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RICE GROWTH AND NITROGEN UPTAKE SIMULATION BY USING ORYZA (V3) MODEL CONSIDERING VARIABILITY IN PARAMETERS

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ORYZA (v3) model was assessed by four water and nitrogen treatments for variability and uncertainty analysis in rice biomass accumulation and nitrogen assimilation simulation. It was accurate in simulating rice biomass accumulation and nitrogen assimilation with treatment specific parameters and performed relatively better under flooded irrigation with limited nitrogen conditions (FS). Variability in treatment specific calibrated parameters was low and fell within an acceptable range, with highest CV of 11.08% for stem biomass and 18.5% for leaf nitrogen content. Weakness in ORYZA (v3) was exposed when simulated by parameters from other treatments. Cross-validation errors for panicle biomass (WSO), total above-ground biomass (WAGT), amount of nitrogen in leaf (ANLV) or panicle (ANSO) were acceptable. However, WAGT accumulation for FS was identified better than others. For WSO, among all parameters datasets, it performed better for parameters of flooded irrigation with full nitrogen (FF) and FS. Similarly, FS parameter was superior to others in simulating ANLV, whereas, under limited water and nitrogen (NFS) was better for ANSO. The uncertainty index, standard deviation and range varied similarly in different treatments where FS treatment showed lower uncertainty as compared to others. Findings of the current study suggested that ORYZA (v3) model can efficiently be adapted under varying water and nitrogen limited conditions.
Keywords: ORYZA; Uncertainty; cross validation; variability; nitrogen and water limited; Nitrogen content.

INTRODUCTION

Nitrogen (N) is the main nutrient in increasing crop yield (Liu and Diamond, 2008) but mismanagement can result in excess nitrogen loss contributing to environmental pollution in China (Jiao *et al.*, 2016; Ju *et al.*, 2009; Li *et al.*, 2005). Water pollution and sustainability of agriculture are main issues currently (Ju *et al.*, 2009; Jiao *et al.*, 2016; Aleem *et al.*, 2018). For controlling N loss and sustaining high productivity, many field experiments have been done (Deng *et al.*, 2014; Wang *et al.*, 2004). However, experimental trial measurements showed nitrogen use efficiency (NUE characterized as the dry mass efficiency per unit N taken up from soil) lower than 50% in tropic (Baligar *et al.*, 2001) and temperate climates (Carreres *et al.*, 2000). In China traditionally flooded paddy rice, because of rapid N losses through denitrification, ammonia volatilization, leaching and surface runoff, has low N use efficiency (Chen *et al.*, 2017; Zhu and Chen, 2002). Water requirements for lowland rice are relative high but its sustainability is vulnerable to water scarcity (Feng *et al.*, 2007; Brahmanand *et al.*, 2009). To cope with water scarcity, water saving irrigations were applied in rice fields. This illustrates different patterns of both water and nitrogen management for rice.

By lessening the negative effect of nitrogen manure, N utilize productivity must be moved forward which can also lead to increase of rice productivity (Wang *et al.*, 2007). In combination of field trials with crop simulation models are effective gears to enhance the N- fertilizer recommendations by matching the soil N supply with crop N demand. IRRI and Wageningen University and Research Centre developed ORYZA (v3 version) model which is actually generated from ORYZA_W, ORYZA1 and ORYZA_N (Bouman and Laar, 2006), which is able to simulate production and rice growth under various conditions of water and nitrogen (*Feng et al.*, 2007; Li *et al.*, 2005; Belder *et al.*, 2007; Bouman and Laar 2006), also a good tool for future climatic situations (Wang *et al.*, 2017; Luo *et al.*, 2015). Oryza (v3) is the most refreshed adaptation of the model for the reproduction of rice development and was productively utilized for rice potential yield (Espe *et al.*, 2016) enhancement of irrigation scheduling (Sudhir *et al.*, 2011; Xue *et al.*, 2008), management of fertilizers (Boling *et al.*, 2010; Jing *et al.*, 2007) also combined fertilized irrigation regimes (Boling *et al.*, 2011; Amiri and Rezaei, 2010). Crop growth simulation models are often very complicated and require multiple parameters (Saltelli *et al.*, 1999). Because of fluctuation in agro-climatic zones and particular cultivars, the estimation of a large number of these parameters are not decisively known. Additional, some are not being directly measurable (Varella *et al.,* 2010).

Generally, experts calibrated one-year data set for several years (Sudhir *et al.,* 2012; Shuai *et al.,* 2009) or particular treatment (Artacho *et al.,* 2011; Jing *et al.,* 2007; Zhang *et al.,*2007; Amiri and Rezaei, 2010) and evaluated it for different treatments. Oryza was evaluated for simulating rice growth of different genotypes at two latitudes (Cao *et al.,* 2017). Oryza was calibrated for full irrigated treatment and evaluated with alternate drying and wetting irrigation management (Jing *et al.,* 2007; Sudhir *et al.,* 2011). Oryza was evaluated for different nitrogen levels using a set of parameters from other nitrogen levels (Jing *et al.,* 2007). Assessment of Oryza model was done with different fertilizer and irrigation levels taking the data of one crop season and evaluated it with data from two other growing years (Amiri and Rezaei, 2010).

Hence, Oryza model parameters showed variation among various varieties or genotypes of rice and climatic situations. Hao *et al.* (2013) ascertained six gatherings of particular treatment parameters of Oryza for two diverse rice assortments with three distinctive planting dates in Anhui, East China. Han *et al.* (2013) likewise aligned the territorial particular Oryza parameters with information in Xuancheng and Nanjing and examined the contrast between the two locales. However, as far as anyone is concerned there has been no work on the inconstancy of parameters among various water-nitrogen treatments or irrigation also on the parameters for cross-validation. (Xu *et al.,* 2018) recently, assessed few parameters for plant growth rate and biomass partition were calibrated treatment specifically based on biomass accumulation of rice from field with different water and nitrogen management Yet, they failed to calibrate the parameters for nitrogen uptakes and assimilation.

Keeping in view the above narrated facts, the current study was designed with specific objectives to; i) calibrate the Oryza (v3) parameters, for both plant biomass accumulation and nitrogen assimilation, based on the rice production and nitrogen concentration data from various nitrogen and water levels, ii) examine the variability of calibrated parameters of Oryza (v3) for particular treatment, iii) assess the evaluation of Oryza (v3) model for each parameter for simulating rice production under cross validation of treatments.

MATERIALS AND METHODS

***Site Description*:** The experiment was carried out during cropping seasons 2007 and 2008 in the experiment station of irrigation and drainage at Kunshan, China. The experimental site is at 120°57′43″E and 31°15′15″N in the east of China. The region climate is subtropical monsoon. The annual average temperature is 17.5 °C with annual mean precipitation of 1,397.1 mm. This study area has dark-yellow hydromorphic paddy soil and clay in texture (Table 1). Plant material, Japonica derived Jia 04-33 rice variety, was transplanted to the fields on June 27th of 2007 and June 28th of 2008. Plants were 0.16 m apart in each row and row spacing was 0.35 m and 0.18 m (wide-narrow row alternation form). Harvesting was done on October 27th of 2007 and October 25th of 2008.

***Experimental Design*:** Experimental fields were assigned two types of irrigation flooded irrigation (FI) and deficit irrigation (DI) in combination with two levels of nitrogen (farmers' fertilization practice FFP, and specific site nitrogen management SSNM) for each irrigation treatment. These treatments were abbreviated as FF (FI + FFP), FS (FI + SSNM), NFF (DI + FFP) and NFS (DI + SSNM), respectively. Experiments were arranged in 6 plots with three replicates.

After transplanting, 30-50 mm water was always kept in FI paddies, excluding in the last tillering and in yellow maturity periods. During the first 7-8 days after transplanting (DAT) 5-25 mm ponded water was kept for DI paddies or in the periods for insecticide and fertilizer applications. For other situations, DI paddy field was irrigated to saturate the soil when the soil moisture measured by time-domain reflectometry (TDR, Soil moisture, USA) approached the lower thresholds for irrigation. Comprehensive information comprising the root zone soil water content measures for DI irrigation can be found in (Xu *et al.,* 2008). Materials regarding fertilization in both FFP and SSNM treatments are listed in Table 2.

Table 1. Soil properties of experimental site.

Soil Bulk Density	**1.30 g cm^{-3}**
Soil organic matter	21.88g kg^{-1}
Soil nitrogen (TN)	1.03g kg^{-1}
Soil phosphorus (TP)	1.35g kg^{-1}
Soil k:	20.86g kg^{-1}
pH	7.40

***Field Measurement*:** An automated weather station (WS-STD1, DELTA-T, UK) was installed at the experimental site to record data on relative humidity (*RH*), air temperature (*Ta*), sunshine hours (*n*), atmospheric pressure (P_a), precipitation and wind speed (*V*) (*Pr*) each 30 minutes. Similarly, irrigation volume for each plot was measured by water gauge mounted at the water supply pipes. Data on plant height and tiller dynamics has been recorded after each five days. Leaf area was calculated from selected three random plants while from roots, panicles, leaves and stem with sheaths was measured for biomass accumulation. CI 203 leaf area meter was used to measure individual leaf area, and summed for the leaf area index and the total leaf area. Samples of different organs (leaves, stems and panicles) of rice plants were processed by H_2SO_4-H_2O_2 to measure their total nitrogen contents by

Table 2. 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
2007	FFP	802.53CF (120.38) [a)]	112.51U (51.98)	225.0U(103.95)	172.51U(79.70)	356.0
	SSNM	699.87CF(104.98)	101.69U(46.98)	-	155.26U (71.73)	223.5
	Date	25 Jun	3 Jul, DAT=9[b)]	16 Jul, DAT=22	9 Aug, DAT=46	-
2008	FFP	717.0CF (107.55) [a)]	263.64U (121.80)	225.97U(104.40)	150.65U(69.60)	403.35
	SSNM	420.0CF(63.0)	77.92U(36.0)	-	136.36U (63.0)	162.0
	Date	25 Jun	11 Jul, DAT=17	23 Jul, DAT=29	10 Aug, DAT=47	-
	Note	Incorporated	Top dressing	Top dressing	Top dressing	-

CF is compound fertilizer (N, P_2O_5 and K_2O contents are 15%, 15% and 15%). 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 the numbers of days start from transplanted date of each year.

indophenol blue spectrophotometric method. Yield data were taken from each plot at harvesting.

***Model Description, Calibration and Validation ORYZA (V3) Model*:** ORYZA (v3) is the most updated version of Oryza2000 model and was released in 2013 by IRRI Philippines. It simulates with time step of one day, the growth, water balance and development of lowland rice for nitrogen-water limited and potential production scenarios. The model assumes that the crop doesn't undergo any other yield reduction stresses. For explanation of the crop model see Bouman and Laar (2006). Model summary descriptions are given here.

The model simulates daily dry matter (DM) growths in different organs of the plants and rate of phonological developmental stages. By integrating these rates over time DM production and developmental stages are simulated throughout the growing season. The daily canopy CO_2 uptake is derived from the daily leaf area index, temperature and radiation. After subtracting maintenance and respiration requirement daily dry matter accumulation is then calculated. The produced dry matter is distributed among stem leaves panicles using derived factors. The quantity of spikelet at blossoming is gotten from the aggregate yield development over the period from panicle commencement to first blooming. Daily potential nitrogen demand is calculated from dry weight, growth rate and difference between N concentrations of each plant organ. Vegetative organs get their N from N uptake from the soil and panicles get their N by translocation from stems and leaves after flowering. Availability of soil N is simulated with indigenous soil N and applied N fertilizer, without simulating any N modification processes in soil (Van *et al.*, 2003; Bouman and Laar 2006 and Shen *et al.*, 2011).

***Model Parameterization and Evaluation*:** The ORYZA (v3) model was parameterized following Bouman and Laar (2006). For parameterization and evaluation, experimental data of 2008 were parameterized and evaluated with experimental data of 2007. Data of various plant traits, soil properties, cultivation practices, nitrogen contents in different crop organs and weather data (daily basis) were used as input data in ORYZA (v3) model. The model output is comprised of partitioning total biomass into various components; leaf area index; yield; nitrogen content in leaf, stem and panicle. Developmental rates and dry mass partitioning were calculated using DRATES and PARAM of ORYZA (v3) model. The crop parameters calibrated were: developmental rates (DVR), partitioning factors to leaf, stem and storage organs (FLV, FST and FSO), leaf death rate (DRLV) and stem reserves fraction (FSTR). Nitrogen related parameters calibrated were: residual N concentration in leaves and stems (RFNST and RFNLV), maximum and minimum concentration in storage organs (NMAXSO and (NMINSO). The calibrated values were further modified by model fitting (edifying the parameters values till simulated values with good agreement with measure values). This calibration of model parameters based on experimental data is very crucial. Some crop parameters are standard (like for variety IR72) and can be used for all varieties whereas, some parameters are variety and environment specific. For detailed information about calibration see Bouman and Laar (2006). The model was calibrated and validated for parameters including weight of above ground mass (WAGT), weight of panicle (WSO), weight of stem (WST), weight of green leaves (WLVG), amount of nitrogen in leaf (ANLV), amount of nitrogen in stem (ANST) and amount of nitrogen in panicle (ANSO). The cross treatment validation was performed based on the results obtained from variability of each treatment parameters with treatments in 2007.

The determination coefficient (R^2) and root mean square error normalized (RMSEn) was used to evaluate uniformity between observed and simulated values (Feng *et al.*, 2007). Variability among different treatment parameters was assessed by coefficient of variance (CV) whereas, uncertainty in simulated biomass of WAGT, WSO, ANLV and ANSO was estimated through standard deviation (STD) and range (R) by using the following formulas;

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

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

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

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

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

Where X_i is measured and Y_i is simulated value, N is the number of the value, x_j is the calibrated treatment parameter, calibrated dataset or treatment number is denoted by n, (n= 4); model simulated value is Y_{ij}, where i denotes number of day begin with transplanting day while j denotes calculated results based on single set of treatment specific calibrated parameter, j = 1-4.

RESULTS AND DISCUSSION

***Treatment Calibration and Validation of ORYZA (v3)*:** The ORYZA (v3) model was calibrated separately for each treatment using data from 2008 and then validated for 2007 data. Each treatment calibrated parameters of partitioning factors, nitrogen factors and other factors in various stages of rice growth are given in Table 3. The determination coefficient R^2 were higher than 0.8437 for all treatments and RMSEn values were satisfactory for each treatment variable between observed and simulated results. The highest RMSEn values 20.85 %, 30.30 %, 18.60 % and 24.94 % were evident for FF, NFS, NFF and FS treatments, respectively (Table 3). The observed and simulated biomass and nitrogen content by individual crop organs (leaves, stems and panicles) for validation are shown in (Fig. 1A, 1B and 2A, 2B), respectively. The R^2 for each variable were in acceptable range while simulation for nitrogen content in stem validation showed low R^2.

***Variation of Treatment Specific Parameters*:** The partitioning factors to leaves under DI was lower than FI at DVS=0.00, revealed that the ratio to sheath without stem was higher under FI than DI. However, at DVS=0.5 or 0.75, accumulation of sheath and stem for biomass in later stages favored green leaves growth in DI field, therefore leaves partitioning factors were same or larger than FI. The value of DI was larger than FI when dry matter partitioning to panicle at DVS=1.0 was observed. This indicated that DI improved the partitioning and accumulation of biomass to panicle in reproductive stage. Partitioning factors to green leaves under different nitrogen treatments indicated a higher trend in SSNM as compared to FFP throughout the cropping season.

For nitrogen contents in crop, higher FNLV values were observed for FS as compared to other three treatments. Whereas NFF exceeded all other treatments in nitrogen content, when the values for NMAXSO were assessed. For maximum nitrogen content of leaf (NMAXLT) the downward trend across different developmental stages for all treatments were observed. Higher values were revealed for NFF in comparison to NFS, FF and FS at DVS= 0.0 or 0.5. However higher values of nitrogen content were evident for FS at DVS=1.00 to 2.50.

Cross Treatments Validation: The biomass accumulation and nitrogen content calibrated parameters of each treatment were validated on data set in 2007 by cross treatment validation. Important variables like total above ground biomass (WAGT), panicle biomass (WSO), amount of nitrogen in leaf (ANLV) and amount of nitrogen in panicle (ANSO) were selected for evaluating the performance of different parameters through cross treatment validation and their uncertainty.

The ORYZA (v3) model revealed same trend in modelling above ground biomass accumulation based on different treatment parameters (Fig 3). Simulated results based on different specific parameters of WAGT matched the observed values well and varied in the same pattern. Different treatment parameters showed no significant differences in simulated WAGT values. The FS based parameters data set performed better, in simulating WAGT (Table 4). The observed values were mostly lowered than the simulated WAGT for treatments other than FS, however NFS treatment showed significant deviation from the observed values. In cross validation it was difficult to point out which calibrated parameter performed best (Fig.3). Moreover, table 4 indicated the consistency of regression line equation between simulated and observed WAGT values with FS calibrated parameters. The highest determination coefficient R^2 and smallest RMSEn values were 0.99 and 8.12%, respectively.

The observed biomass in WSO (Fig. 4), variation among simulated results performed well with measured values. The performance of all treatment parameters were found better except for NFF, where deviation was observed in the last stages of crop growth. Simulated WSO among cross treatment parameters matched the observed values well in FS followed by NFS, FF and NFF, respectively. Simulated WSO based on FF parameters performed better among different parameters datasets. However, the parameters from FS and NFS were more suitable as compared to FF and NFF in modelling WSO by ORYZA (v3). Similarly, among all the parameters dataset, linear regressions between observed and simulated WSO were found best for FF and FS parameters. The coefficient of determination R^2 for FF and FS parameters ranging between 0.95 and 0.99. For FF calibrated parameters smaller RMSEn were observed for WSO simulation, ranging between 16% and 26.90%.

Table 3. Treatment calibrated parameters values of partitioning biomass factors, its coefficient of variation (CV) and the ORYZA (v3) model performance for calibration data in 2008 or validation data in 2007 rice season. The parameters in Changshu and Nangjing were calibrated by (Zhang *et al.*, 2007).

	DVS	**NFF**	**NFS**	**FF**	**FS**	**CV (%)**	**Changsu**
Biomass	0	0.62/0.38/0.00	0.63/0.37/0.00	0.66/0.34/0.00	0.68/0.32/0.00	4.25/7.81/-	0.60/0.40/0.00
partitioning factors	0.5	0.42/0.58/0.00	0.43/0.57/0.00	0.41/0.59/0.00	0.43/0.57/0.00	2.26/1.65/-	0.60/0.40/0.00
(FLV /FST/FSO)	0.75	0.40/0.60/0.00	0.40/0.60/0.00	0.40/0.60/0.00	0.40/0.60/0.00	-/-/-	0.30/0.70/0.00
	1	0.00/0.55/0.45	0.00/0.51/0.49	0.00/0.57/0.43	0.00/0.44/0.46	-/11.08/5.46	0.00/0.40/0.60
	1.2	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
	2.5	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
	0	0.73	0.78	0.73	0.73	3.36	
FSHTB	0.43	0.53	0.57	0.54	0.53	3.48	
	1	1	1	1	1	-	
	2.5	1	1	1	1	-	
FNLVI		0.028	0.027	0.034	0.039	17.4	
NMAXSO		0.018	0.016	0.017	0.015	7.82	
NMAXLT	0	0.046	0.04	0.046	0.039	8.8	
	0.5	0.046	0.04	0.042	0.039	7.4	
	0.75	0.043	0.027	0.035	0.036	18.5	
	1	0.028	0.024	0.03	0.03	10.1	
	1.2	0.022	0.017	0.019	0.02	10.6	
	2.5	0.015	0.014	0.015	0.015	3.3	
Calibration							
RMSEn and R^2 of WAGT		10.5/0.98	6.58/0.99	9.10/0.98	5.69/0.99		
RMSEn and R^2 of WSO		8.90/0.98	9.24/0.99	18.6/0.97	9.29/0.99		
RMSEn and R^2 of WST		17.4/0.93	14.4/0.92	11.2/0.96	14.6/0.91		
RMSEn and R^2 of WLVG		14.1/0.94	15.1/0.97	15.0/0.90	11.3/0.93		
RMSEn and R^2 of LAI		10.4/0.94	13.9/0.93	18.3/0.88	19.7/0.84		
RMSEn and R^2 of ANSO		20.8/0.98	4.40/0.99	9.12/0.99	10.1/0.99		
RMSEn and R^2 of ANST		8.91/0.95	30.3/0.99	14.3/0.94	24.9/0.84		
RMSEn and R^2 of ANLV		17.1/0.91	14.8/0.95	18.5/0.88	16.1/0.95		
Validation							
RMSEn and R^2 of WAGT		8.94/0.98	18.0/0.99	16.2/0.95	16.5/0.98		
RMSEn and R^2 of WSO		21.8/0.99	17.5/0.94	26.9/0.98	15.4/0.99		
RMSEn and R^2 of WST		10.9/0.97	17.9/0.97	18.0 /0.95	15.3/0.96		
RMSEn and R^2 of WLVG		20.4/0.98	22.7/0.96	23.9/0.91	19.7/0.96		
RMSEn and R^2 of LAI		13.5/0.95	17.1/0.95	10.7/0.98	15.5/0.97		
RMSEn and R^2 of ANSO		29.4/0.95	15.2/0.95	22.5/0.97	35.8/0.98		
RMSEn and R^2 of ANST		17.8/0.78	34.2/0.69	22.5/0.63	20.1/0.80		
RMSEn and R^2 of ANLV		16.3/0.87	23.4/0.97	20.2/0.89	11.9/0.94		

CV(%): coefficient of variation; FLV, FST and FSO: assimilate partitioning factors to leaves, stems and panicle, respectively; FNLV: Initial leaf N fraction (on weight basis: kg N kg-1 leaf), FSHTB: Table of fraction total dry matter partitioned to the shoot, NMAXSO : Maximum N concentration in storage organs (kg N kg-1) , NMAXLT: Table of maximum leaf N fraction on weight basis (kg N kg-1 leaves), RMSEn (%):normalized root mean squared error between simulated and measured values; R^2: coefficient of determination.

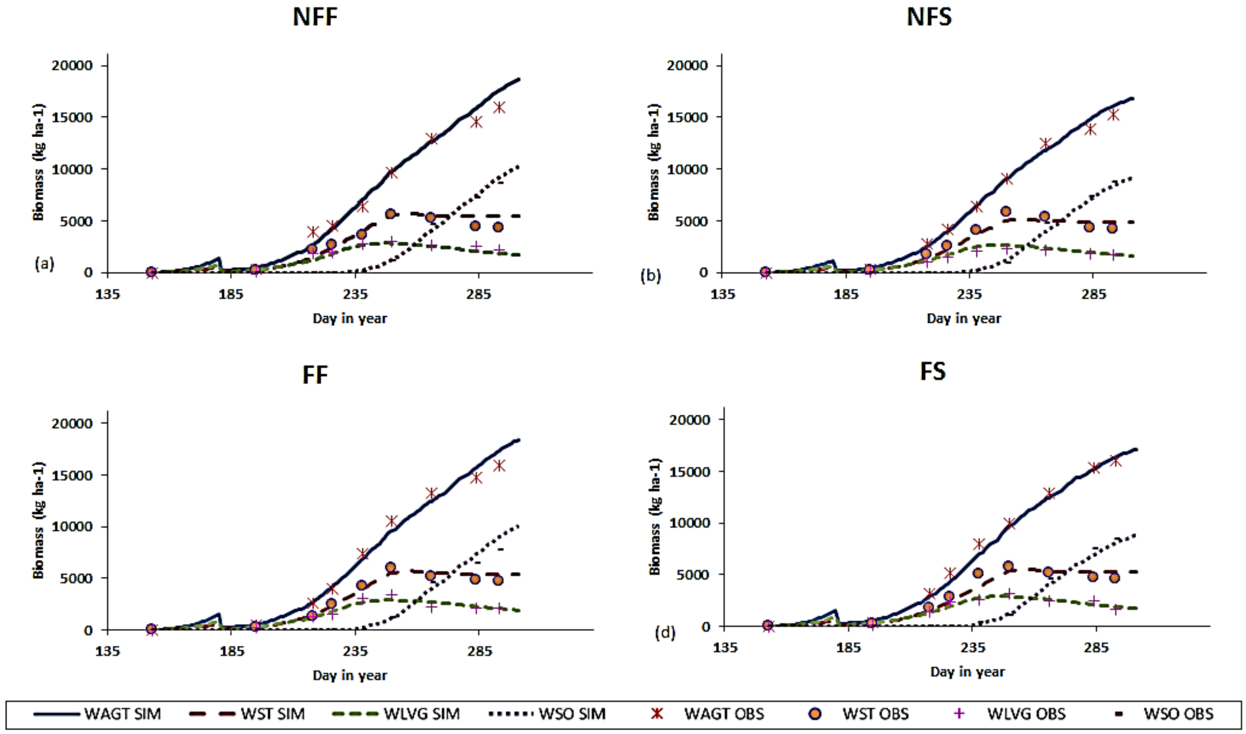

Figure 1A. Simulated versus measured total above ground biomass (WAGT) and its partitions in various parts (; stems biomass, WST; panicles biomass, WSO; green leaves biomass, WLVG;) for calibration (a,b,c,d) 2008 .

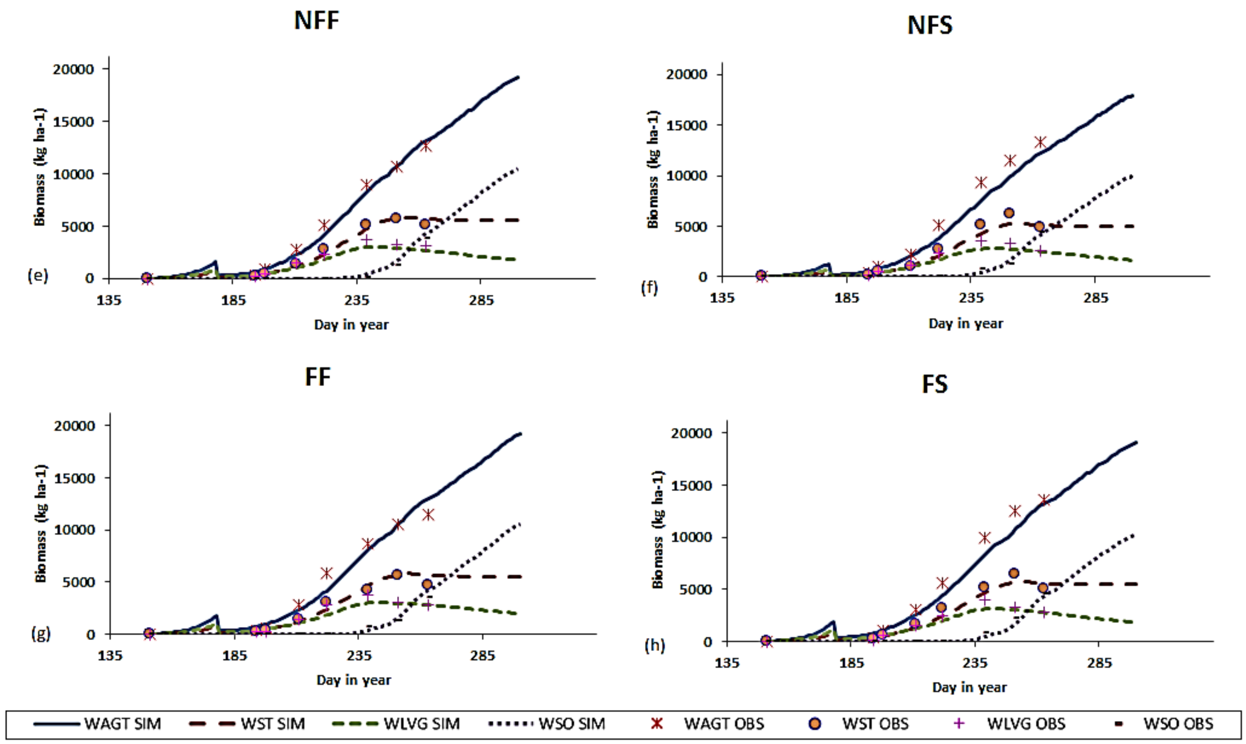

Figure 1B. Simulated versus measured total above ground biomass (WAGT) and its partitions in various parts (; stems biomass, WST; panicles biomass, WSO; green leaves biomass, WLVG;) validation (e,f,g,h) 2007.

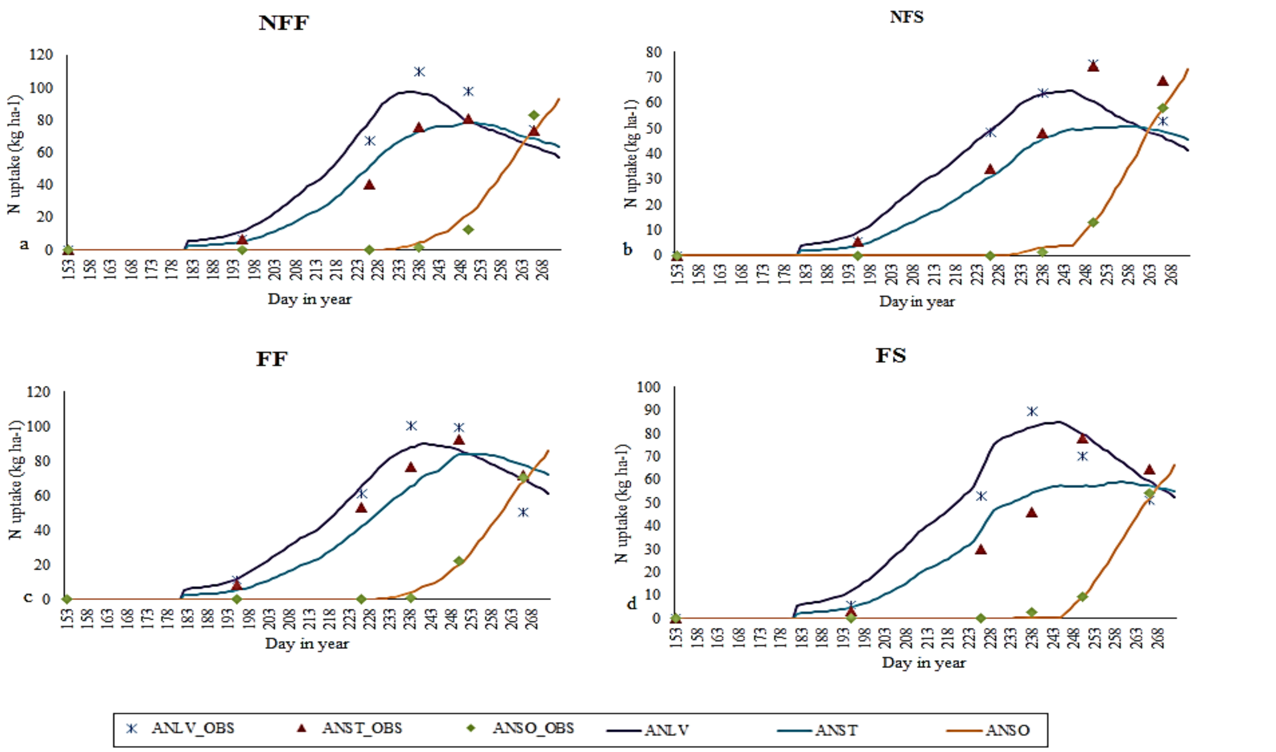

Figure 2A. **Simulated versus measured nitrogen contents in different organs of crop (leaf nitrogen content, ANLV; stem nitrogen content, ANST; panicle nitrogen content, ANSO) for calibration (a,b,c,d) 2008.**

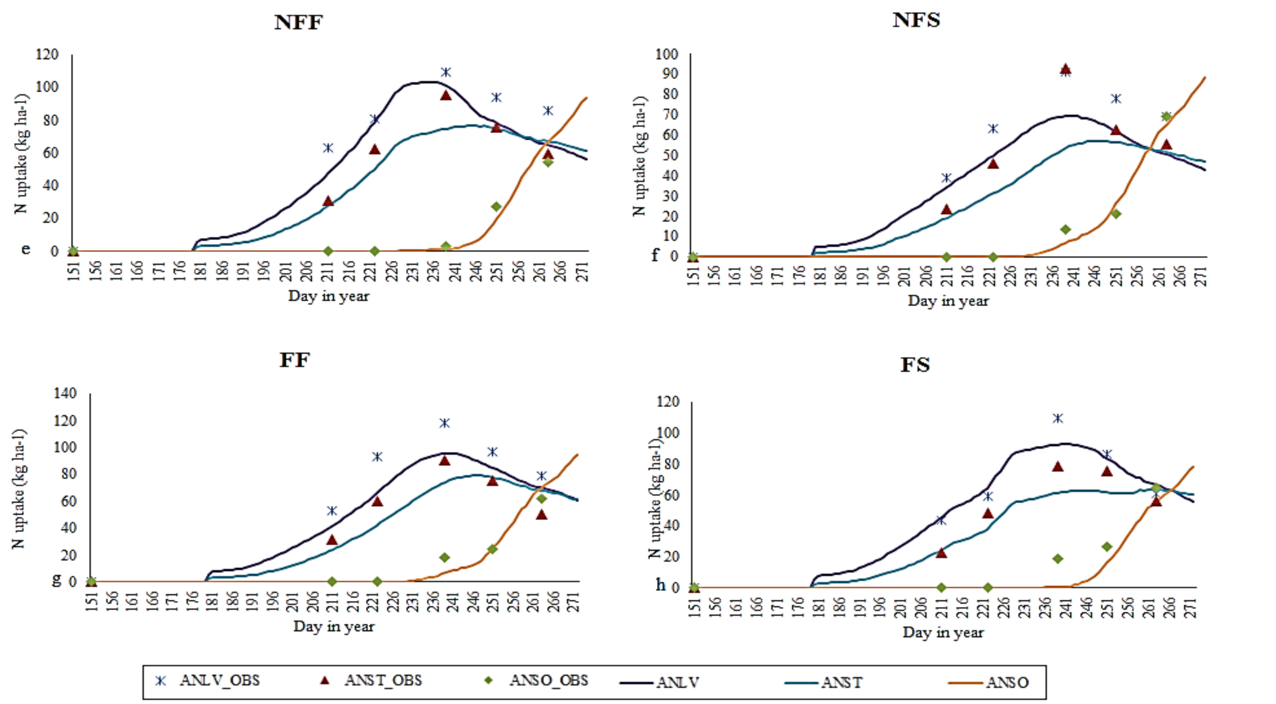

Figure 2B. **Simulated versus measured nitrogen contents in different organs of crop (leaf nitrogen content, ANLV; stem nitrogen content, ANST; panicle nitrogen content, ANSO) for validation (e,f,g,h) 2007.**

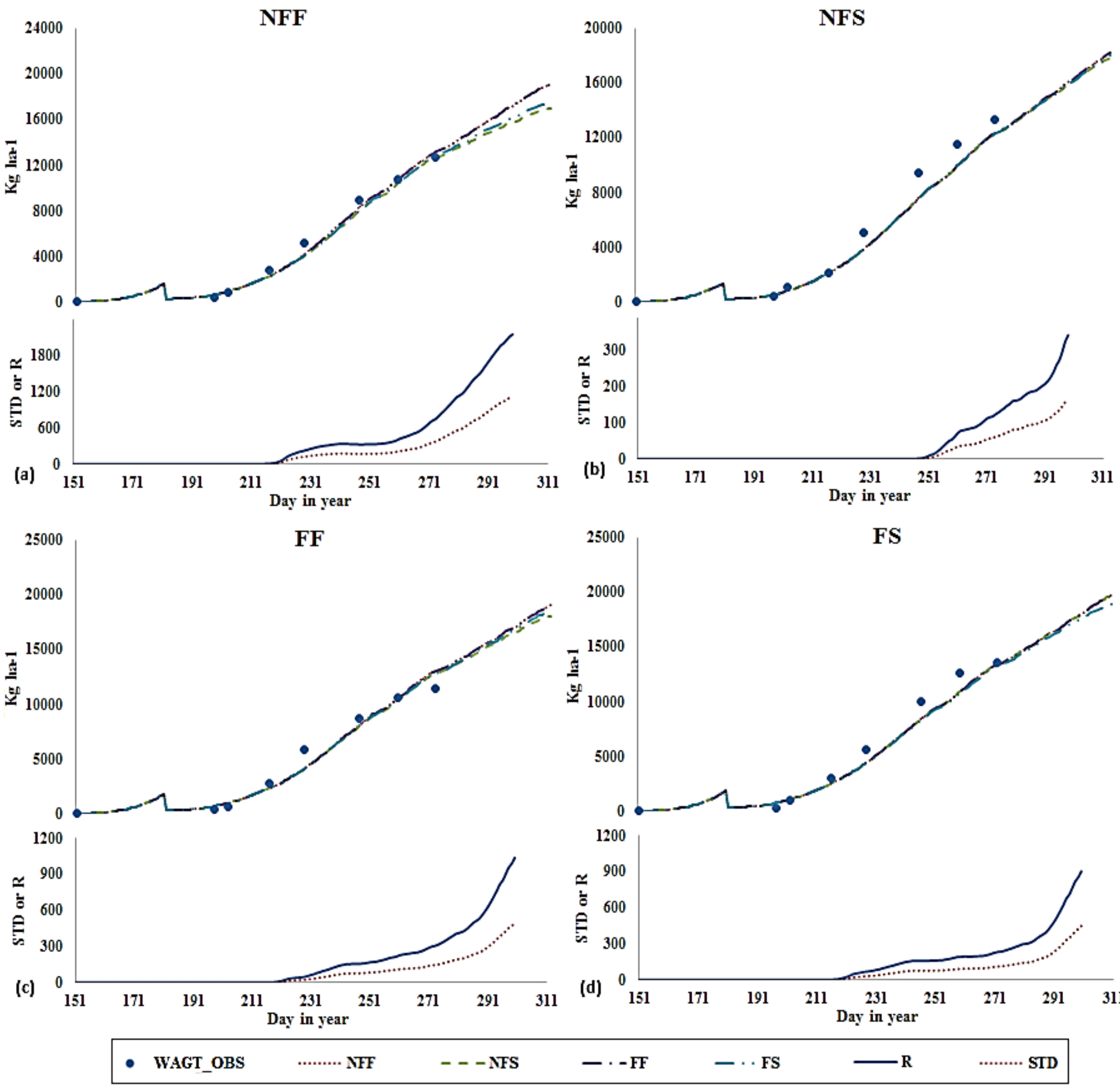

Figure 3. Measured and simulated total above ground dry biomass (WAGT) for different treatments (NFF, FF, NFS and FS) by treatment calibrated parameters from unlike treatments, combine with the standard deviation (STD) and daily range (R_i: max (Y_{ij}) – min (Y_{ij}) of simulated results.

The amount of nitrogen in leaf (ANLV) simulated by ORYZA (v3) model is presented in Figure 5. It illustrates that the performance of treatment parameters was adequate for all parameters dataset. Simulated ANLV values for FS were close to observed values among different treatments based on different treatment parameters and also performed better among different parameters dataset. Likewise, in modelling ANLV by ORYZA (v3) parameters from FS and NFS were relatively appropriate. As per linear regressions observed and simulated values for ANLV were recorded best for FS treatment among different parameters dataset. The coefficient determination R^2 for FS ranged from 0.94 to 0.98 also the smallest RMSEn was recorded for FS varied from 11.85% to 15.32%.

Table 4. Linear regressions, coefficient of determination (R^2) and normalized root mean square error (RMSEn) between the observed WAGT, WSO, ANLV and ANSO and simulated results by ORYZA (v3) with different treatment calibrated parameters in cross validation.

Variables	Statistics	Specific parameters	NFF	NFS	FF	FS
WAGT	Y=ax+b	**NFF**	y=1.01x-282.5	y=0.91x-18.2	y=1.05x-363.7	y=0.87x-202.8
		NFS	y=0.94x-323.0	y=0.88x-113.0	y=0.98x-395.3	y=0.84x-277.7
		FF	y=0.99x-205.1	y=0.90x+35.2	y=1.03x-282.6	y=0.87x-142.3
		FS	y=1.01x-103.9	y=0.95x+113.4	y=1.06x-186.7	y=0.89x-36.3
	R^2/RMSEn	**NFF**	0.98/8.94	0.99/13.5	0.96/16.4	0.98/20.1
		NFS	0.98/13.9	0.99/18.0	0.95/17.5	0.98/24.7
		FF	0.98/9.33	0.99/13.1	0.95/16.2	0.98/19.8
		FS	0.98/8.12	0.99/8.72	0.96/16.6	0.98/16.5
WSO	Y=ax+b	**NFF**	y=1.01x+354.4	y=0.94x+65.2	y=1.32x-300.6	y=1.02x-489.9
		NFS	y=1.01x+374.3	y=0.95x+88.5	y=1.31x-273.9	y=1.02x-467.4
		FF	y=1.01x+310.1	y=0.95x-0.08	y=1.31x-342.6	y=1.02x-537.7
		FS	y=1.05x+354.9	y=1.02x+34.8	y=1.37x-322.2	y=1.06x-533.8
	R^2/RMSEn	**NFF**	0.99/21.8	0.94/17.1	0.98/29.2	0.99/17.4
		NFS	0.997/22.5	0.94/17.5	0.97/29.6	0.99/16.2
		FF	0.99/18.5	0.95/16.3	0.98/26.9	0.99/19.6
		FS	0.99/25.7	0.95/17.2	0.97/33.4	0.99/15.4
ANLV	Y=ax+b	**NFF**	y=1.09x-20.5	y=0.80x+12.1	y=0.82x+1.49	y=0.65x+20.8
		NFS	y=0.786x-13.7	y=0.68x+6.62	y=0.52x+8.06	y=0.49x+17.9
		FF	y=1.18x-30.7	y=0.89x+5.75	y=0.80x+1.11	y=0.66x+20.1
		FS	y=1.19x-27.9	y=1.07x+2.56	y=0.84x+1.39	y=0.67x+21.9
	R^2/RMSEn	**NFF**	0.87/16.3	0.85/9.96	0.98/16.7	0.96/13.4
		NFS	0.96/37.3	0.97/23.4	0.85/40.1	0.91/30.9
		FF	0.97/17.7	0.97/5.33	0.89/20.2	0.89/14.7
		FS	0.97/13.6	0.98/11.8	0.96/15.3	0.94/11.9
ANSO	Y=ax+b	**NFF**	y=1.29x-7.17	y=1.04x-9.01	y=1.39x-19.3	y=0.65x+12.5
		NFS	y=1.21x+0.12	y=0.96x-0.65	y=1.28x-10.3	y=1.23x-11.4
		FF	y=1.25x-0.95	y=1.01x-8.62	y=1.33x-12.4	y=1.26x-19.9
		FS	y=1.12x-3.30	y=0.98x-1.07	y=1.20x-13.8	y=1.16x-18.3
	R^2/RMSEn	**NFF**	0.95/29.4	0.97/24.9	0.97/29.5	0.98/31.7
		NFS	0.97/29.3	0.95/15.2	0.95/21.6	0.96/19.4
		FF	0.96/33.4	0.97/26.8	0.97/22.5	0.98/32.3
		FS	0.95/18.9	0.95/15.2	0.97/24.5	0.98/35.8

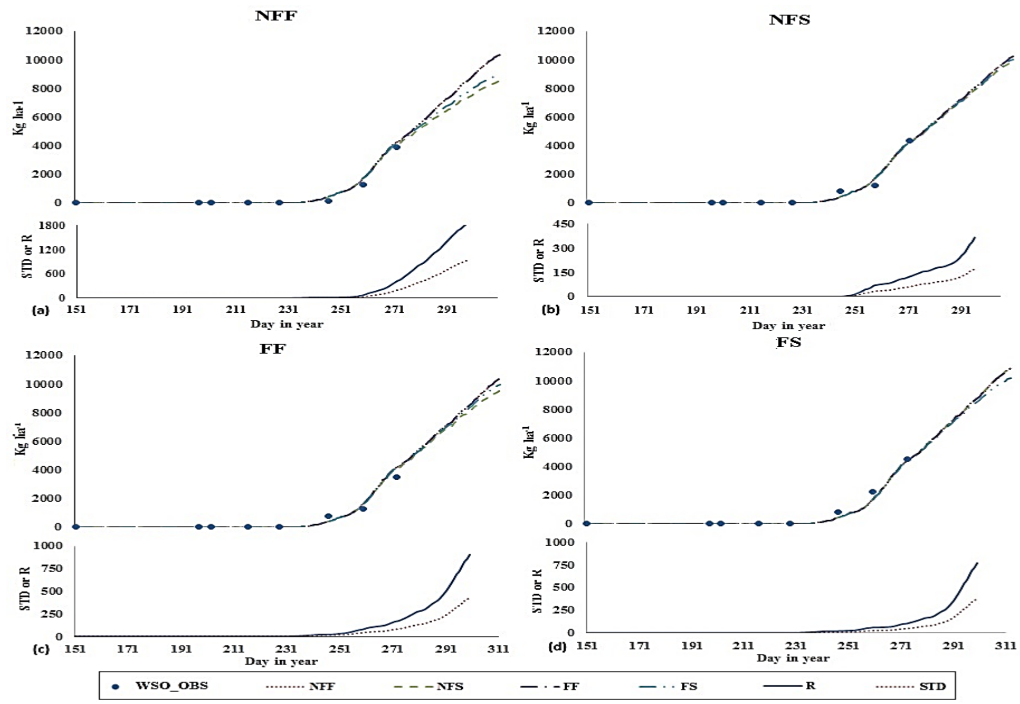

Figure 4. Measured and simulated panicle biomass (WSO) for different treatments (NFF, FF, NFS and FS) by treatment calibrated parameters from unlike treatments, combine with the standard deviation (STD) and daily range (Ri: max (Yij) – min (Yij) of simulated results.

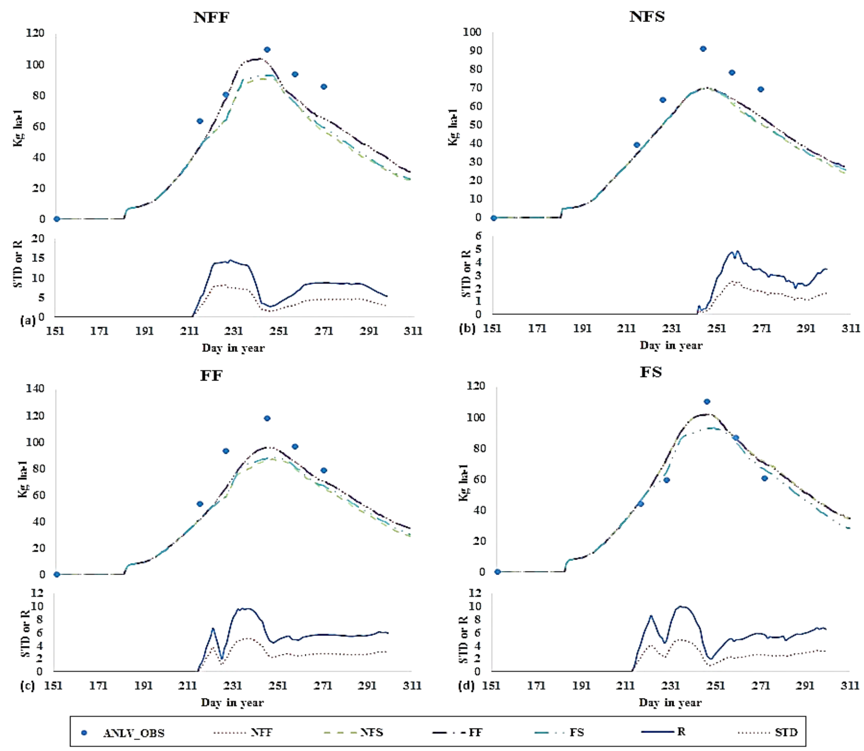

Figure 5. Simulated and observed Leaf nitrogen content (ANLV) in each treatment (NFF, NFS, FF and FS) using treatment calibrated parameters from different treatments, together with the daily range (R_i: max (Y_{ij}) – min (Y_{ij})) and standard deviation (STD) of the simulated results

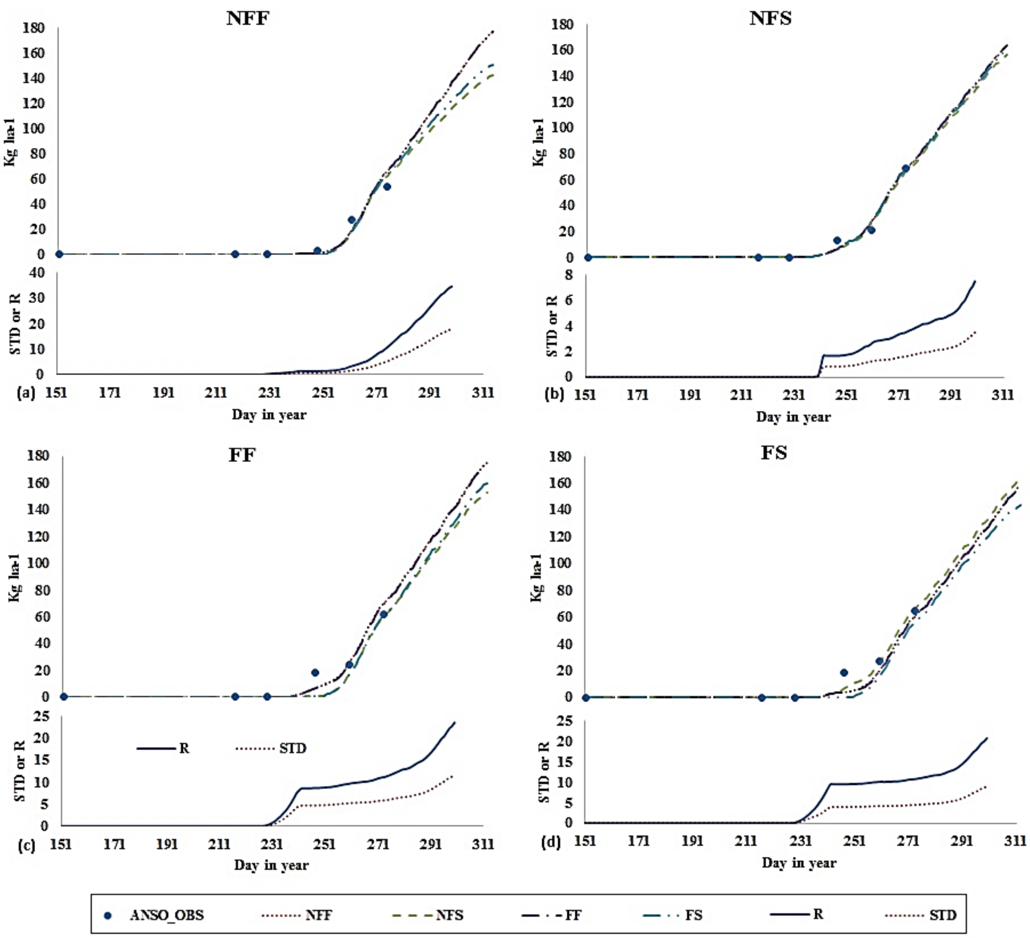

Figure 6. Simulated and observed panicle nitrogen content (ANSO) for different treatment (NFF, FF, NFS and FS) by treatment calibrated parameters from unlike treatments, combine with the standard deviation (STD) and daily range (R_i: max (Y_{ij}) – min (Y_{ij}) of simulated results.

The graphical view of simulation by ORYZA (v3) for the amount of nitrogen in storage organ (ANSO) is represented in Figure 6. It can be inferred from Figure 6 that similar trend was observed for all parameters nevertheless, the performance of NFS was superior. Similarly, the performance and parameters of NFS were satisfactory among various parameters dataset and were relatively better. The good performance of NFS was also confirmed by linear regressions between observed and simulated values of ANSO. The range for coefficient determination R^2 for NFS was between 0.95 and 0.97 with relatively smaller RMSEn.

Overall, simulation in rice biomass and nitrogen content in crop organs through ORYZA (v3) model using the studied parameters dataset was instrumental. The performance of each treatment was found satisfactory when cross validated with other treatments and the errors were relatively not contrasting. However, FS treatment showed fairly better results in simulating WAGT. Similarly, for WSO, under varying water and nitrogen conditions each treatment underestimated WSO in early boot stage, wherein FF and FS performed better. On the other hand, for ANLV each treatment parameters in cross validation were in acceptable range and FS treatment values were relatively close to observed values. For the results of ANSO, calibrated parameters from NFS revealed better results among other treatments. The simulation errors for the studied parameters were varied to some extend when it was cross validated with other treatment parameters, however, the range was not wide.

Treatment Parameters**:** The biomass partitioning factors for the treatment parameters were compared with the results of (Zhang *et al.*, 2007) in Changshu. The results were found in agreement with all DVS except when DVS were 0.50 and 1.00. The changes observed for biomass partitioning factors in stem (with sheathes) and panicle might be the result of different application of irrigation and fertilizers. Nitrogen content in green leaves at early growth stage of rice was higher under sufficient water with limited fertilization. These results are contrary to the findings of (Liang *et al.*, 2015) who reported that biomass of leaves was enhanced with increased nitrogen level. This could be the result of differences in efficacy of nitrogen contents in germplasms.

At DVS=0.75~1.0 the green leaves partitioning factors at was identical at all studied conditions. This suggested that rice leaves at this growth stage were insensitive to varying fertilization and irrigation. Similarly, accumulation in panicle at reproductive stage was higher at limited nitrogen or water as compared to sufficient nitrogen or water conditions, which is supported by the findings of (Wang *et al.,* 2007) as limited nitrogen escalates panicle accumulation in rice. Ye *et al.,* (2013) proposed that alternate wetting and drying (AWD) irrigation could boost accumulation of panicle in propagative stage. Conversely, Peng and Xu supported that limited application of water for higher production of biomass in rice because root system becomes healthier in water deficit condition which acts as compensation effect during panicle development stage (Peng and Xu, 2011).

The nitrogen content in panicle was higher under limited irrigation with sufficient fertilization which could be the result of highly saturated fertilization. Nitrogen is highly soluble in water and limited amount of water with sufficient fertilization caused saturated aqueous solution. There is a high probability that higher nitrogen level in soil with limited water would have positive effect on nitrogen content efficiency of rice in panicle. It can be inferred that higher the dose of fertilization, higher would be the nitrogen level in panicle. Same trend was observed for leaves under deficit water with sufficient nitrogen. Arai *et al.,* (2015) reported that nitrogen content in leaves depends upon the amount of fertilizer applied. Conversely, maximum nitrogen level in leaves at different developmental stages varied under different nitrogen and water management, wherein, nitrogen content in leaves declined with the progress of maturity under all treatments. These results endorsed the findings of (Borah and Johari, 1987 and Singh *et al.,* 2014) that nitrogen content in vegetative parts of rice was subsequently reduced as the plant progressed towards maturity.

Generally, each treatment parameters were found appropriate in simulation by ORYZA (v3), however, the FS treatment performed relatively better in both calibration and validation. The biomass components WLVG, WST and WSO of other three treatments were also close to the simulated values. For nitrogen content, the ORYZA (v3) model simulation for all treatments were in acceptable range except for ANST. Nitrogen content in stem was calculated along with sheath which might have caused higher underestimation for ANST by ORYZA (v3). Highest RMSEn were observed 26.9%; 35.8%; 34.2% for WSO, ANSO and ANST, respectively. Usually, RMSEn values for validation dataset are high and extensively reported in other studies as well (Cao *et al.,* 2017 and Azarpour *et al.,* 2000). Compared with the results by (Xu *et al.,* 2018), who calibrated the parameters regarding plant growth rate and biomass partition, the error of RMSEn was reduced in a certain degree. For example, the RMSEn in WAGT of FS treatment for calibration was reduce by 39.7% and 16.1% for model validation, respectively. It implied that the performance of ORYZA (v3) can be enhanced by calibrating more parameters regarding biomass production and nitrogen assimilation.

***Variability Among Each Treatment Calibrated Parameters*:** Contrasting water and nitrogen management had significant impact on biomass partitioning in rice. The variability among each treatment calibrated parameters are presented in Table 3. It can be observed that coefficient of variation for leaves and stem at DVS = 0.00 was 4.25% and 7.81%. At DVS = 0.50, the CV for leaves and stem reduced to 2.26% and 1.65% respectively. No variation existed at DVS = 0.75 which might be due to insensitivity of rice biomass to different water and nitrogen management. At developmental stage 1.00, the partitioning factor to green leaves ceases and panicle partitioning factor begins. The coefficient of variation for stem and panicle at DVS = 1.00 was 4.6% and 5.46%, respectively. However, insufficient literature supports the findings of the current study. Values of CV for parameters regarding biomass production and partition were mostly the same as reported by (Xu *et al.,* 2018), but the maximum CV (7.81 % at DVS = 0.0) was slightly higher in the current results.

Similarly, nitrogen content in leaves and panicle CV values were higher than the CV of biomass partitioning. The CV for FNLVI (on weight basis Initial Leaf N fraction: kg N kg^{-1} leaf) was calculated on try and error basis which resulted in higher (17.4%) coefficient of variation. For NMAXSO the CV was 7.8%. The CV for NMAXLT was calculated for each developmental stage where, at DVS = 0.75 maximum variation was observed (18.5%). Generally, low CV for NMAXLT was noted at DVS = 2.50, suggesting minor demand of nitrogen in leaves at maturity.

***Uncertainty in Biomass and Nitrogen Content due to Variation Among Treatment Specific Parameters*:** Certain degree of uncertainty in biomass and nitrogen content of rice is expected to exist while different water and nitrogen treatments parameters are used in the model. The graphical representation for standard deviation (STD) and range (R) of simulated WSO and WAGT to evaluate the uncertainty caused by variation among specific treatments are presented in Figure 3 & 4. It can be seen in figure 3 that similar pattern of R and STD of simulated WAGT was observed among different treatments. There is a rapid increase in uncertainty as the crop progressed towards maturity. The STD and R values of simulated WAGT varied for all treatments, however, the highest STD and R values were observed for NFF (Fig. 3a). Similarly, the lowest STD and R values were recorded for NFS (Fig. 3b). For simulated WAGT of NFF, STD and R values continued to rise from 0.0 to 182.2 and 339.4 kg ha^{-1} until 243rd day at DVS = 0.96. There was a gradual decline in STD and R values from 243rd to 255th day of the year (DVS = 1.19) afterwards it increased again till harvesting (300th day of year). The high uncertainty of NFF for simulated WAGT among treatment specific parameters might be caused by surplus amount of fertilization in limited water. Comparatively, the STD and R values for simulated WAGT of NFS and FS were lower than their corresponding NFF and FF.

Similarly, for simulated WSO, values of STD and R varied in same pattern for all treatment specific parameters, however, highest uncertainty was observed in NFF treatment (Fig. 4). Generally, both STD and R values were very low at the beginning and suddenly increased after 250th day of year (DVS = 1.07). The STD and R values were minimal for NFF treatment till 260th day at DVS = 1.3 and later on increased sharply till physiological maturity (Fig.4a). In comparison to other treatments, NFS treatment showed lower magnitude of uncertainty.

The simulated nitrogen content in leaves (ANLV) for various treatment specific parameters are displayed in Figure 5. In general, the STD and R values for simulated ANLV varied in alternative pattern. Highest STD and R values of simulated ANLV were noted for NFF followed by FS, FF and NFS (Fig. 5). The STD and R values for NFF were highest (7.4 and 14 kg ha^{-1}) on 231st day of year at DVS = 0.8 (Fig. 5a). Thereafter, a sharp decline was observed till 251st day of year at DVS = 1.1 and then it enlarged again progressively till 289th day and then start declining to the end of rice season. Different physiological stages of leaves might have different nitrogen demand which resulted in alternating pattern of STD and R values. Similarly, simulation of ANSO for various treatment specific parameters shown in Figure 6 displayed similar pattern for STD and R values in all treatments. Lowest STD and R values were recorded for NFS treatment followed by FS, FF and NFF. Slow increase of STD and R values was observed for almost all treatments. In NFF treatment, highest STD and R values were 17.77 and 34.4 kg ha^{-1}, respectively.

***Conclusion*:** Both parameters for plant biomass accumulation and nitrogen assimilation in ORYZA (v3) were calibrated separately for each treatment, based on the rice production and nitrogen concentration data from various nitrogen and water management. The calibrated model, by treatment data, was instrumental in modelling accumulation of rice biomass and nitrogen content. And it performed a little better in model validation than the model calibrated only regarding plant growth rate and biomass partition. The treatment under nitrogen stress with sufficient water relatively performed better in both calibration and validation. For cross validation, the ORYZA (v3) model exhibited satisfactory results for each treatment. It was hard to identify the variance in different treatment parameters for simulated WAGT values. However, WAGT accumulation for FS was found better than other treatments. For WSO, among all the parameters dataset, the linear regressions between observed and simulated WSO performed better for the parameters of FF and FS. Similarly, FS treatment was superior to other treatments in simulating ANLV. On the other hand, under water and nitrogen stress conditions, ANSO responded positively. Hence, varying water and nitrogen levels had significant impact on biomass partitioning in rice suggesting its sensitivity to fertilization and irrigation during developmental stages. The coefficient of variation among treatment specific parameters were typically in acceptable range. In rice biomass production and nitrogen contents, a certain degree of uncertainty is likely to be expected when simulated with different treatment specific calibrated parameters by ORYZA (v3) model. The magnitude of R and STD values (uncertainty) diverse in a parallel fashion amongst treatments where FS treatment showed lower uncertainty as compared to other treatments. Based on the results of current study, the use of ORYZA model (v3) is equally feasible in sufficient water with limited nitrogen in rice. Likewise, current results suggested that the performance of ORYZA (v3) could be improved by cross validations of different calibrated treatment parameters.

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