotypes. International Journal of Sustainable Crop Production, 2, 6: 25-30