Crop Monitoring as an
E-agricutural tool in
Developping Countries

EVALUATION REPORT ON RICE SIMULATION AT FIELD LEVEL

Reference: *E-AGRI_D32.3_Evaluation Report On Rice Simulation at Field Level_1*
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Version: 1.0
Date: 31/01/2013

DOCUMENT CONTROL

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Change record

Release	Date	Pages	Description	Editor(s)/Reviewer(s)
1.0	31/01/2013			

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EXECUTIVE SUMMARY

This report presents the results of the evaluation at field level of the models WARM, WOFOST and CropSyst for rice growth and development in the Jiangsu province. For both calibration and validation purposes, the observations datasets were split in two parts, taking into account different sowing techniques (transplanting and direct sowing). Evaluation metrics showed good performances for the three models.

NOTE:
The deliverable corresponding to this report (D32.3) is scheduled for month 30. This version of the report contains the results of the calibration/validation performed using the data from the field experiments carried out during the first year of project. This report will be integrated in the next months with data coming from the new field experiments.
This strategy – i.e., submitting partial versions of the deliverable, each integrating the previous one – is due to an explicit request form the Project Reviewers, to avoid an accumulation of too many reports to be reviewed in the last months of the Project.

1. Materials and methods

1.1. Field level calibration and validation of the models WARM, WOFOST and CropSyst for rice simulation in Jiangsu

1.1.1. The observation datasets

The data used for the calibration and validation of the three models were collected in the Jianghuai plain and in particular at nine sites selected during the year 2011 (see the D31.1 report).

The experiments with directly sown rice are separated from ones in which rice was transplanted, because the three models simulating transplanted rice are integrated within a specific component. The criteria to split the datasets for calibration from the ones of validation is based on (i) the cultivation method (i.e., direct sowing or transplanting), (ii) the rice type, and (iii) the spatial distribution of the sites. Figure 1 shows the distribution of the selected sites.

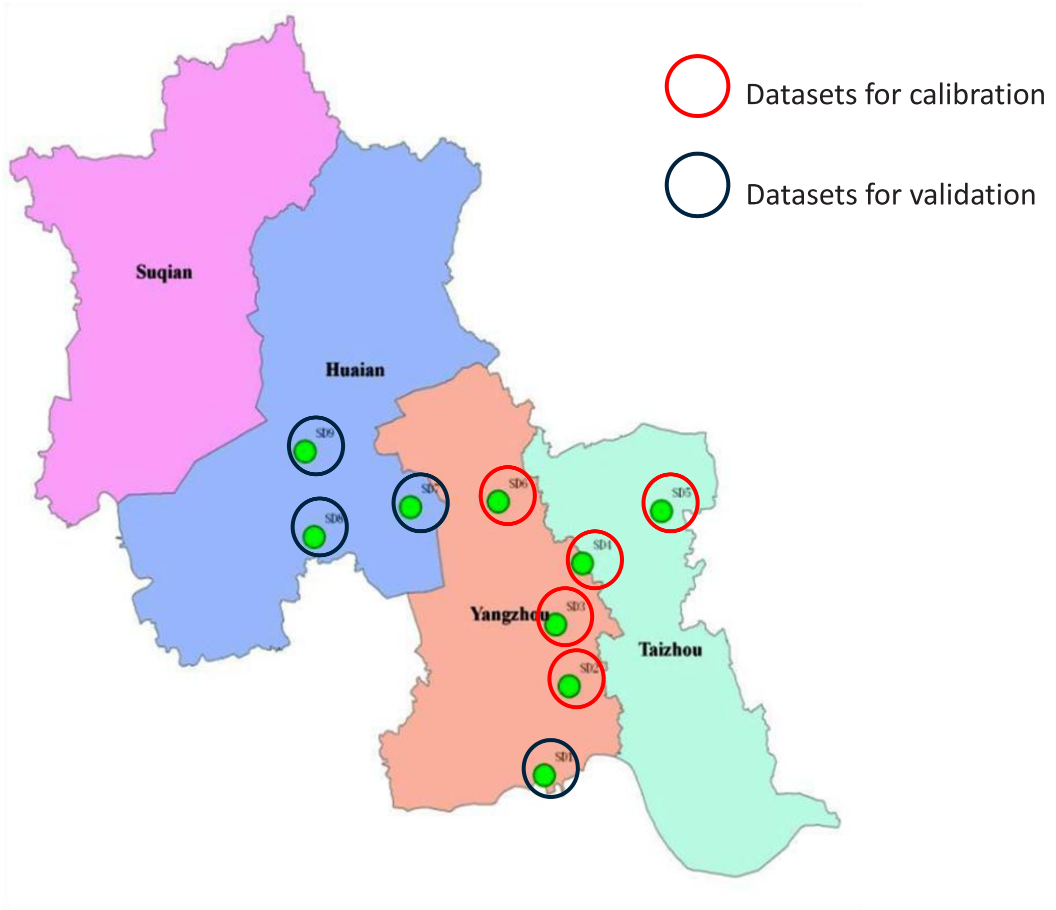

Figure 1 Distribution of calibration and validation datasets in the study region

Five varieties were used in the field experiments, part of which were directly sown and the others were mechanically or artificially transplanted.

Table 1 Jiangsu datasets selected for calibration

	Rice variety	Rice type	Cultivation method
SD1	Yangjing 4227	Early-maturing *Japonica* rice	Mechanical transplanting
SD3	Huaidao 5	Late-maturing *Japonica* rice	Direct broadcasting
SD5	Huaidao 5	Late-maturing *Japonica* rice	Direct broadcasting
SD6	Huaidao 5	Late-maturing *Japonica* rice	Direct broadcasting
SD7	C Liangyou 608	Late-maturing *Indica* rice	Artificial transplanting

Table 2 Jiangsu datasets selected for validation

	Rice variety	Rice type	Cultivation method
SD2	Zhendao 88	Medium-maturing *Japonica* rice	Direct broadcasting
SD4	Huaidao 5	Late-maturing *Japonica* rice	Direct broadcasting
SD8	Y Liangyou 1	Late-maturing *Indica* rice	Artificial transplanting
SD9	Huaidao 5	Late-maturing *Japonica* rice	Mechanical transplanting

Before the model calibration, an analisys of rice aerial biomass observations was performed.
All datasets showed a large accumulation of total biomass in the last part of the growing season. In Figure 2 an anomalous linear increasing between flowering (i.e., the fifth point in the graph) and ripening (i.e., the last point) is shown, from the SD3 dataset for illustration.

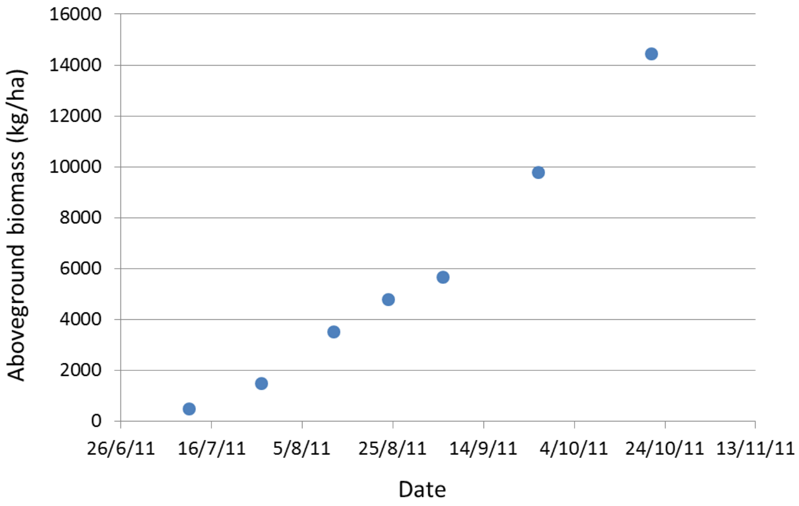

Figure 2 Total aboveground biomass observed at SD3

This particular trend is due to an anomalous accumulation of biomass in two different periods and organs of the plant (see Figure 3 and Figure 4). Grain filling presented a linear increasing trend during the last 25 days before physiological maturity even though the value of Harvest Index in all datasets is about 0.5, which is typical of rice. Moreover, biomass accumulation in stems presented an anomalous increase during the first 20 days after flowering. In this period the plant typically stores most of products of photosynthesis in the ear, while the portion given to leaves and stems should decrease until remaining constant.

Given (i) the anomalies of these values, and (ii) the three model theory, the simulations can unlikely reproduce the last growing period trends. Therfore we decided to exclude the last measured points from all datasets for models calibration and validation.

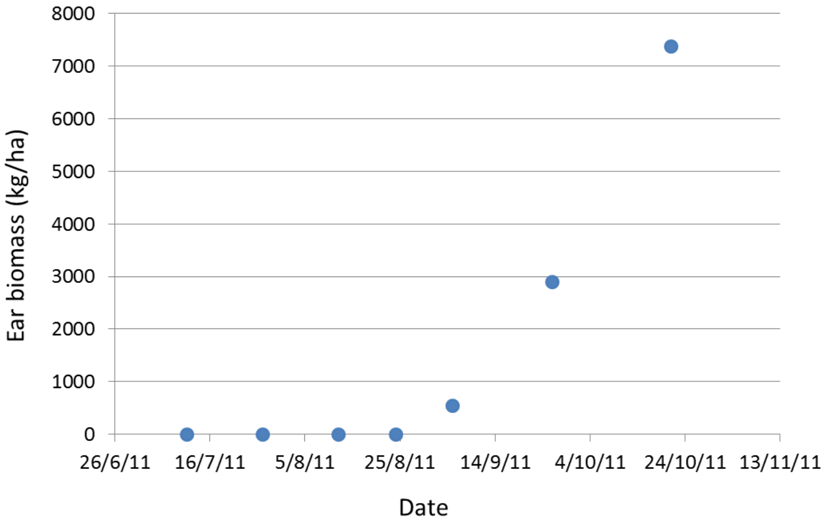

Figure 3 Ear biomass observed at SD3

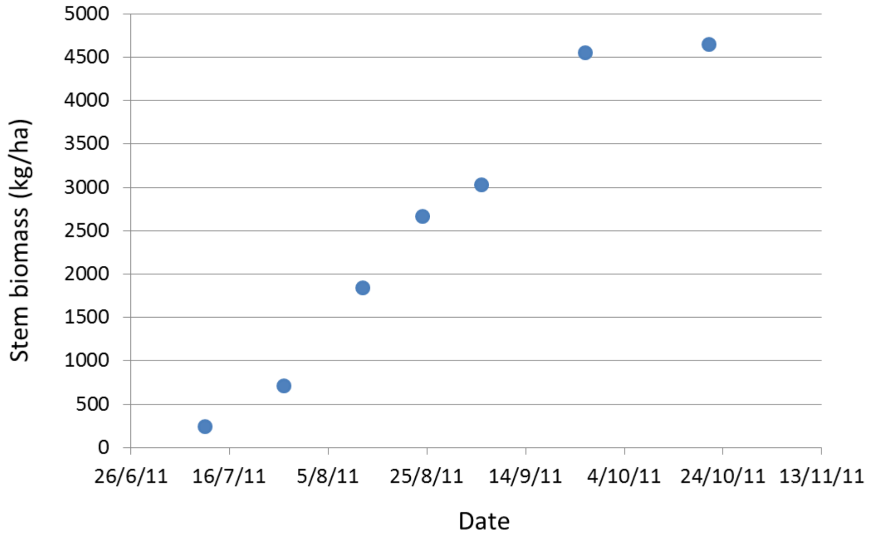

Figure 4 Stem biomass observed at SD3

1.1.2. The meteorological datasets

Given the proximity of the field observation sites, six meteorological observation datasets were supplied. All of them were characterized by very low values of global solar radiation, considering the rice growing period and the latitudes at which experiments were performed (i.e., about 32°N). More in detail the maximum value is rarely larger than 20 MJ/m^2 in the summer season. Figure 5 shows the comparison between the radiation data observed at the SD3 site and the ones retrieved from the Era-Interim reanalysis database of the European Centre for Medium-Range Weather Forecasts (ECMWF) with 25x25 km grid resolution. ECMWF values are mostly larger than observation. Moreover, the graph points out that in some periods the same observation value is repeated for several consecutive days. The good agreement between ECMWF and measured maximum air temperature (Figure 6) further confirm a possible error in field radiation data.

Considering this comparison, we decided to use ECMWF data for model calibration and validation.

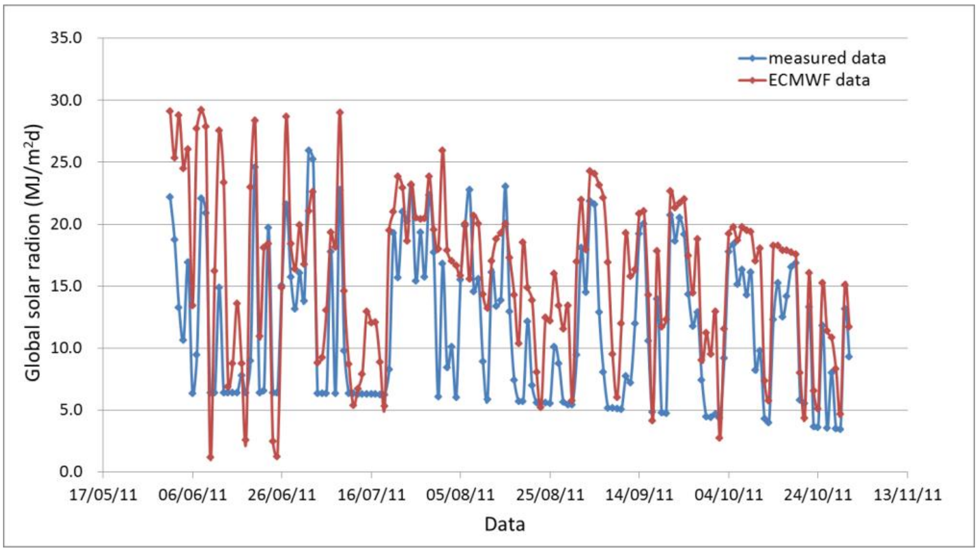

Figure 5 Comparison of daily global solar radiation measured at the SD3 site and retrieved from the ECMWF Era Interim archive

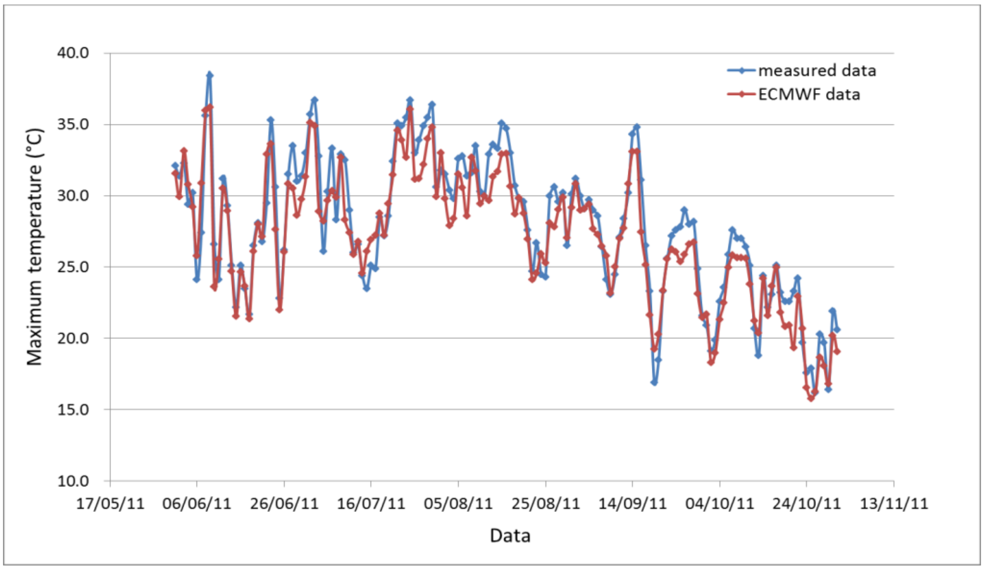

Figure 6 Comparison of daily maximum air temperature measured at the SD3 site and retrieved from the ECMWF Era Interim archive

2. Results and Discussion

2.1. Calibration and validation of the models WARM, WOFOST and CropSyst for rice simulation in Jiangsu

The complete list of the calibrated parameter values of WARM, WOFOST, and CropSyst is detailed in Appendix A, B, and C, respectively. Result discussion is separated according to direct sowed and transplanted datasets.

2.1.1. Results obtained with direct sowing dataset

The first parameters calibrated are those affecting plant development. The parameter values chosen for the three models led to a good performance of phenological phases simulation, determining a maximum difference of seven days between the observed and simulated values. The validation confirmed the good results obtaining with parameters used during the calibration.

Once crop development was calibrated, the parameters involved in rice growing were considered. A particular effort was put in the calibration of those parameter that showed a maximum influence on output variation, according to the sensitivity analysis results (see report D32.1).

Since the observation sites chosen for calibration are located at similar latitudes and there were no significant differences in meteorological data, the simulated aboveground biomass (AGB) and leaf area index (LAI) trends are similar and only SD5 results are showed for illustration.

The AGB and LAI trends simulated by the WARM model are shown in Figure 7, where they are compared with data collected at different stages of rice growth.

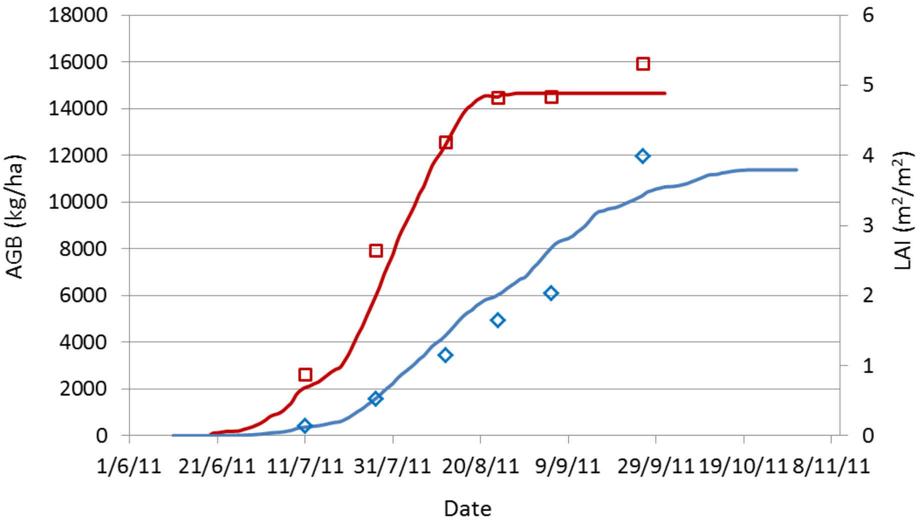

Figure 7 Comparison between simulated (blue line) and measured (blue diamonds) aboveground biomass and simulated (red line) and measured (red squares) Leaf Area Index. Experiment SD5, WARM model

The overall measured trends were well reproduced by WARM. More into detail, as it was decided to exclude only the last collected point, model parameters values try to minimize also the error between simulated and measured variables after flowering. Thereby a slightly decrease of the quality of simulation of aboveground biomass and LAI before flowering was observed. Similar results were obtained for WOFOST (Figure 8) and CropSyst (Figure 9) calibration.

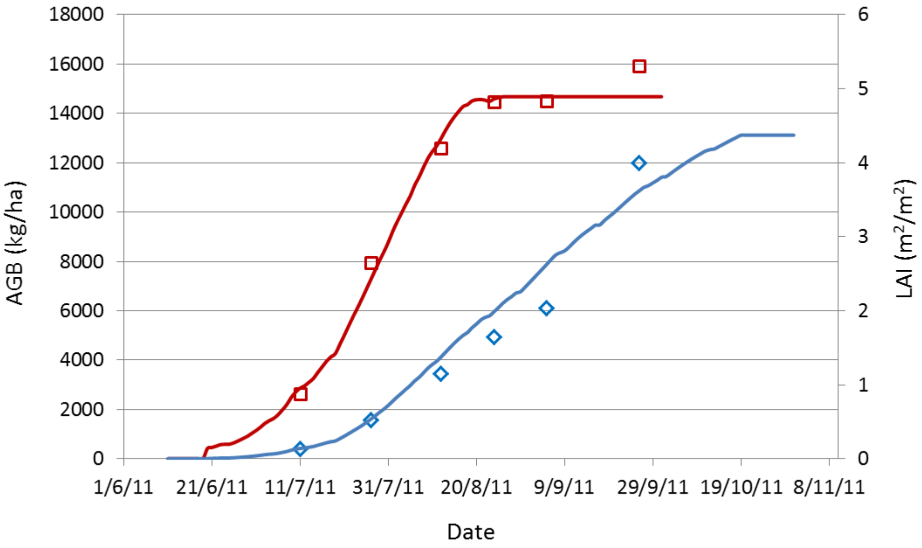

Figure 8 Comparison between simulated (blue line) and measured (blue diamonds) aboveground biomass and simulated (red line) and measured (red squares) Leaf Area Index. Experiment SD5, WOFOST model

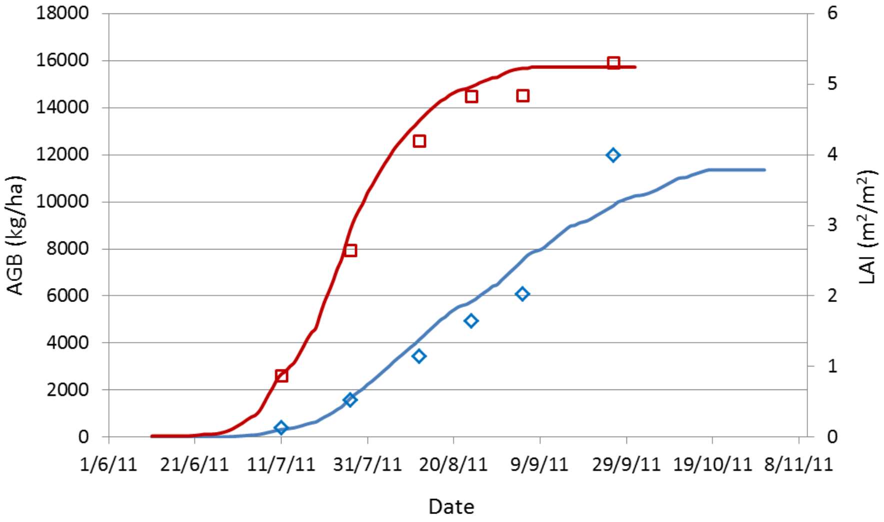

Figure 9 Comparison between simulated (blue line) and measured (blue diamonds) aboveground biomass and simulated (red line) and measured (red squares) Leaf Area Index. Experiment SD5, CropSyst model

For evaluating the accuracy of the three models in Table 3 are presented the values of the most important fitting indices, which quantify the agreement between measured and simulated values. These indeces are (i) the relative root mean squared error (RRMSE, minimum and optimum = 0%; maximum = + ∞), (ii) the modelling efficiency (EF, - ∞ ÷ 1, optimum =1, if positive, indicates that the model is a better predictor than the average of measured values), and (iii) the coefficient of residual mass (CRM, 0-1, optimum = 0, if positive indicates model underestimation). These values confirmed the good performance of models in reproducing both calibration and validation datasets. The overall RRMSE referred to aboveground biomass showed a mean value of 22% , while the value referred to LAI was even closer the optimum (14%). In detail, CropSyst resulted the model that better simulated AGB , with mean RRMSE = 21%, EF = 0.92 and CRM = - 0.07.

The good performance of the three models was also confirmed by the values of regression parameters (i.e., slope, intercept and coefficient of determination) listed in Table 4. The coefficient of determination of the regression had a mean value of 0.93-0.94, the mean value of intercept of regression line was 0, which is the optimum, and slope is close to 1.

The index of robustness (I_R) of the three models, which can be defined as a measure of models reliability under different sets of experimental conditions, was also calculated. As previously highlighted, the datasets used were characterized by very similar meteorological conditions, therefore I_R did not give information about the proper model performances in conditions very different from those analysed. The idea was to calculate the ratio variability of error to variability of explored conditions, thus, with I_R ranging from 0 (optimum) to +∞. WARM achieved the best value of AIC (50.58), marking its ability in estimating AGB with a similar accuracy (values of fitting indices are about the same for the three models, Table 3), but using a lower number of parameters compared to the other models. WOFOST was confirmed as the most complex model, with a value of the 87.92, because it reached the same level of accuracy of the other models, requiring twice the number of parameters. CropSyst AIC was 57.90, a value closer to the WARM one.

Table 5 are presented the values of I_R for the three models. Cropsyst resulted the model that better reproduces AGB trend in different experimental conditions, while WARM and WOFOST had nearly the same robustness. Values of robustness for LAI are not very good for all models, with WOFOST slightly better performing.

Lastly, the complexity of models with the use of the index AIC (Akaike's information Criterion) was performed. The AIC is an operational way of trading off the complexity of a model against how well the model fits the data. The index not only rewards goodness of fit, but also includes a penalty (i.e., an increasing function of the number of model parameters) to prevent from over-parameterization. It therefore gives a good score to models that guarantee good performances while requiring few inputs. In this study the model output considered was AGB and the total parameters involved in the development and potential growth simulation were 16 for WARM, 20 for Cropsyst and 34 for WOFOST.

Table 3 Idices of agreement between measured and simulated AGB and LAI values referred to the directly sowing datasets

Variable	Experiment	RRMSE (%)			EF			CRM		
		WARM	WOFOST	CropSyst	WARM	WOFOST	CropSyst	WARM	WOFOST	CropSyst
					Calibration set					
AGB	SD3	26.64	24.46	20.11	0.86	0.88	0.92	-0.19	-0.18	-0.13
	SD5	25.13	21.11	24.20	0.90	0.93	0.91	-0.08	-0.09	-0.03
	SD6	19.57	18.00	18.07	0.92	0.93	0.93	-0.02	-0.06	0.02
LAI	SD3	9.19	5.14	14.82	0.94	0.98	0.86	-0.02	-0.03	-0.12
	SD5	9.07	5.71	6.37	0.95	0.98	0.98	0.06	0.02	-0.05
	SD6	22.82	17.71	18.36	0.51	0.71	0.68	0.07	0.02	-0.03
					Validation set					
AGB	SD2	26.33	24.05	22.30	0.88	0.90	0.91	-0.19	-0.19	-0.15
	SD4	25.12	20.58	22.91	0.90	0.93	0.91	-0.11	-0.10	-0.05
LAI	SD2	20.48	18.90	33.81	0.72	0.76	0.24	-0.14	-0.17	-0.31
	SD4	10.10	9.08	8.89	0.94	0.95	0.95	0.05	0.05	-0.04
Mean (AGB)		24.56	21.64	21.52	0.89	0.91	0.92	-0.12	-0.12	-0.07
Mean (LAI)		14.33	11.31	16.45	0.81	0.88	0.74	0.00	-0.02	-0.11

Table 4 Regression idices between measured and simulated AGB and LAI values referred to the directly sowing datasets

Variable	**Experiment**	**Slope**			**Intercept (t/ha)**			**R^2**		
		WARM	WOFOST	CropSyst	WARM	WOFOST	CropSyst	WARM	WOFOST	CropSyst
					Calibration set					
AGB	SD3	0.86	0.85	0.92	-0.09	-0.01	-0.14	0.95	0.98	0.96
	SD5	1.04	1.02	1.10	-0.54	-0.50	-0.63	0.91	0.94	0.92
	SD6	0.94	0.89	0.99	0.21	0.26	0.15	0.92	0.95	0.93
LAI	SD3	0.84	0.94	0.87	0.00	0.00	0.00	0.98	0.99	0.97
	SD5	0.94	1.02	0.98	0.00	0.00	0.00	0.98	0.98	0.99
	SD6	0.65	0.73	0.70	0.00	0.00	0.00	0.78	0.82	0.85
					Validation set					
AGB	SD2	0.94	0.94	1.00	-0.55	-0.53	-0.66	0.95	0.97	0.95
	SD4	1.00	0.99	1.06	-0.49	-0.42	-0.55	0.92	0.95	0.92
LAI	SD2	0.79	0.91	0.81	0.00	0.00	0.00	0.93	0.95	0.93
	SD4	0.92	1.04	0.96	0.00	0.00	0.00	0.96	0.96	0.96
Mean (AGB)		0.95	0.94	1.01	-0.29	-0.24	-0.37	0.93	0.96	0.94
Mean (LAI)		0.83	0.93	0.86	0.00	0.00	0.00	0.93	0.94	0.94

WARM achieved the best value of AIC (50.58), marking its ability in estimating AGB with a similar accuracy (values of fitting indices are about the same for the three models, Table 3), but using a lower number of parameters compared to the other models. WOFOST was confirmed as the most complex model, with a value of the 87.92, because it reached the same level of accuracy of the other models, requiring twice the number of parameters. CropSyst AIC was 57.90, a value closer to the WARM one.

Table 5 Robustness indices of relative to the directly sowing datasets

Variable	Model	Robustness
AGB	WARM	1.081
	CropSyst	0.418
	WOFOST	1.096
LAI	WARM	9.031
	CropSyst	14.11
	WOFOST	6.056

2.1.2. Results obtained with transplanting dataset

The calibration of parameters involved with development led to flowering and maturity stages lenghts similar to measured ones. The results of the calibration are comparable to those obtained with datasets of rice directly sown, therefore the graphs representing trend of AGB and LAI are not showed here.

On the other hand during validation all three models showed a difference between measured and simulated maturity date ofabout 15 days. This error reveals that there is probably something to improve in the transplanting model and partially led to poor performances in simulating plant growth in validation.

Values of fitting indices (Table 6 and Table 7) proved that there is a problem in the transplanting component. Mean values are globally worse than those obtained with directly sowing datasets, in particular for LAI estimation. Although also transplanted experiments are located in a restricted area (i.e., meteorological data are not notably variable) the values of fitting indices widely varied with different datasets. In particular the lowest agreement between measured and simulated data was obtained with validation datasets and this was likely due to the difficulties encountered in simulating rice development.

Table 6 Idices of agreement between measured and simulated AGB and LAI values referred to the transplanting datasets

Variable	**Experiment**	**RRMSE (%)**			**EF**			**CRM**		
		WARM	WOFOST	CropSyst	WARM	WOFOST	CropSyst	WARM	WOFOST	CropSyst
					Calibration set					
AGB	SD1	31.52	19.29	13.40	0.79	0.92	0.96	-0.30	-0.17	-0.10
	SD7	24.65	18.69	32.50	0.89	0.94	0.81	0.14	0.13	0.27
LAI	SD1	20.12	13.09	22.39	0.80	0.92	0.76	-0.14	-0.09	-0.15
	SD7	31.84	29.38	20.57	0.69	0.74	0.87	0.08	0.23	0.12
					Validation set					
AGB	SD8	14.64	8.98	25.84	0.96	0.98	0.87	-0.02	0.02	0.22
	SD9	36.39	29.56	42.11	0.72	0.82	0.63	0.24	0.19	0.34
LAI	SD8	31.01	54.50	35.57	0.56	-0.36	0.42	0.08	0.43	0.26
	SD9	43.53	37.14	40.28	-0.21	0.12	-0.04	0.37	0.32	0.34
Mean (AGB)		26.80	19.13	28.46	0.84	0.91	0.82	0.02	0.04	0.18
Mean (LAI)		31.62	33.52	29.70	0.46	0.35	0.50	0.10	0.22	0.14

Table 7 Regression idices between measured and simulated AGB and LAI values referred to the transplanting datasets

Variable	**Experiment**	**Slope**			**Intercept (t/ha)**			**R^2**		
		WARM	WOFOST	CropSyst	WARM	WOFOST	CropSyst	WARM	WOFOST	CropSyst
					Calibration set					
AGB	SD1	0.89	0.89	0.89	-0.66	-0.16	0.07	0.99	1.00	1.00
	SD7	1.34	1.17	1.29	-0.99	-0.16	0.35	0.99	0.99	0.99
LAI	SD1	1.00	0.87	0.83	-0.41	0.15	0.12	0.90	0.98	0.91
	SD7	1.65	1.17	1.13	-1.74	0.33	0.02	0.85	0.92	0.93
					Validation set					
AGB	SD8	1.22	1.07	1.22	-1.55	-0.34	0.26	0.99	0.99	1.00
	SD9	1.56	1.39	1.52	-1.31	-0.90	-0.01	0.97	0.97	0.98
LAI	SD8	1.71	0.85	1.01	-2.32	2.05	1.02	0.71	0.49	0.74
	SD9	1.51	1.22	1.21	0.24	0.88	1.07	0.74	0.78	0.74
Mean (AGB)		1.25	1.13	1.23	-1.13	-0.39	0.17	0.99	0.99	0.99
Mean (LAI)		1.47	1.03	1.05	-1.06	0.85	0.56	0.80	0.79	0.83

3. Conclusions

The evaluation of the WARM, WOFOST, and CropSyst models in simulating rice development and growth at the Jiangsu province was carried out into two steps. The nine observations datasets available were then splitted in two parts, the first used for calibration and a second for validation purposes.

The three model calibration successfully allowed to reproduce the validation datasets in case of direct sowing management. The quantitative evaluation by means of the fitting indices designated CropSyst as the most accurate model. According to the AIC index, WARM resulted the less complex model, while WOFOST required a much larger number of parameters to reach comparable results. Since the datasets were located in a restricted area and the meteorological inputs are retrieved from the ECMWF archive, the low variability in the rainfall data influenced the reliability of the robustness index.

In the case of the transplanted datasets, all models showed good performances in calibration. However, the fitting indices relative to the validation datasets suggested that the three models required an improvement of the transpanting component.

Appendix A. Parameter values (DS: direct sowing, T: transplanting) and determination (C: calibrated parameters; L: literature; D: default) relative to WARM model.

Parameter	Unit	Value DS	Value T*	Det.
Development				
Base temperature for development (TbaseD)	°C	12	-	C
Maximum temperature for development (TmaxD)	°C	42	-	C
GDD emergence (GDDem)	°C-d	80	50	C
GDD flowering (GDDfl)	°C-d	1130	1310	C
GDD maturity (GDDmat)	°C-d	365	445	C
Growth				
Maximum radiation use efficiency (RUE)	g MJ^{-1}	2.5		C
Extinction coefficient for solar radiation (k)	-	0.45	0.44	C
Base temperature for growth (Tbase)	°C	13		C
Optimum temperature for growth (Topt)	°C	29	30	C
Maximum temperature for growth (Tmax)	°C	42		C
Initial specific leaf area (SLAini)	m^2 kg^{-1}	31	28	C
Specific leaf area at tillering (SLAtill)	m^2 kg^{-1}	18	20	C
Partition coefficient to leaf at early stages (RipL0)	kg kg^{-1}	0.7	0.6	C
Leaf duration (LeafDur)	°C-d	800	680	C
Maximum panicle height (Hmax)	cm	100	100	D

* Values are specified only when differ from direct sowing ones

Appendix B. Parameter values (DS: direct sowing, T: transplanting) and determination (C: calibrated parameters; L: literature; D: default) relative to WOFOST model.

Parameter	Unit	Value DS	Value T*	Det.
Development				
Base temperature for emergence (TBASEM)	°C	12	-	C
Maximum temperature for emergence (TEFFMX)	°C	30	-	C
Temperature sum emergence (TSUMEM)	°C-d	80	50	C
Temperature sum from emergence to anthesis (TSUM1)	°C-d	1170	1385	C
Temperature sum from anthesis to maturity (TSUM2)	°C-d	393	490	C
Daily increase in temperature sum (DTSMTB)	°C; °C-d	12; 0	-	C
Daily increase in temperature sum (DTSMTB)	°C; °C-d	30; 19	-	C
Daily increase in temperature sum (DTSMTB)	°C; °C-d	42; 0	-	L
Growth				
Leaf area index at emergence (LAIEM)	m^2 m^{-2}	0.3	0.1	C
Relative leaf area growth rate (RGRLAI)	°C d^{-1}	0.008	0.0085	C
Specific leaf area at DVS[a] = 0 (SLATB00)	ha kg^{-1}	0.0031	0.003	C
Specific leaf area at DVS[a] = 20 (SLATB20)	ha kg^{-1}	0.0028	-	C
Specific leaf area at DVS[a] = 30 (SLATB30)	ha kg^{-1}	0.0025	-	C
Specific leaf area at DVS[a] = 40 (SLATB40)	ha kg^{-1}	0.0021	0.0023	C
Specific leaf area at DVS[a] = 50 (SLATB50)	ha kg^{-1}	0.0019	0.0021	C
Specific leaf area at DVS[a] = 100 (SLATB100)	ha kg^{-1}	0.0019	0.0021	C
Specific leaf area at DVS[a] = 200 (SLATB200)	ha kg^{-1}	0.0019	0.0021	C
Life span of leaves growing at 35°C (SPAN)	d	30	38	C
Base temperature for leaves aging (Tbase)	°C	9	-	C
Extinction coefficient for diffuse visible light at DVS = 0 (KDIF000)	-	0.4	-	D
Extinction coefficient for diffuse visible light at DVS = 65 (KDIF65)	-	0.4	-	D
Extinction coefficient for diffuse visible light at DVS = 100 (KDIF100)	-	0.6	-	D
Extinction coefficient for diffuse visible light at DVS =200 (KDIF200)	-	0.6	-	D
Light use efficiency at Tavg[b] = 10°C (EFFTB10)	kg ha^{-1} h^{-1} J^{-1}	0.54	-	D
Light use efficiency at Tavg = 40°C (EFFTB40)	kg ha^{-1} h^{-1} J^{-1}	0.35	-	D
Maximum CO$_2$ assimilation rate at DVS = 000 (AMAXTB000)	kg ha^{-1} h^{-1}	25	24	C
Maximum CO$_2$ assimilation rate at DVS = 200 (AMAX200)	kg ha^{-1} h^{-1}	25	24	C
AMAX reduction factor at Tavg = 0°C (TMPFTB0)	°C	0	-	C
AMAX reduction factor at Tavg = 12°C (TMPFTB12)	°C	0.69	-	C
AMAX reduction factor at Tavg = 18°C (TMPFTB18)	°C	0.85	-	C
AMAX reduction factor at Tavg = 24°C (TMPFTB24)	°C	1	-	C
AMAX reduction factor at Tavg = 30°C (TMPFTB30)	°C	1	-	C
AMAX reduction factor at Tavg = 36°C (TMPFTB36)	°C	0.87	-	C
AMAX reduction factor at Tavg = 42°C (TMPFTB42)	°C	0.27	-	C
Correction factor for transpiration rate (CFET)	-	1		D
Efficiency of conversion into leaves (CVL)	kg kg^{-1}	0.55	-	D
Efficiency of conversion into storage organs (CVO)	kg kg^{-1}	0.684	-	D
Efficiency of conversion into roots (CVR)	kg kg^{-1}	0.754	-	D
Efficiency of conversion into stems (CVS)	kg kg^{-1}	0.685	-	C
Relative increase in respiration rate per 10°C of temperature increase (Q10)	-	1.8	-	C
Relative maintenance respiration rate for leaves (RML)	kg CH$_2$O kg^{-1} d^{-1}	0.02	-	C
Relative maintenance respiration rate for storage organs (RMO)	kg CH$_2$O kg^{-1}	0.01	-	C

	d^{-1}			
Relative maintenance respiration rate for roots (RMR)	kg CH_2O kg^{-1} d^{-1}	0.01	-	D
Relative maintenance respiration rate for stems (RMS)	kg CH_2O kg^{-1} d^{-1}	0.015	-	D
Fraction of total biomass to roots at DVS = 0 (FRTB000)	kg kg^{-1}	0.5	-	D
Fraction of total biomass to roots at DVS = 43 (FRTB43)	kg kg^{-1}	0.25	-	D
Fraction of total biomass to roots at DVS = 100 (FRTB100)	kg kg^{-1}	0	-	D
Fraction of total biomass to roots at DVS = 200 (FRTB200)	kg kg^{-1}	0	-	D
Fraction of aboveground dry matter to leaves at DVS = 0 (FLTB000)	kg kg^{-1}	0.76	-	C
Fraction of aboveground dry matter to leaves at DVS = 9 (FLTB009)	kg kg^{-1}	0.76	-	C
Fraction of aboveground dry matter to leaves at DVS = 29 (FLTB029)	kg kg^{-1}	0.66	-	C
Fraction of aboveground dry matter to leaves at DVS = 52.5 (FLTB052)	kg kg^{-1}	0.46	-	C
Fraction of aboveground dry matter to leaves at DVS = 72 (FLTB072)	kg kg^{-1}	0.37	0.39	C
Fraction of aboveground dry matter to leaves at DVS = 89.5 (FLTB089)	kg kg^{-1}	0.123	0.24	C
Fraction of aboveground dry matter to leaves at DVS = 100 (FLTB100)	kg kg^{-1}	0	-	C
Fraction of aboveground dry matter to leaves at DVS = 127.5 (FLTB127)	kg kg^{-1}	0	-	C
Fraction of aboveground dry matter to leaves at DVS = 200 (FLTB200)	kg kg^{-1}	0	-	C
Fraction of aboveground dry matter to storage organs at DVS = 0 (FOTB000)	kg kg^{-1}	0	-	C
Fraction of aboveground dry matter to storage organs at DVS = 29 (FOTB029)	kg kg^{-1}	0	-	C
Fraction of aboveground dry matter to storage organs at DVS = 52.5 (FOTB052)	kg kg^{-1}	0	-	C
Fraction of aboveground dry matter to storage organs at DVS = 72 (FOTB072)	kg kg^{-1}	0	-	C
Fraction of aboveground dry matter to storage organs at DVS = 89.5 (FOTB089)	kg kg^{-1}	0.23	-	C
Fraction of aboveground dry matter to storage organs at DVS = 100 (FOTB100)	kg kg^{-1}	0.5	0.58	C
Fraction of aboveground dry matter to storage organs at DVS = 127.5 (FOTB127)	kg kg^{-1}	1	-	C
Fraction of aboveground dry matter to storage organs at DVS = 200 (FOTB200)	kg kg^{-1}	1	-	C
Fraction of aboveground dry matter to stems at DVS = 0 (FSTB000)	kg kg^{-1}	0.24	-	C
Fraction of aboveground dry matter to stems at DVS = 9 (FSTB009)	kg kg^{-1}	0.24	-	C
Fraction of aboveground dry matter to stems at DVS = 29 (FSTB029)	kg kg^{-1}	0.34	-	C
Fraction of aboveground dry matter to stems at DVS = 52.5 (FSTB525)	kg kg^{-1}	0.54	-	C
Fraction of aboveground dry matter to stems at DVS = 72 (FSTB072)	kg kg^{-1}	0.63	0.61	C
Fraction of aboveground dry matter to stems at DVS = 89.5 (FSTB089)	kg kg^{-1}	0.64	0.53	C
Fraction of aboveground dry matter to stems at DVS = 100 (FSTB100)	kg kg^{-1}	0.5	0.42	C
Fraction of aboveground dry matter to stems at DVS = 127.5 (FSTB127)	kg kg^{-1}	0	-	C
Fraction of aboveground dry matter to stems at DVS = 200 (FSTB200)	kg kg^{-1}	0	-	C
Specific stem area at DVS = 0 (SSA000)	ha kg^{-1}	0.0003	-	D
Specific stem area at DVS = 90 (SSA090)	ha kg^{-1}	0.0003	-	D
Specific stem area at DVS = 200 (SSA200)	ha kg^{-1}	0	-	D
Initial total crop dry weight (TDWI)	kg ha^{-1}	110	80	C

[a] Development stage code (unitless; 0: emergence, 100: flowering, 200: physiological maturity)

[b] Average air daily temperature (°C)

[*] Values are specified only when differ from direct sowing ones

Appendix C. Parameter values (DS: direct sowing, T: transplanting) and determination (C: calibrated parameters; L: literature; D: default) relative to CropSyst model.

Parameter	Unit	Value DS	Value T[*]	Det.
Development				
Base temperature (Tbase)	°C	12	-	C
Cutoff temperature (Tcutoff)	°C	42	-	C
GDD emergence (GDDem)	°C-d	80	50	C
GDD flowering (GDDfl)	°C-d	1215	1370	C
GDD from flowering to maturity (GDDm)	°C-d	1570	1810	C
Growth				
Biomass-transpiration coefficient (BTR)	kPa kg m^{-3}	7	7.2	C
Radiation use efficiency (RUE)	g MJ^{-1}	2.56	2.85	C
Specific leaf area (SLA)	m^2 kg^{-1}	30	-	C
Stem/leaf partition coefficient (SLP)	-	4.5	4.2	C
Leaf duration (LeafDur)	°C-d	1000	750	C
Extinction coefficient for solar radiation (k)	-	0.5	-	C
Base temperature for growth (Tbase)	°C	12	-	C
Optimum temperature for growth (Topt)	°C	28	-	C
Initial leaf area index (LAIini)	m^2 m^{-2}	0.018	-	C
Full canopy coefficient (Kc)	-	1.2	-	C
Maximum leaf area index (LAImax)	m^2 m^{-2}	6	-	D

[*] Values are specified only when differ from direct sowing ones