INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
17–0317/2018/20–2–221–229
DOI: 10.17957/IJAB/15.0471
http://www.fspublishers.org

Full Length Article

Variability of Parameters of ORYZA (v3) for Rice under Different Water and Nitrogen Treatments and the Cross Treatments Validation

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Abstract

To reveal the variability in ORYZA (v3) model parameters among different water and nitrogen treatments, and illustrate the model performance and uncertainty in rice biomass simulation with different treatment specific calibrated parameters, ORYZA (v3) model were calibrated and validated treatment specifically based on data from four different water and nitrogen treatments. Generally, the treatment specific calibrated ORYZA (v3) model is accurate in modelling rice biomass accumulation in the exact specific treatment, and it performed a little better under potential condition than water or nitrogen limited condition. Variability of treatment specific calibrated parameters for ORYZA (v3) model was low, with the maximum CV of 6.43% for biomass partitioning factor to leaf. The cross treatment validation indicated the errors in simulated total above ground biomass (WAGT) and panicles biomass (WSO) for a specific treatment were enlarged in a certain degree, when it was simulated by parameters calibrated from others. For WAGT simulation, the FF (flooding irrigation + farmers' fertilization practice) treatment calibrated parameters performed slightly better than others. For WSO simulation, all the four group calibrated parameters underestimated it in the early panicle growth phrase under water or nitrogen limited conditions, and FF and NFS (non-flooding controlled irrigation + site specific nitrogen management) treatment parameters performed slightly better than FS (flooding irrigation + site specific nitrogen management) treatment and NFF (non-flooding controlled irrigation + farmers' fertilization practice treatment). There would be a certain degree of uncertainty when rice biomass production simulated by ORYZA (v3) model with different treatment specific calibrated parameters. The range and standard deviation of simulated WAGT or WSO is low at beginning and increased along with crop development, with the values in FF and FS treatment are generally lower than that in NFF and NFS.

Keywords: Rice production; ORYZA (v3); Variability; Uncertainty; Water and nitrogen limitation; Cross validation

Introduction

Nitrogen (N) input, which played an important role in increasing crop yield, resulted in serious N losses and non-point pollution in China when it was excessive (Liu and Diamond, 2008; Ju *et al*., 2009; Xu *et al*., 2012; Jiao *et al*., 2016). Drainage occurred after rainfall or irrational irrigation is one of the major process by which water and nutrients discharged from agricultural field entered into surface water body. Reducing water and nitrogen inputs in agricultural, in the premise of no remarkable reduction in crop yield, is an essential topic to enhance agricultural sustainability and alleviate the water pollution (Ju *et al*., 2009; Jiao *et al*., 2016). Many effort has been done by field experiments to reduce the N losses, and to improve field N fertilization management (Wang *et al*., 2004; Xia and Yan, 2011; Deng *et al*., 2014). Other than field trials, crop models which can describe the response of crop growth and production to field cultivation practice including irrigation and fertilization management are potential tools for optimization of the crop irrigation and fertilizer management.

For rice paddies in China, which are flooded traditionally, N use efficiency is relatively low because of rapid N losses through ammonia volatilization, denitrification, surface run off, and leaching (Zhu and Chen, 2002). ORYZA model (v3 version), developed by IRRI and Wageningen University and Research Centre (Bouman *et al*., 2001) based on model of ORYZA1, ORYZA_N and ORYZA_W, can simulate the rice growth and production either under a potential condition, water-limited or nitrogen-limited situation (Li *et al*., 2005; Bouman and Van Laar, 2006; Feng *et al*., 2007), or future climate conditions (Luo *et al*., 2015; Wang *et al*., 2017). It is the most updated model for rice growth simulation, used as a useful tool to estimate a crop's potential yield (Espe *et al*., 2016) and optimize the irrigation schedules (Xue *et al*., 2008; Li *et al*., 2011; Humphreys *et al*., 2012), fertilization regimes (Jing *et al*., 2007; Boling *et al*., 2010) and irrigation-fertilization management (Amiri and Rezaei, 2010; Boling *et al*., 2011) for rice by scenario simulation. Model calibration is

To cite this paper: Xu, J., Q. Liao, S. Yang, Y. Lv, Q. Wei, Y. Li and F. Hameed, 2018. Variability of parameters of ORYZA (v3) for rice under different water and nitrogen treatments and the cross treatments validation. *Int. J. Agric. Biol*., 20: 221–229

essential, before it was applied for scenario simulation. Mostly, researchers use one set of carefully calibrated parameters either with data from several years or several specific treatments, and validate it with data for other years or other treatments. Mostly, researchers use one set of parameters calibrated either with data from several years (Shuai *et al*., 2009; Li *et al*., 2011) or several specific treatments (Jing *et al*., 2007; Zhang *et al*., 2007; Amiri and Rezaei, 2010; Artacho *et al*., 2011) and validate it with data for other years or treatments. For example, Li *et al*. (2011) calibrated ORYZA with data under continuous flooding irrigation and validated it with data under alternated wetting and drying irrigation regimes. Jing *et al*. (2007) calibrated a set of parameters using data from three different nitrogen levels, and evaluated it with data from other two different nitrogen levels. Amiri and Rezaei (2010) evaluated the ORYZA model in variable irrigation and fertilizer regimes using data in the 2007 growing season for calibration, and the data in 2005 and 2006 seasons for validation in Iran.

Yet, the parameters in ORYZA model varied among different rice genotypes or varieties, different cultivation and meteorological conditions. Recently, Hao *et al*. (2013) presented six groups of treatment specific ORYZA parameters for two rice varieties with three different planting dates in Anhui, east China. And Han *et al*. (2013) calibrated the regional specific ORYZA parameters with data in Nanjing and Xuancheng and analyzed the difference in parameters between both sites. Other than rice varieties, cultivation practices (i.e. irrigation and N treatments) also resulted in difference in calibrated ORYZA parameters. For example, Sailaja *et al*. (2013) calibrated treatment specific parameters of crop development rates in different crop stages (DVRJ, DVRI, DVRP and DVRR) for each of the three rice varieties based on data under different N levels. But to our knowledge, there was no result on the variability of parameters among different irrigation or water-nitrogen treatments, as well as on the cross-treatments validation of the parameters.

Therefore, parameters of ORYZA (v3) were calibrated based on data of rice production collected from four different water and nitrogen treatments, to interpret the variability of treatment specific calibrated parameters of ORYZA (v3), and to test the performance of each treatment specific calibrated parameters in simulating rice production under different water-nitrogen treatments by cross treatments validation.

Materials and Methods

Experiment Description

Field experiments were conducted in 2012 and 2013 rice seasons at Kunshan irrigation and drainage experiment station (31°15′15″N, 120°57′43″E) in east China. The study area has a subtropical monsoon climate, with an average annual air temperature of 15.5°C, a mean annual precipitation of 1,097.1 mm. The soil in rice field is dark-yellow hydromorphic paddy soil, with soil texture of clay. The rice, variety of Nanjing 46 (Japonica), was transplanted with the row space of 0.23 m and plant space of 0.16 m on June 29th in 2012 and June 27th in 2013. It was harvested on October 25th in both 2012 and 2013.

Two irrigation treatments (flooding irrigation FI and non-flooding controlled irrigation NFI) have been designed with two different N fertilizer treatments for each irrigation treatment (farmers' fertilization practice FFP, and site specific nitrogen management SSNM). These treatments were abbreviated as FF (FI+FFP), FS (FI+SSNM), NFF (NFI+FFP) and NFS (NFI+SSNM), respectively.

In FI paddies, 30–50 mm water was always maintained after transplanting, except in the later tillering and the yellow maturity period. In NFI paddies, 5–25 mm ponded water was kept during the first 7–8 days after transplanting (DAT) in regreening, or during the periods for pesticide and fertilizer applications or for rainwater harvesting in other stages. For other circumstances, irrigation in NFI paddies was applied to saturate the soil when the soil moisture measured by time-domain reflectometry (TDR, Soil moisture, USA) was approaching the lower thresholds for irrigation. Detailed information including the root zone soil water content criteria for NFI irrigation can be found in reference by Xu *et al*. (2012). Information about fertilization in both FFP and SSNM treatments was listed in Table 1.

Field Measurement

Soil bulk density, particle size distribution, soil water characteristic curve, and contents of organic matter, nitrate nitrogen, ammonium nitrogen, phosphorus and pH were determined for soil samples collected before transplanting from 0–10 cm, 10–20 cm and 20–40 cm depth. During field experiment, air temperature (*Ta*), relative humidity (*RH*), atmospheric pressure (P_a), sunshine hours (*n*), wind speed (*V*) and precipitation (*Pr*) were recorded every 30 min by an automatic meteorological station (WS-STD1, DELTA-T, UK). Plant tiller dynamics and plant height were measured every five days. Three plants were sampled every ten days to determine the leaf area, and biomass accumulation in parts of root, stem (with sheath), leaf and panicle (if available). Irrigation water volume was recorded by the water gauge installed at the water supply pipes for each plot, drainage was calculated as the change in water depth prior or after drainage.

Model Calibration and Cross Validation

The most updated version of ORYZA (v3), which was published in 2013 and is a successor of ORYZA2000, used in current research. The inputs of ORYZA include the crop properties, cultivation practice, soil properties, and daily meteorological data. The outputs of the model include the biomass of different parts, leaf area index and yields.

In the ORYZA model, DVS was used to describe the development of rice crop, with values of 0, 0.4, 0.65, 1.0 and 2.0 for the start of the basic vegetative phase, photoperiod-sensitive phase, panicle initiation, flowering and physiological maturity date, respectively. Before application of the model, calibration of the model parameters based on field measurements is critical. There are many parameters in ORYZA to be calibrated for rice growth simulation, which are associated with geno-types, meteorological and soil conditions and cultivation practice. Some of those crop parameters are generic and can be used for all varieties. However, some parameters and functions should be calibrated specifically according to the specific variety and environment conditions, namely development rates, partitioning factors, relative leaf growth rate, specific leaf area, leaf death rate, and fraction of stem reserves (Bouman *et al*., 2001).

In current research, the ORYZA (v3) was firstly calibrated based on data from each treatment in 2012, and then validated based on data from same treatment in 2013. The total above ground biomass (WAGT) and its partition in different parts (green leaves biomass, WLVG; stems biomass, WST; panicles biomass, WSO), and leaf area index (LAI) were used for model calibration and validation. Base on the analysis of variability of the treatment specific parameters, cross treatment validation were conducted by modelling the rice production for other three treatments in 2013 with each group of the treatment specific parameters.

Statistical Analysis

Consistency between the simulated (either for calibration, validation or cross treatments validation) and observed values was evaluated by using several statistical indexes, namely coefficient of determination (R^2) and the normalized root mean square error (RMSEn) (Kobayashi and Salam, 2000; Gauch *et al*., 2003). The closer the R^2 to 1 and the lower of RMSEn is the better performance of the model. Coefficient of variation (CV) was used to evaluate the variability of treatment specific calibrated parameters among different treatments, range (R) and standard deviation (STD) in calculated daily biomass were used to evaluate the uncertainty in simulated biomass (WAGT and WSO) caused by using four different treatment specific calibrated parameters in ORYZA (v3) model.

$$R^2=\frac{\left(\sum_{i=1}^{N}\left(X_i-\frac{1}{N}\sum_{i=1}^{N}X_i\right)\left(Y_i-\frac{1}{N}\sum_{i=1}^{N}Y_i\right)\right)^2}{\sum_{i=1}^{N}\left(X_i-\frac{1}{N}\sum_{i=1}^{N}X_i\right)^2-\sum_{i=1}^{N}\left(Y_i-\frac{1}{N}\sum_{i=1}^{N}Y_i\right)^2} \quad (1)$$

$$RMSEn=100\%\times\frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(Y_i-X_i)^2}}{\frac{1}{N}\sum_{i=1}^{N}X_i} \quad (2)$$

$$CV=100\%\times\frac{\sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(x_j-\frac{1}{n}\sum_{j=1}^{n}x_j\right)^2}}{\frac{1}{n}\sum_{i=1}^{n}x_j} \quad (3)$$

$$R_i=\max(Y_{ij})-\min(Y_{ij}) \quad (4)$$

$$STD_i=\sqrt{\frac{\sum_{j=1}^{n}\left(Y_{ij}-\frac{1}{n}\sum_{j=1}^{n}Y_{ij}\right)^2}{n-1}} \quad (5)$$

Where X_i and Y_i is the observed value and the corresponding simulated value, N is the number of the value, x_j is the treatment specific calibrated parameter, n is the number of the calibrated parameter datasets or treatments, (n =4); Y_{ij} is the model value, in which i is the number of day begin with the transplanting and j denotes result is calculated based on one set of specific treatment specific calibrated parameter, j = 1-4.

Results

Treatment Specific Model Calibration and its Performance

Based on data from each treatment in 2012, ORYZA (v3) were calibrated treatment-specifically, and then validated based on data in 2013. For model calibration, the determined coefficients R^2 are higher than 0.85 and RMSEn values between the observed and simulated results for each variable from each treatment were acceptable, with the largest RMSEn as 17.47, 23.77, 20.76 and 15.80% for NFF, NFS, FF and FS treatments (Table 2). Fig. 1 shows the simulated and observed biomass for validation data of each treatment in 2013 rice season. Generally, all the R^2 were higher than 0.83, but the errors in simulation results increased compared with results for the model calibration.

Treatment Specific Calibrated Parameters

The parameters of ORYZA (v3) were firstly calibrated treatment specifically (Table 2). Compared the treatment specific calibrated parameters of ORYZA (v3) among different water and nitrogen treatments, there was no significant difference in development rates during vegetative growth stage (DVS = 0~0.4). The growth rates under FFP were frequently higher than SSNM. Yet, in the panicle initiation stage (DVS = 0.65~1.0), development rates of rice under NFI or SSNM were a little larger than FI or FFP.

At stage of DVS=0.00 or 0.25, partitioning factor to leaves under NFI was lower than FI, it indicated that ratio to sheath (no stem in this stage) is larger under NFI. For stage of DVS =0.50 or 0.75, more sheath and stem biomass accumulation in former stages favored the growth of green leaves in NFI field, so the partitioning factor to leaf was larger than FI.

Table 1: Fertilizer application for farmers' fertilization practice (FFP) and site specific nutrient management (SSNM) treatments (kg ha^{-1})

Year	Treatment	Base fertilizer	Tillering fertilizer	Strong seedling fertilizer	Panicle fertilizer	Total nitrogen
2012	FFP	375.0CF (60.0) [a)]	350.8AB (60.1)	225.9U(104.4)	224.9U(103.9)	328.4
	SSNM	264.4CF(42.3)	265.9AB(45.2)	162.3U(75.0)	113.6U (52.5)	215.0
	Date	29 Jun	4 Jul, DAT=6[b)]	13 Jul, DAT=15	3 Aug, DAT=36	-
2013	FFP	281.3CF (45.0) [a)]	376.5AB (64.5)	263.6U(121.8)	188.3U(87.0)	318.3
	SSNM	264.4CF(42.3)	265.9AB(45.2)	162.3U(75.0)	113.6U (52.5)	215.0
	Date	27 Jun	2 Jul, DAT=6	20 Jul, DAT=24	10 Aug, DAT=44	-
	Note	Incorporated	Top dressing	Top dressing	Top dressing	-

a) CF is compound fertilizer (N, P_2O_5 and K_2O contents are 16%, 12% and 17%). AB is ammonium bicarbonate (N content is 17%). U is urea (N content is 46.2%). Data in the brackets is the N rate
b) DAT is days after transplanting

Table 2: Treatment specific calibrated parameters values of development rates and biomass partitioning factors, its coefficient of variation (CV) and the ORYZA2000 model performance for calibration data in 2012 or validation data in 2013 rice season. The parameters in Changshu and Nangjing were calibrated by Zhang *et al*. (2007) and Han *et al.* (2013), respectively

	DVS	NFF	NFS	FF	FS	CV (%)	Changsu (Zhang *et al*. 2007)	Nanjing (Han *et al*. 2013)
Development rates	0~0.4	0.000482	0.000473	0.000498	0.000493	2.30	0.000518	0.000488
	0.4~0.65	0.000758	0.000758	0.000758	0.000758	0.00	0.000723	0.000758
	0.65~1.0	0.000751	0.000798	0.000720	0.000721	4.90	0.000735	0.000687
	1.0~2.0	0.001803	0.001813	0.001861	0.001887	2.16	0.001562	0.001998
Biomass partitioning factors (leaf /stem/panicle)	0.00	0.40/0.60/0.00	0.40/0.60/0.00	0.40/0.60/0.00	0.40/0.60/0.00	0/0/ -	0.60/0.40/0.00	-
	0.25	0.45/0.55/0.00	0.43/0.57/0.00	0.49/0.51/0.00	0.47/0.53/0.00	5.61/4.78/ -	-	-
	0.50	0.43/0.57/0.00	0.40/0.60/0.00	0.39/0.61/0.00	0.40/0.60/0.00	4.28/2.91/ -	0.60/0.40/0.00	-
	0.75	0.44/0.56/0.00	0.48/0.52/0.00	0.42/0.58/0.00	0.42/0.58/0.00	6.43/5.05/ -	0.30/0.70/0.00	-
	1.00	0.00/0.38/0.62	0.00/0.37/0.63	0.00/0.42/0.58	0.00/0.41/0.59	- /6.03/3.93	0.00/0.40/0.60	-
	1.20	0.00/0.00/1.00	0.00/0.00/1.00	0.00/0.00/1.00	0.00/0.00/1.00	- / - / -	0.00/0.00/1.00	-
	2.50	0.00/0.00/1.00	0.00/0.00/1.00	0.00/0.00/1.00	0.00/0.00/1.00	- / - / -	0.00/0.00/1.00	-
Calibration								
RMSEn and R^2 of WAGT		9.33/0.9964	8.56/0.9919	11.36/0.9893	9.43/0.9854			
RMSEn and R^2 of WSO		13.62/0.9903	13.80/0.9918	14.76/0.9978	12.78/0.9889			
RMSEn and R^2 of WST		11.67/0.9396	13.47/0.8499	14.77/0.9075	11.92/0.9519			
RMSEn and R^2 of WLVG		10.46/0.8785	17.88/0.9016	15.59/0.9091	15.80/0.9084			
RMSEn and R^2 of LAI		17.47/0.9319	23.77/0.8920	20.76/0.9478	13.45/0.9326			
Validation								
RMSEn and R^2 of WAGT		14.22/0.9817	17.90/0.9723	10.88/0.9886	12.08/0.9878			
RMSEn and R^2 of WSO		16.73/0.9928	11.66/0.9993	11.79/0.9899	15.74/0.9909			
RMSEn and R^2 of WST		19.00/0.9382	27.35/0.8296	25.43/0.9725	14.53/0.9677			
RMSEn and R^2 of WLVG		25.25/0.8498	32.05/0.9272	16.77/0.9817	24.77/0.9451			
RMSEn and R^2 of LAI		25.84/0.8629	26.71/0.8665	18.53/0.9024	20.65/0.9041			

CV (%): coefficient of variation; RMSEn (%): normalized root mean squared error between simulated and measured values; R^2: coefficient of determination

And when DVS =1.0, dry matter partitioning to panicle in NFI was larger than FI. It indicated, NFI enhanced the accumulation and partitioning of biomass to panicle in reproductive stage. For different nitrogen treatments, partitioning factors to green leaves (DVS = 0.00, 0.25 or 0.50) under SSNM was lower than FFP in most cases. When DVS was 1.0, partitioning factors to panicles under SSNM treatment was larger than FFP.

Cross Treatments Validation

Cross treatments validation were done by applying the parameters calibrated for each one specific treatment to model the rice growth and biomass accumulation in other three treatments for validation data set in 2013. Two important variables, total above ground biomass (WAGT) and panicle biomass (WSO), were selected out for discussing the performance of different parameters in the cross treatments validation and the uncertainty.

Generally, based the different treatment specific parameters, the ORYZA (v3) model performed almost the same in modelling the total above ground biomass accumulation (Fig. 2). The simulated results of WAGT varied in the same pattern among results simulated based on different treatment specific parameters, and matched the observed values well. For each specific treatment, there is no significant difference in WAGT values simulated by different treatment specific parameters. All the four group treatment specific parameters performed better in simulating the WAGT accumulation for FF treatment than for other three treatments.

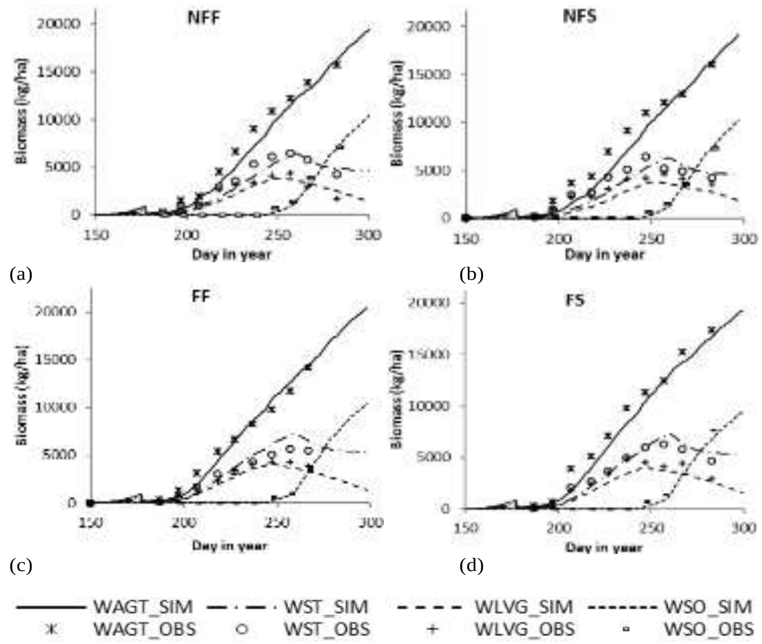

Fig. 1: Simulated versus observed total above ground biomass (WAGT) and its partitions in different parts (green leaves biomass, WLVG; stems biomass, WST; panicles biomass, WSO) for the validation data set in 2013 under NFF, NFS, FF and FS treatments

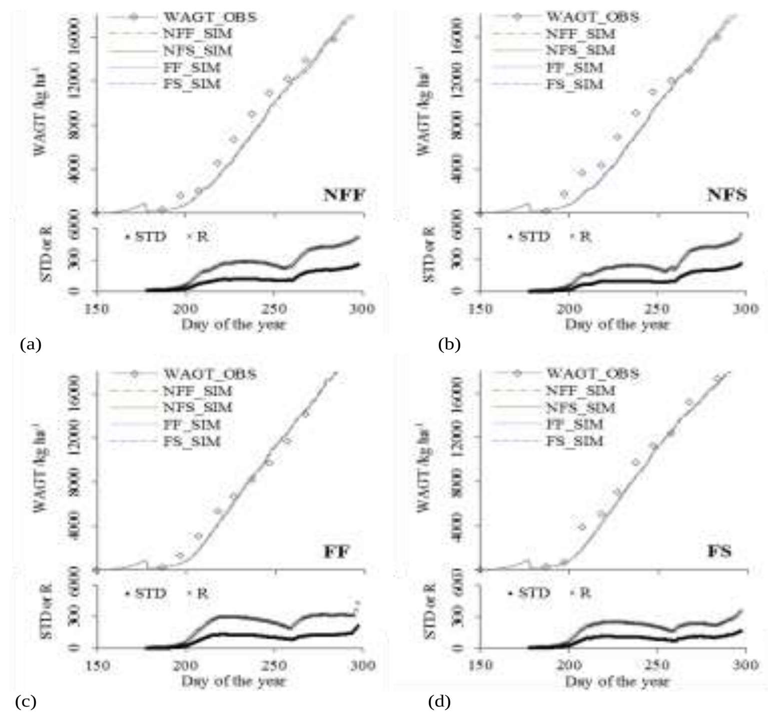

Fig. 2: Simulated and observed total above ground dry biomass (WAGT) in each treatment (NFF, NFS, FF or FS) using treatment specific calibrated parameters from different treatments, together with the daily range [R_i: $\max(Y_{ij})$–$\min(Y_{ij})$] and standard deviation (STD) of the simulated results

The simulated WAGT for treatments other than FF were mostly lower than the observed values, with the most significant underestimation occurred in NFS treatment. In indicated again that, the ORYZA (v3) model might be too sensitive to water and nitrogen stress, and overestimated the reduction in WAGT accumulation

Table 3: Linear regressions, coefficient of determination (R^2) and normalized root mean square error (RMSEn) between the observed WAGT or WSO and the simulated result by ORYZA2000 with different treatment specific calibrated parameters in cross validation

Variables	Statistics	Specific parameters	NFF	NFS	FF	FS
WAGT	Y=ax+b	NFF	y=1.01x-899.1	y=1.06x-1496.4	y=1.12x-915.8	y=1.00x-718.9
		NFS	y=1.01x-931.9	y=1.07x-1528.6	y=1.11x-921.5	y=1.00x-736.3
		FF	y=1.00x-769.7	y=1.04x-1355.4	y=1.11x-787.9	y=0.99x-573.4
		FS	y=0.99x-882.9	y=1.04x-1458.9	y=1.10x-905.1	y=0.99x-715.3
	R^2/RMSEn	NFF	0.9817/14.22	0.9725/17.79	0.9878/11.62	0.9880/11.12
		NFS	0.9813/14.44	0.9723/17.90	0.9872/11.48	0.9875/11.67
		FF	0.9852/13.30	0.9776/16.64	0.9886/10.88	0.9894/10.49
		FS	0.9822/15.62	0.9736/18.62	0.9871/11.19	0.9878/12.08
WSO	Y=ax+b	NFF	y=1.06x-666.4	y=1.08x-602.2	y=1.05x-216.4	y=0.95x-312.0
		NFS	y=1.08x-664.0	y=1.10x-594.1	y=1.11x-262.1	y=0.97x-289.5
		FF	y=1.04x-607.0	y=1.05x-543.1	y=1.05x-192.5	y=0.94x-253.8
		FS	y=1.04x-630.9	y=1.06x-567.9	y=1.06x-226.4	y=0.96x-288.8
	R^2/RMSEn	NFF	0.9928/16.73	0.9997/12.50	0.9885/13.13	0.9931/16.25
		NFS	0.9961/14.53	0.9993/11.66	0.9899/13.75	0.9874/15.07
		FF	0.9933/16.48	0.9996/12.27	0.9899/11.79	0.9919/16.59
		FS	0.9937/17.04	0.9996/12.83	0.9905/12.55	0.9909/15.74

Statistical indexes values in shadowed cell were the validation results simulated by the calibrated parameters from the same specific treatment, and the other values were the cross treatment validation result

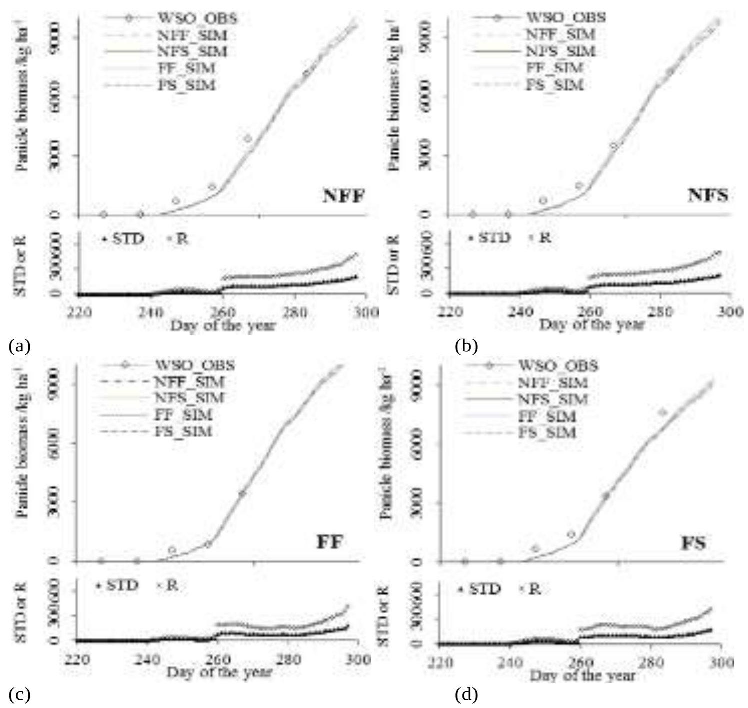

Fig. 3: Simulated and observed panicle dry matter weights (WSO) in each treatment (NFF, NFS, FF or FS) using treatment specific calibrated parameters from different treatments, together with the daily range [R_i: $\max(Y_{ij})–\min(Y_{ij})$] and standard deviation (STD) of the simulated results

under water and nitrogen limited conditions. By analysis Fig. 2, it was hard to figure out that which calibrated parameters performed better than others in the cross validation. However, the statistical analysis (Table 3) indicated that FF calibrated parameters matched best with the most consistent regression linear equations between the simulated and measured WAGT values, and the highest determination coefficient R^2 (from 0.98 to 0.99) and the smallest RMSEn values (from 10.49 to 16.64%).

When it comes to biomass in panicle WSO (Fig. 3), generally, the ORYZA (v3) model is acceptable in modelling the accumulation of WSO. The simulated WSO varied in the same pattern among results simulated based on different treatment specific parameters, and matched the observed values well. All the four group treatment specific parameters performed better in FF and FS treatment than in

NFF and NFS treatments. Among different treatments, the simulated WSO by ORYZA (v3) based on different treatment specific parameters match the observed value well in FF treatment, and mostly lower than the observed results in NFF, NFS and FS. Among different parameter datasets, the simulated WSO based on NFS parameters were the highest, and followed by parameters of NFF, FS, and FF in sequentially. And the parameters from FF and NFS performed better than from FS and NFS in modelling WSO by ORYZA (v3) model. Table 3 indicates linear regressions between observed WSO and simulated by FF parameters is the best among all the four parameters sets, and with the highest determination coefficient R^2 (ranged from 0.98 to 0.99). For statistics of RMSEn, it is smaller for simulated WSO by the NFS calibrated parameters than others, ranged from 11.79 to 16.59%.

Generally, each set of treatment specific calibrated parameters performed well in simulating rice biomass production (both WAGT and WSO) for all the four treatments, with all the errors for cross validation varied within an acceptable narrow range (Table 3). For the results of WAGT, FF calibrated parameters performed slightly better than other treatment specific parameters. Yet for WSO, the four group calibrated parameters underestimated the WSO in the early panicle growth phrase under water or nitrogen limited conditions, and FF and NFS treatment parameters performed a little better. The errors in simulated WAGT and WSO for a specific treatment were enlarged to a certain degree, when it was simulated by parameters calibrated from other three treatments, although the error varied within an acceptable narrow range. For FF treatment, errors of RMSEn in WAGT were enlarged by 6.8, 5.5 and 2.8% when simulated by parameters from other three treatments. And for NFS treatment, errors of RMSEn in WSO were enlarged by 7.2, 5.2 and 10.0%, when simulated by using parameters from other three treatments.

Discussion

Treatment Specific Parameters and its Performance

The treatment specific calibrated parameters of development rates were near the results in Changshu by Zhang *et al*. (2007) or in Nanjing by Han *et al*. (2013). However, biomass partitioning factors is quite different from that in Changshu, especially when the DVS were 0.00 and 0.50, with partitioning factor to stems (with sheaths) are frequently higher than to green leaves in Kunshan. The difference between results in Kunshan and Changshu might be caused by the difference in fertilization management.

In the early rice growth stage (DVS = 0.0~0.5), development rates or partitioning factors to green leaves under water or nitrogen sufficient conditions were higher than deficit conditions, these were supported by Liang *et al*. (2015) who found the plant dry matter increased with the increasing N level, Dingkuhn and Gal (1996) who found that early drainage reduced dry matter but enhanced compensatory mobilization of stem reserves and Krishnan and Nayak (2000) who found that with the increase in nitrogen inputs, partitioning factors to green leaves increased.

When DVS = 0.65~1.0, development rates or partitioning factors to green leaves under water or nitrogen deficit conditions were higher than sufficient conditions. It supported by the result of Ye *et al*. (2013) who found alternate wetting and drying irrigation enhanced the panicle accumulation and partitioning in reproductive stage and Wang *et al*. (2007) who found that SSNM increased rice yield significantly compared to FFP. That might be due to the deep and healthy root system under mild or moderate water deficit which resulted in a compensation effect (enhanced biomass production and delayed canopy senescence) and biomass production in panicle forming stage (Peng and Xu, 2011).

The treatment specific calibrated parameters performed much better for FF treatment than other treatments. For other three treatments, the ORYZA (v3) model under estimated above ground biomass production and components of WLVG, WST and WSO in most of the rice season. The highest RMSEn values under the NFF, NFS and FS treatments were 25.84, 32.05 and 24.77% for WLVG or LAI. The higher error for model validation than calibration of ORYZA (v3) on individual validation data set was reported almost for all case studies, the highest error of RMSEn is acceptable for validation data set in current research, and fall in the range or much lower than results reported in other case studies (Bouman *et al*., 2006; Amiri, 2008; Artacho *et al*., 2011; Soundharajan and Sudheer, 2013). The underestimation for rice biomass production in treatment other than FF indicated that the ORYZA (v3) model might be too sensitive to water and nitrogen stress, and rice might can adapt itself to a certain degree of water stress (Belder *et al*., 2004; Lu *et al*., 2016) or nitrogen stress (Wang *et al*., 2007; Pampolino *et al*., 2007).

Variation of Treatment Specific Calibrated Parameters

Variability of treatment specific calibrated parameters was listed in Table 2. There has no significant difference in the development rates among different treatments, with all CV values less than 5%. The biggest CV of 4.90% occurred in the stage from panicle initiation to flowering (DVS = 0.65~1.0). There are very few results on parameters variability of ORYZA (v3) model. Only Sailaja *et al*. (2013) reported six groups of calibrated development rates for two rice varieties (Ajaya and BPT 5204, both Indica rice variety) under three nitrogen levels (0, 100 and 200 kg N ha^{-1}). Base on their results, the maximum CV values were calculated as 4.99% of DVRI for Ajaya and 9.9% of DVRR for BPT5204. The degree of variation in development rates among water-nitrogen treatments for variety of Nanjing 46 is almost the same to variety of Ajaya under different nitrogen levels, and is lower than that for variety of BPT5204.

Biomass partitioning factors also varied among different water and nitrogen treatments (Table 2). Generally, the cross treatment variability in parameters of biomass partitioning factors is larger than that for crop development rates. For DVS = 0.25, coefficient of variation CV in partitioning factors to green leaves and stems (with sheaths) were 5.61 and 4.78%. Then for DVS = 0.5, the CV reduced to 4.28 and 2.91%, respectively. When DVS = 0.75, CV in partitioning factor to green leaves or stems (with sheaths) were the highest, with CV values of 6.43 and 5.05%. When DVS = 1.0, when biomass production was partition into stems (with sheaths) and panicles, CV in partitioning factor to stem and panicle were high (6.03 and 3.93%).

Uncertainty in Biomass Simulation Caused by Variation in Treatment Specific Parameters

There will be a certain degree of uncertainty in rice biomass simulation when the model parameters come from different water and nitrogen treatments. The uncertainty range R and standard deviation STD of simulated WAGT caused by variation in treatment specific calibrated parameters were plotted in Fig. 2, and of WSO in Fig. 3. As shown in Fig. 2, the STD and R of simulated WAGT varied in a similar pattern among different treatment. Both STD and R were very low at the beginning of rice season, and increased along with crop development. There were twice remarkable increased during DVS= 0.25–0.40 and DVS= 0.96–1.27. In the NFF treatment (Fig. 2a), the STD and R values of simulated WAGT increased from 0 to 81.0 and 186.2 kg ha^{-1} before the 210th day of year (DVS = 0.40). And then STD and R increased slowly to 112.5 and 260.2 kg ha^{-1} until 222th day of year (DVS = 0.54). At 256th day of year (DVS = 0.96), reduced to 101.4 and 209 kg ha^{-1} before it increased rapidly to 255.4 and 509 kg ha^{-1} at the day 297th (DVS = 2.0). Comparison among different treatments indicated that the STD and R of simulated WAGT in FF and FS treatment are generally lower than that in NFF and NFS treatments. When it comes to simulated WSO (Fig. 3), the STD and R also varied in a similar pattern among different treatments. Both STD and R were very low before it increased abruptly at the 259th day of year (DVS = 1.0), and then increased gradually to the end of rice season. In NFF treatment (Fig. 3a), STD and R of simulated WSO were lower than 25.3 and 59.3 kg ha^{-1} before the 259th day of year (DVS = 1.0), and increased to 80.1 and 186.2 kg ha^{-1} one day latter. Then increased gradually to the maximum of 210.0 and 477.3 kg ha^{-1} at the 297th day of year. Comparing among different treatments indicated that the STD and R of simulated WAGT in FF and FS treatment are generally lower than in NFF and NFS treatments.

Conclusion

The ORYZA (v3) model, calibrated specifically by treatment data, was applied to model the rice biomass accumulation for Japonica rice variety of Nanjing 46 under different water and nitrogen conditions in east China. Generally, the treatment specific calibrated ORYZA (v3) model is accurate in modelling rice biomass accumulation in the exact specific treatment, and it performed a little better under potential condition than water or nitrogen limited condition, which indicated that the ORYZA (v3) model might be too sensitive to water and nitrogen stress. Variability of treatment specific calibrated parameters (development rates and partitioning factors) for ORYZA (v3) model was low by calculating the coefficient of variation, with maximum CV of 4.90% for development rates in the stage from panicle initiation to flowering (DVS=0.65~1.0), and maximum of 6.43% for biomass partitioning factor to leaf at DVS=0.75. By the cross treatment validation, it was hard to figure out the difference among the WAGT simulated by each set of calibrated parameters, with the FF calibrated parameters performed slightly better than others according to the statistical analysis. And for WSO, the four group calibrated parameters underestimated the WSO in the early panicle growth phrase under water or nitrogen limited conditions, and FF and NFS treatment parameters performed a little better according to the statistical analysis. The errors in simulated WAGT and WSO for a specific treatment were enlarged in a certain degree, when it was simulated by parameters calibrated from other treatments. It indicated that there will be a certain degree of uncertainty in rice biomass production simulation by ORYZA (v3) model with different treatment specific calibrated parameters. The uncertainty index of STD and R (for WAGT or WSO simulated by different calibrated parameters) varied in a similar pattern among different treatment, with the values in FF and FS treatment are generally lower than in NFF and NFS treatments.

Acknowledgements

This research was financially supported by National Key Research and Development Plan (No. 2016YFC0400103), the Innovative Young Scholar Project of State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering (No. 20145027912), Fundamental Research Funds for the Central Universities (No. 2015B14914), the Advanced Science and Technology Innovation Team in Colleges and Universities in Jiangsu Province and A Project Funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions.

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(Received 20 March 2017; Accepted 05 September 2017)