Crop Monitoring as an
E-agricultural tool in
Developing Countries

REPORT ON CGMS ADAPTATION IN ANHUI

V1.0

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TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

ACRONYMS & GLOSSARY

Term	Explanation
AIFER	Anhui Institute For Economic Research
CGMS	Crop Growth Monitoring System
DOA	Day of anthesis
DOD	Day of dough
DOE	Day of emergence
DOH	Day of heading
DOG	Day of regreening
DOL	Days Of growing Length
DOJ	Day of jointing
DOM	Day of maturity
DOP	Day of planting
DOT	Day of tillering
NUTS	Nomenclature of Territorial Units for Statistics
TSUM1	The effective temperature sum from emergence to anthesis
TSUM2	The effective temperature sum from anthesis to maturity
WOFOST	WOrld FOod STudies

EXECUTIVE SUMMARY

A calibration of the CGMS/WOFOST was carried out by Alterra using data collected for Anhui, China by partner AIFER. The calibration was carried in two steps:

1. A detailed calibration using biophysical observations of wheat from the Fengqiu agro-experimental site
2. A regional calibration using general phenological observations for wheat from 11 stations in and around Anhui.

Results from the first calibration demonstrate that WOFOST simulates the first two years quite well for the Zhengmai9023 cultivar. Results for the two later years are more variable, but also the quality of the observations for these years is less good. A general problem we encountered is that the final crop yield is still underestimated because the related parameter (FOTB) could not be calibrated due to problem with the calibration platform (CALPLAT).

The analysis of the 11 stations showed that a gradient in sowing dates exists from north to south Anhui. This gradient was implemented by splitting Anhui into three zones. For each zone the phenological parameters of WOFOST were optimized using data from all stations within a zone. The results demonstrate that the phenological variability can be captured by the model and the values of the TSUM1 and TSUM2 parameter show consistent changes from one zone to the next. Nevertheless, there is still a considerable scatter which is present inherently in the observations itself.

A validation of the system has to be carried out at regional level by comparing with the reported yield values for each county. These results will be reported in the CGMS-Anhui piloting report.

1. Introduction

Crop data are crucial for accurate simulation of crop growth using the WOFOST model in the CGMS-Anhui. AIFER has collected crop calendar data, crop experimental data and regional yield statistics for winter-wheat in the project target region around Anhui. SDLO, with the support from AIFER, has evaluated the collected data and built databases ready for being used in the CGMS-Anhui. Three types of data were collected which were reported in deliverables D21.1 and D21.2:

- Crop experimental data between 2003 and 2011 were collected at Fengqiu Comprehensive Agroecology Experiment Station (35°1’ N, 114°4’ E), Chinese Academy of Sciences. Besides crop phenological information, this dataset also includes the crop biophysical properties (LAI, biomass etc.) under different conditions (potential, water-limited, nutrient-limited).
- Crop calendar data from 11 counties in the northern Anhui province were collected by the project partner Anhui Institution for Economic Research. The data include winter wheat phenology between 1992 and 2012, some counties with shorter record period (DangShan, TiangChang, HuoQiu: 2002 - 2012).
- Yield statistics between 2000 and 2011 from several regions in the northern Anhui area were also collected. More years of data will be added into the database with the execution of the project.

This deliverable reports the work that was carried to adapt the parameterisation and crop calendar for the CGMS Anhui. Note that the calibration effort was already reported as part of deliverable D21.2 as it is a logical follow-up of the description of the calibration data. However, since a separate deliverable is foreseen for the adaptation for CGMS in Anhui (D23.4) these results should have been reported as in D23.4 (this document) as a separate deliverable.

Figure 1 shows the overview of the study area with the spatial distribution of the 11 counties along with the DEM (Red stars indicate the capital towns of the relevant counties, light lines are boundaries of counties, thick lines are boundaries of provinces). Most sites are located in the Huaibei Plain. The elevation difference in this region is less than 100m.
This report will give detailed description of the general characteristics of the data and the databases built upon the above mentioned data to operate CGMS –Anhui.

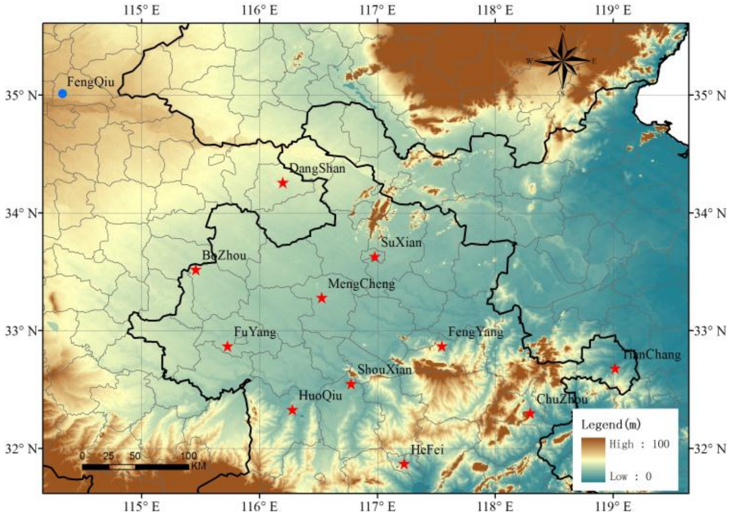


Figure 1: The study area with location of counties in Anhui province and Fengqiu experimental site.

2. CGMS adaptation for Anhui

2.1. Calibration using the comprehensive experimental data from Fengqiu station

2.1.1. Calibration approach

Detailed calibration was done using the crop data collected from Fengqiu Comprehensive Agroecology Experiment Station. It is found that the cultivar Zhengmai9023 has similar phenology with those collected from the 11 counties in the northern Anhui, while and Xinmai19 has rather different phenological characteristics. The optimization of parameters used in WOFOST model therefore was carried out using the data for cultivar Zhengmai9023 only also the quality and number of observations in the database was better for cultivar Zhengmai9023 then for cultivar Xinmai19.

The calibration itself was carried out using the CGMS calibration platform (CALPLAT) which iteratively searches for the best solution by varying the values of selected parameters in the parameter space. The objective function used by CALPLAT is the Relative Root Mean Squared Error and the calibration was done using a two-stage approach: 1) calibrate the parameters related to phenology (TSUM1, TSUM2, DLC, DLO) using the observed phenological stages; 2) calibrate the parameters related to photosynthesis and leaf area development (AMAXTB, SPAN and TDWI). Moreover, the Specific Leaf Area (SLATB) was modified by directly calculating the SLATB values from measurements of crop leaf area and leaf biomass.

The final crop yield, was not directly used as target parameter in the calibration of the system due to problems with the adjusting the FOTB (partitioning to storage organs) in the CGMS Calibration Platform (CALPLAT).

2.1.2. Calibration results

2.1.2.1. Calibration of Tsums

The calibrated values of Tsums (Tsum1 and Tsum2) are given in Table 5. Tsum1 is the effective temperature sum from emergence to anthesis, Tsum2 is the effective temperature sum from anthesis to maturity. It is found that the calibrated values of Tsums are very different form the default values, in particular for Tsum1.

Table 1: Recalibrated parameters TSUM1, TSUM2, DLO, DLC at for winter wheat using data from Fengqiu site.

		Default	Calibrated
TSUM1	Thermal time from emergence to anthesis (°C.d).	1100	599
TSUM2	Thermal time from anthesis to maturity (°C.d).	975	751
DLO	Optimal day length for phenological development	12	13.95
DLC	Critical day length for phenological development	8	10.09

2.1.2.2. Parameters optimization

Full set of calibrated parameters in WOFOST model using data from Fengqiu site are listed below in Table 6.

Table 2: List of WOFOST model parameters optimized through the calibration using data from Fengqiu site.

		Default		Calibrated	
PARAMETER	**Description**	**XVALUE**	**YVALUE**	**XVALUE**	**YVALUE**
AMAXTB_01	+	0	35.83	0	29.476601
AMAXTB_02		1	35.83	1	29.476601
AMAXTB_03		1.3	35.83	1.3	29.476601
AMAXTB_04		2	4.48	2	3.6856
CFET	Correction factor for evapotranspiration in relation to the reference crop.	1			
CVL	Conversion efficiency of assimilates into leaf (kg/kg).	0.685			
CVO	Conversion efficiency of assimilates into storage organ (kg/kg).	0.709			
CVR	Conversion efficiency of assimilates into root (kg/kg).	0.694			
CVS	Conversion efficiency of assimilates into stem (kg/kg).	0.662			
DEPNR	Crop group number for soil water depletion.	4.5			
DLC	Critical day length (photoperiod)	8		10.09	

		Default		Calibrated	
PARAMETER	**Description**	**XVALUE**	**YVALUE**	**XVALUE**	**YVALUE**
	(hr).				
DLO	Optimum day length (photoperiod) (hr).	12		13.95	
DTSMTB_01	Daily increase in thermal time as function of average temperature (°C.d).	0	0		
DTSMTB_02		25	25		
DTSMTB_03		45	25		
DVSEND	Development stage at harvest.	2			
EFF	Initial light-use efficiency of CO2 assimilation of single leaves ((kg/ha.hr)/(J/m2.s)) as function of mean daily temperature.	0.45			
FLTB_01	Fraction of above ground dry matter increase partitioned to leaves as a function of development stage (-; kg/kg).	0	0.65		
FLTB_02		0.1	0.65		
FLTB_03		0.25	0.7		
FLTB_04		0.5	0.5		
FLTB_05		0.646	0.3		
FLTB_06		0.95	0		
FLTB_07		2	0		
FOTB_01	Fraction of above ground dry matter increase partitioned to storage organs as a function of development stage (-; kg/kg).	0	0		
FOTB_02		0.95	0		
FOTB_03		1	1		
FOTB_04		2	1		
FRTB_01	Fraction of total dry matter increase partitioned to roots as a function of development stage (-; kg/kg).	0	0.5		
FRTB_02		0.1	0.5		
FRTB_03		0.2	0.4		
FRTB_04		0.35	0.22		
FRTB_05		0.4	0.17		
FRTB_06		0.5	0.13		
FRTB_07		0.7	0.07		
FRTB_08		0.9	0.03		
FRTB_09		1.2	0		
FRTB_10		2	0		
FSTB_01	Fraction of above ground dry matter increase partitioned to stems as a function of development stage (-; kg/kg).	0	0.35		
FSTB_02		0.1	0.35		
FSTB_03		0.25	0.3		
FSTB_04		0.5	0.5		
FSTB_05		0.646	0.7		
FSTB_06		0.95	1		

		Default		Calibrated	
PARAMETER	**Description**	**XVALUE**	**YVALUE**	**XVALUE**	**YVALUE**
FSTB_07		1	0		
FSTB_08		2	0		
IAIRDU	Presence of air ducts in roots (e.g. rice).	0			
IDSL	Factor on which development rate between development stage 0 and 1 depends (temperature)	1			
KDIF	Extinction coefficient for diffuse visible light as function of development stage.	0.6			
LAIEM	Leaf area index at emergence (ha/ha).	0.138			
PERDL	Max. relative death rate of leaves due to water stress (-; kg/kg.d).	0.03			
Q10	Relative change in respiration rate per 10°C temperature change.	2			
RDI	Initial rooting depth (cm).	10			
RDMCR	Max. rooting depth of mature crop (plant characteristic) (cm)	125			
RDRRTB_01	Relative death rate of roots as a function of development stage (-; kg/kg.d).	0	0		
RDRRTB_02		1.5	0		
RDRRTB_03		1.5001	0.02		
RDRRTB_04		2	0.02		
RDRSTB_01	Relative death rate of stems as a function of development stage (-; kg/kg.d).	0	0		
RDRSTB_02		1.5	0		
RDRSTB_03		1.5001	0.02		
RDRSTB_04		2	0.02		
RFSETB_01	Reduction factor for senescence as function of development stage.	0	1		
RFSETB_02		2	1		
RGRLAI	Max. relative increase in LAI (ha/ha.d).	0.00817			
RML	Relative maintenance respiration rate leaves (kg(CH2O)/kg.d).	0.03			
RMO	Relative maintenance respiration rate storage organs (kg(CH2O)/kg.d).	0.01			
RMR	Relative maintenance respiration rate roots (kg(CH2O)/kg.d).	0.015			

		Default		Calibrated	
PARAMETER	**Description**	**XVALUE**	**YVALUE**	**XVALUE**	**YVALUE**
RMS	Relative maintenance respiration rate stems (kg(CH2O/kg.d)).	0.015			
RRI	Max. daily increase in rooting depth (cm/d).	1.2			
SLATB_01	Specific leaf area as a function of development stage (-; ha/kg).	0	0.00212	0	0.00212
SLATB_02		0.5	0.00212	0.5	0.0015
SLATB_03		2	0.00212	2	0.0015
SPA	Specific pod area (ha/kg).	0			
SPAN	Life span of leaves growing at 35°C (days).	35		23.5	
SSA	Specific stem area (ha/kg) as a function of development stage.	0			
TBASE	Lower threshold temperature for ageing of leaves (°C).	0			
TBASEM	Lower threshold temperature for emergence(°C).	0			
TDWI	Initial total crop dry weight (kg/ha).	50		195	
TEFFMX	Max. effective temp. for emergence (°C).	30			
TMNFTB_01	Reduction factor of gross assimilation rate as function of low min. temperature (°C;-).	-5	0		
TMNFTB_02		0	1		
TMPFTB_01	Reduction factor of AMAX as function of average temperature (°C).	0	0.01		
TMPFTB_02		10	0.6		
TMPFTB_03		15	1		
TMPFTB_04		25	1		
TMPFTB_05		35	0		
TSUM1	Thermal time from emergence to anthesis (°C.d).	1100		599	
TSUM2	Thermal time from anthesis to maturity (°C.d).	975		751	
TSUMEM	Thermal time from sowing to emergence (°C.d).	100			

2.1.2.3. Predicted biomass, yields and LAI

The values of calibrated parameters are applied in CGMS-Anhui to simulate the crop growth in terms of biomass, crop yield and leaf area index so that the calibration can be evaluated. The simulation results are shown in **Fig. 15** and **16**.

While the simulated curves of biomass and yield in the two cases in 2003-2004 and 2005-2006 growing cycle have followed well the observed values (**Fig. 15a, b**), the other two cases showed poorer simulation results (**Fig. 15c. d**). Similar performance was found for LAI simulation (**Fig. 16**). Moreover, the curves for the simulated crop yield tend to underestimate the final observed crop yield in all four cases.

(a) (b)

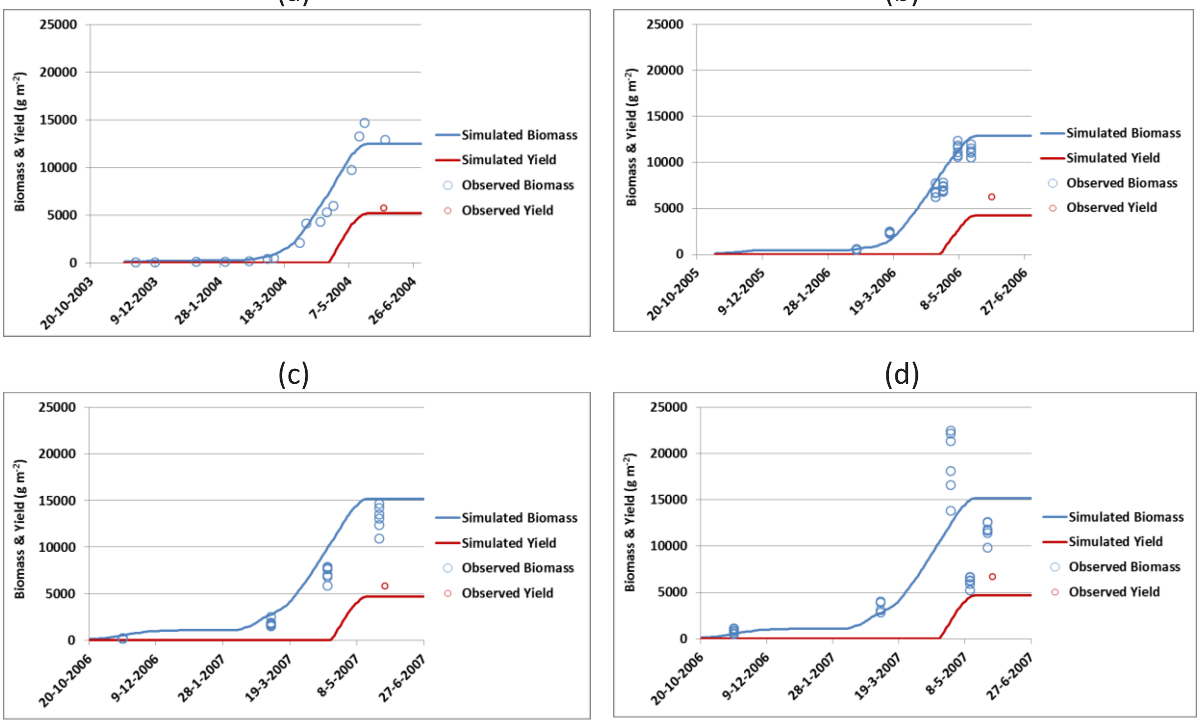
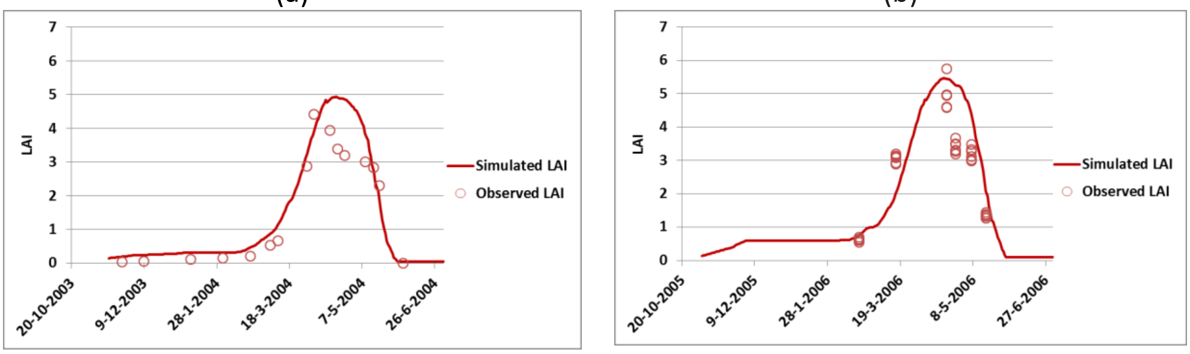
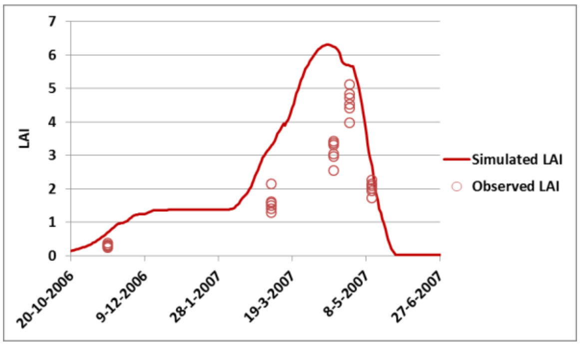


Figure 2: Comparison of the simulated biomass and yield against the observations for winter wheat crop at Fengqiu experimental site in different years.

(a) (b)



(c) (d)



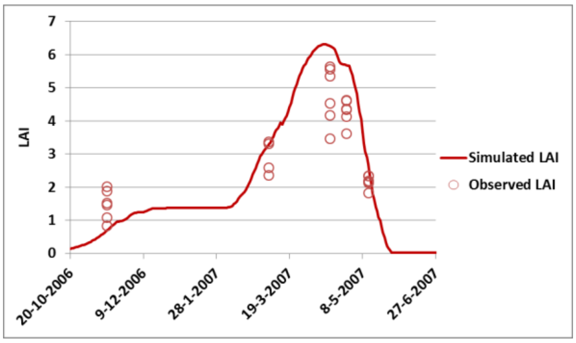


Figure 3: Comparison of the simulated leaf are index against the observations for winter wheat crop at Fengqiu experimental site in different years (same data as in Fig. 15).

2.2. Calibration using the crop phenology data from northern Anhui

2.2.1. Calibration approach

Considering that only the data of crop phenological stages are available in the northern Anhui region, only major crop parameters that influence the phenological development stages were calibrated, say Tsum1 and Tsum2. Tsum1 is the effective temperature sum from emergence to anthesis, Tsum2 is the effective temperature sum from anthesis to maturity. All other parameters are taken from the calibration from Fengqiu experimental sites.

Crop calendar data used for calibration are day of planting (DOP), day of emergence (DOE), day of anthesis (DOA), day of maturity (DOM) and day of harvest (DOH) are used for calibration. Since DOA was not observed in the dataset, it is calculated by adding 7 days to the observed day of heading. Day of harvest was also not observed. Although the DOH depends highly on management practices and favourable weather conditions, it is assumed that a farmer left his crop on the field for on average one week after physiological maturity. Therefore DOH for calibration was calculated by adding 7 days to the DOM.

For calibrating Tsum1, the observed DOP, DOE and DOA were used. For calibrating Tsum2, observed DOA and DOM and/or DOH were used.

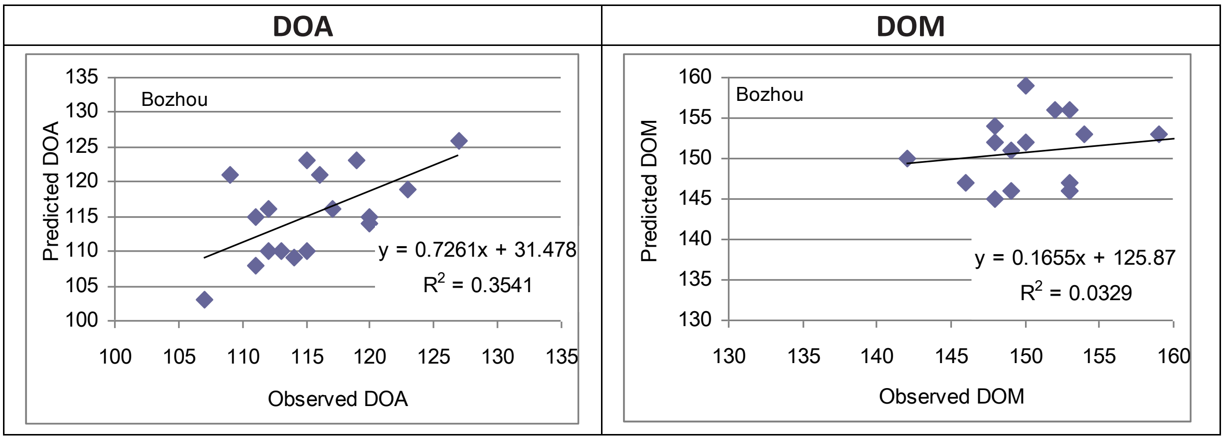
2.2.2. Calibration results and predicted anthesis and maturity dates at each county

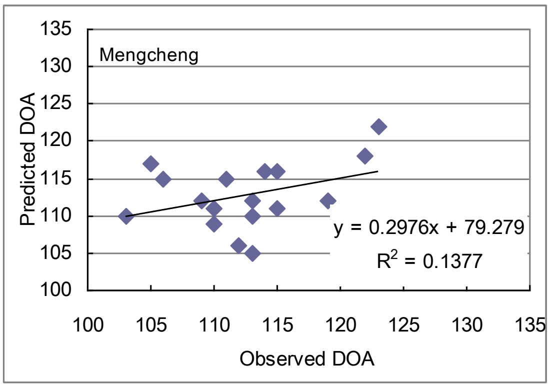
The calibrated Tsum1 and Tsum2 for each county together with the errors in the predicted DOA and DOM are listed in **Table 7**. The calibrated Tsum1 and Tsum2 have the mean values of 787.1 ^{o}C day (default as 1100) and 700.8 ^{o}C day (default as 750) with their standard deviations as 47.6 and 45 ^{o}C day respectively. For the predicted DOA, the RMSE of the ranges between 2.9 and 6.53 days, the coefficient of determination R^2 is between

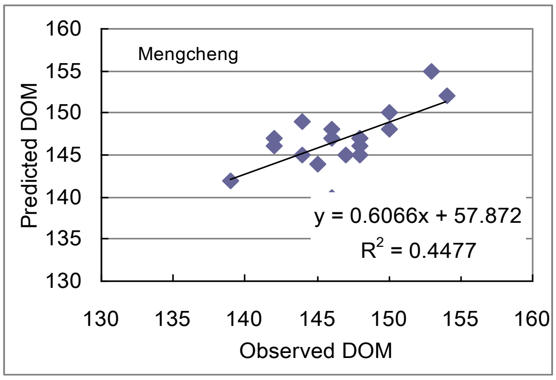
0.138 and 0.744. For the predicted DOM, the RMSE of the ranges between 2.88 and 5.43 days, the coefficient of determination R^2 is between 0.033 and 0.882. Comparison between the predicted and the observed DOA and DOM in each county are shown in **Figs. 17**. **Fig. 18** gives the results taking the 11 counties as whole.

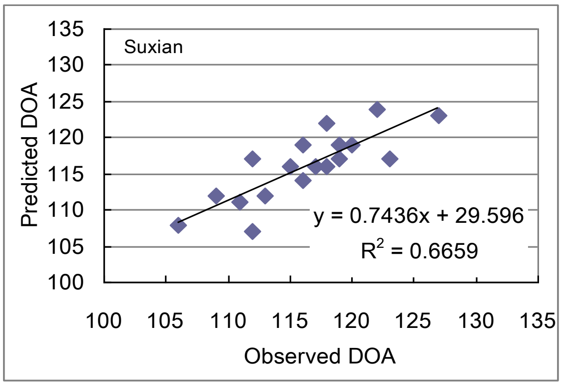
Table 3: Recalibrated parameters Tsum1 and Tsum2 and the performance of prediction on DOA and DOM for each county in the northern Anhui region.

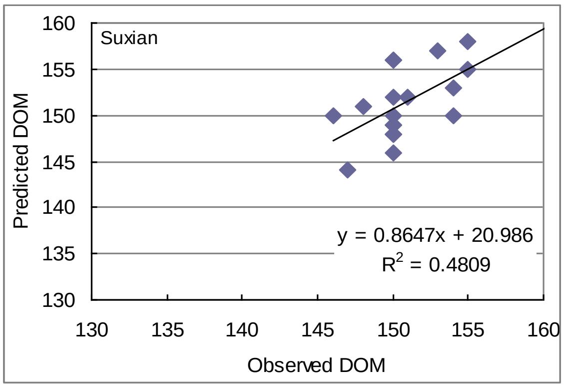
ID	County	Tsum1	Tsum2	DOA			DOM		
		°C day	°C day	RMSE (day)	R^2	Slope	RMSE (day)	R^2	slope
58015	Dangshan								
58102	Bozhou	838.9	736.0	5.2	0.354	0.726	5.43	0.033	0.166
58118	Mengcheng	753.0	673.6	5.41	0.138	0.298	2.88	0.448	0.607
58122	Suxian	815.3	720.7	2.98	0.666	0.744	3.08	0.481	0.865
58203	Fuyang	837.1	744.1	4.7	0.472	0.497	2.41	0.529	0.592
58214	Huoqiu	849.3	589.9	3.61	0.556	0.619	2.62	0.689	1.489
58215	Shouxian	748.0	691.4	3.76	0.695	0.686	2.49	0.584	0.731
58222	Fengyang	805.7	691.8	4.7	0.474	0.497	3.21	0.530	0.592
58236	Chuzhou	769.3	732.3	3.67	0.599	0.605	3.15	0.414	0.503
58240	Tianchang	727.3	722.4	3.23	0.682	0.596	2.08	0.882	1.862
58321	Hefei	726.9	706.0	6.53	0.493	0.307	3.77	0.659	0.458
Mean(Total)		787.1	700.8	4.5			3.3		
Std (Total)		47.6	45.0						

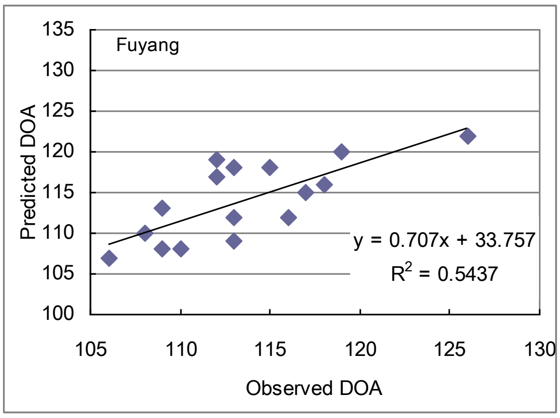


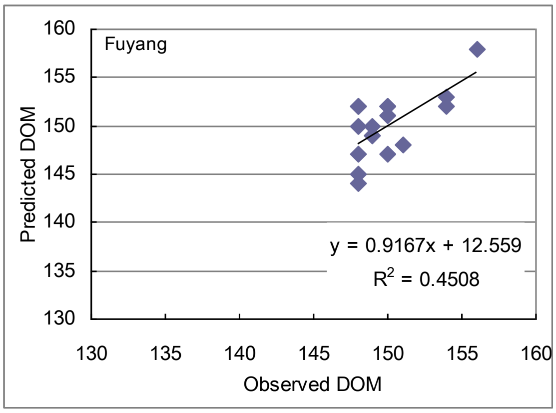

Mengcheng
Predicted DOA
Observed DOA
y = 0.2976x + 79.279
R² = 0.1377

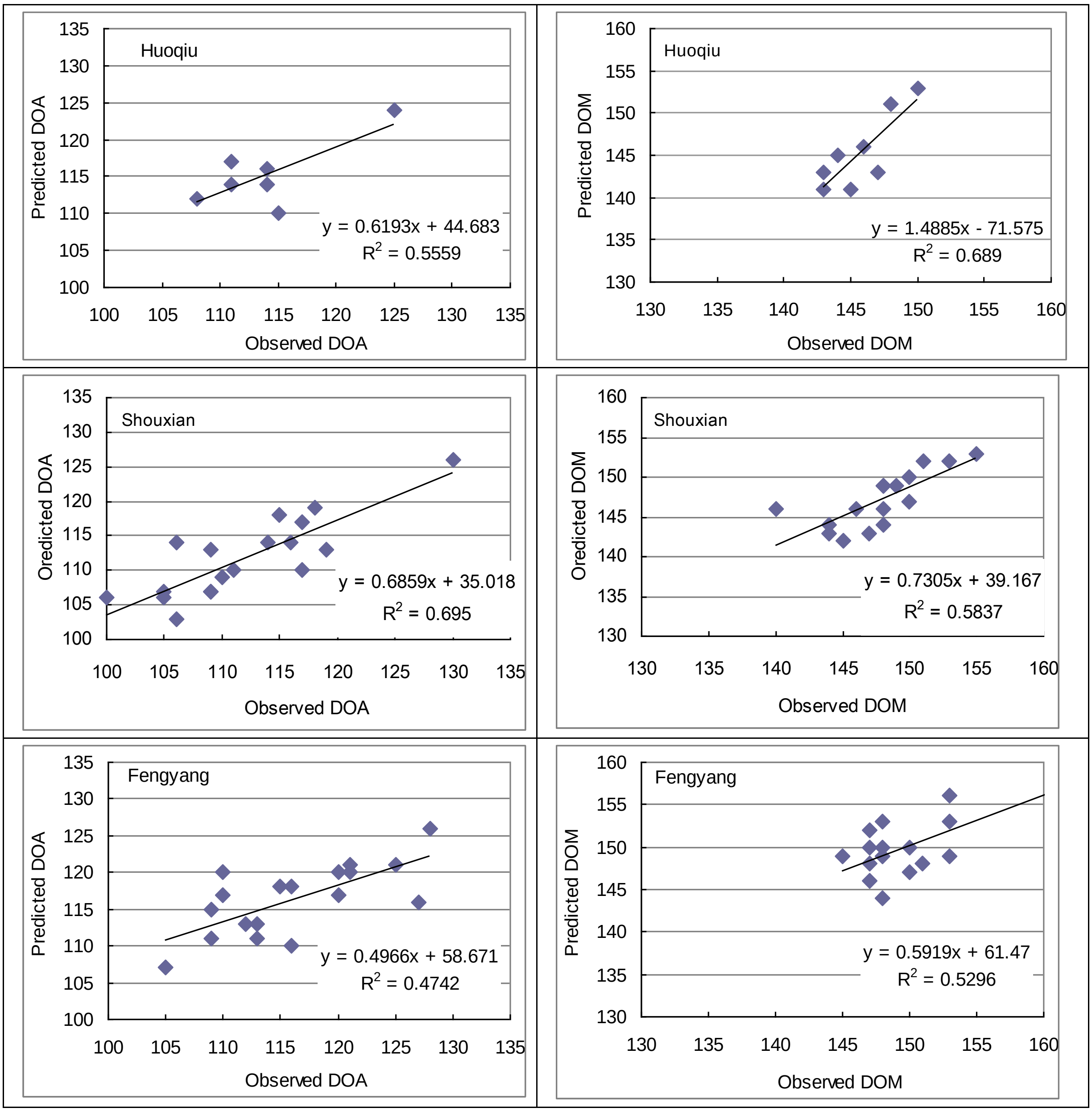

Mengcheng
Predicted DOM
Observed DOM
y = 0.6066x + 57.872
R² = 0.4477


Suxian
Predicted DOA
Observed DOA
y = 0.7436x + 29.596
R² = 0.6659


Suxian
Predicted DOM
Observed DOM
y = 0.8647x + 20.986
R² = 0.4809


Fuyang
Predicted DOA
Observed DOA
y = 0.707x + 33.757
R² = 0.5437


Fuyang
Predicted DOM
Observed DOM
y = 0.9167x + 12.559
R² = 0.4508


Huoqiu
Predicted DOA
Observed DOA
y = 0.6193x + 44.683
R2 = 0.5559
Huoqiu
Predicted DOM
Observed DOM
y = 1.4885x - 71.575
R2 = 0.689
Shouxian
Oredicted DOA
Observed DOA
y = 0.6859x + 35.018
R2 = 0.695
Shouxian
Oredicted DOM
Observed DOM
y = 0.7305x + 39.167
R2 = 0.5837
Fengyang
Predicted DOA
Observed DOA
y = 0.4966x + 58.671
R2 = 0.4742
Fengyang
Predicted DOM
Observed DOM
y = 0.5919x + 61.47
R2 = 0.5296

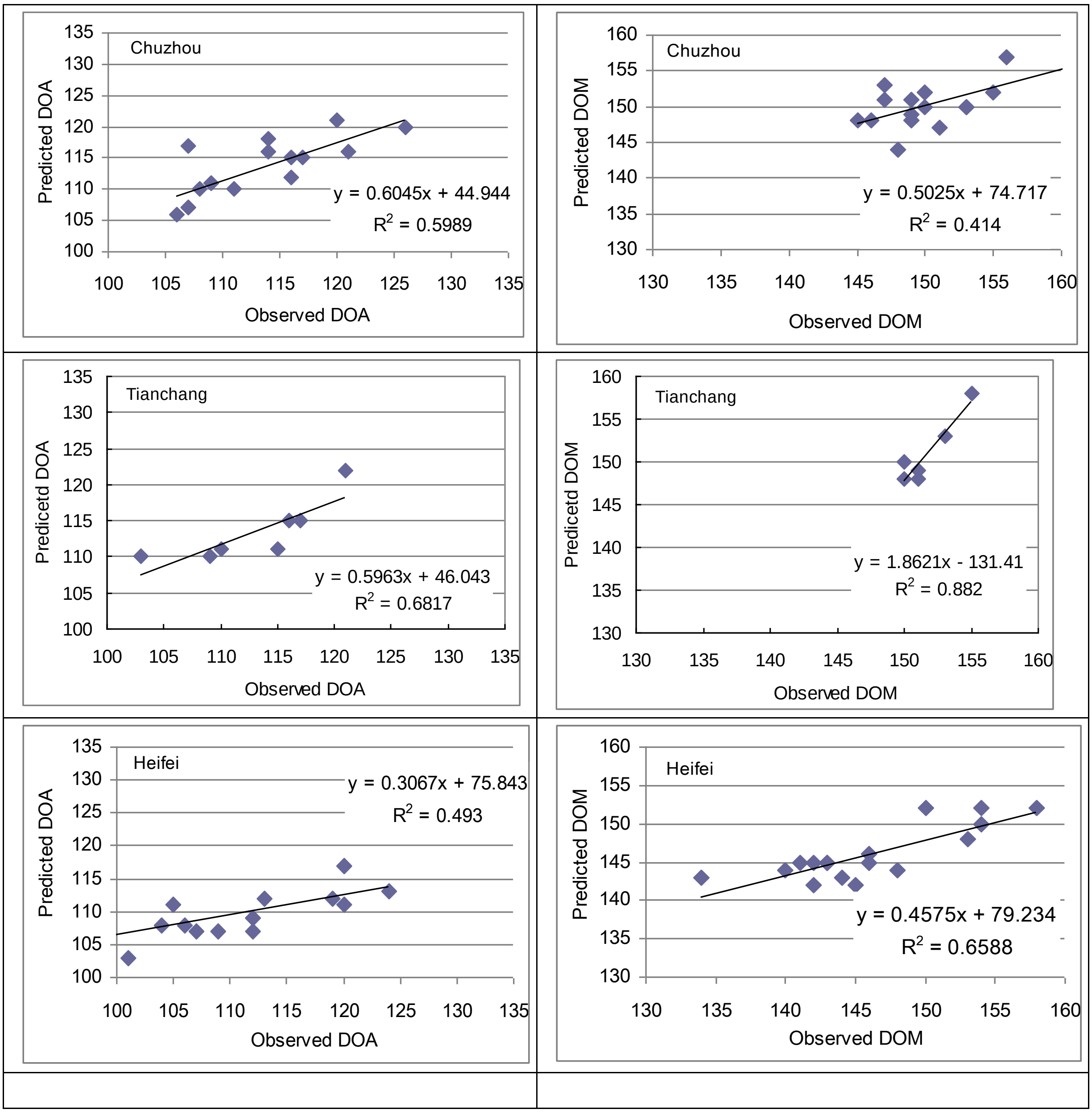


Figure 4: The comparison between the predicted and observed DOA and DOM of each county in northern Anhui.

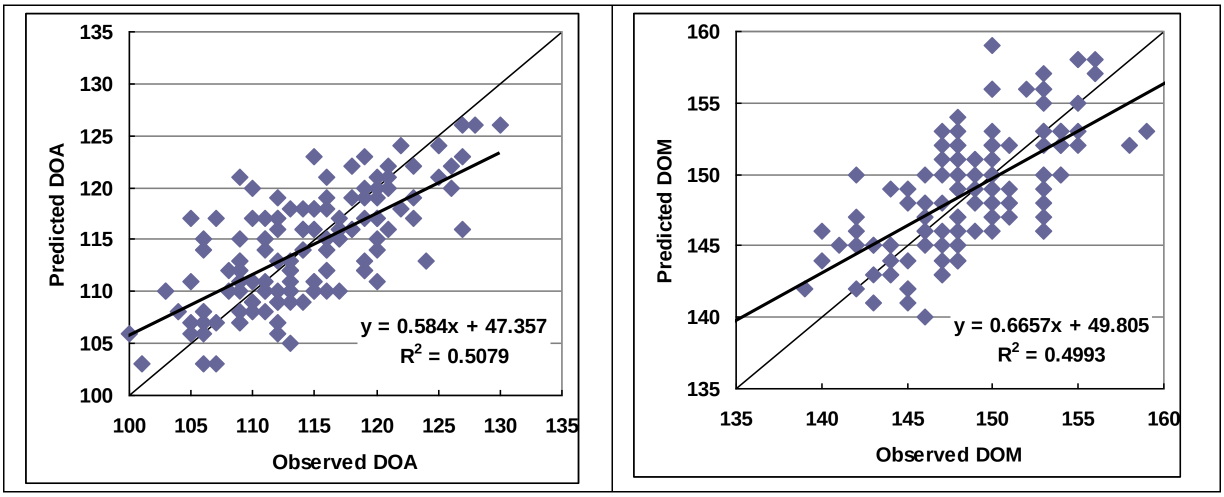


Figure 5: The comparison between the predicted and observed as the whole in northern Anhui.

2.3. Regional Calibration of CGMS-Anhui

2.3.1. Calibration approach

As found in section 3.1, the study region of Anhui showed differences in climate and in turn the crop phenology, i.e. with gradient in phenology from north to the south. Therefore, the study region in Anhui is divided into three zones for calibration (**Fig. 19**). Except Tsum1 and Tsum2, the optimized parameters calibrated at Fengqiu experimental station (see section 3.2) are applied uniquely to the three zones in Anhui, while calibration of Tsum1 and Tsum2 are carried out for each one of the tree zones separately.

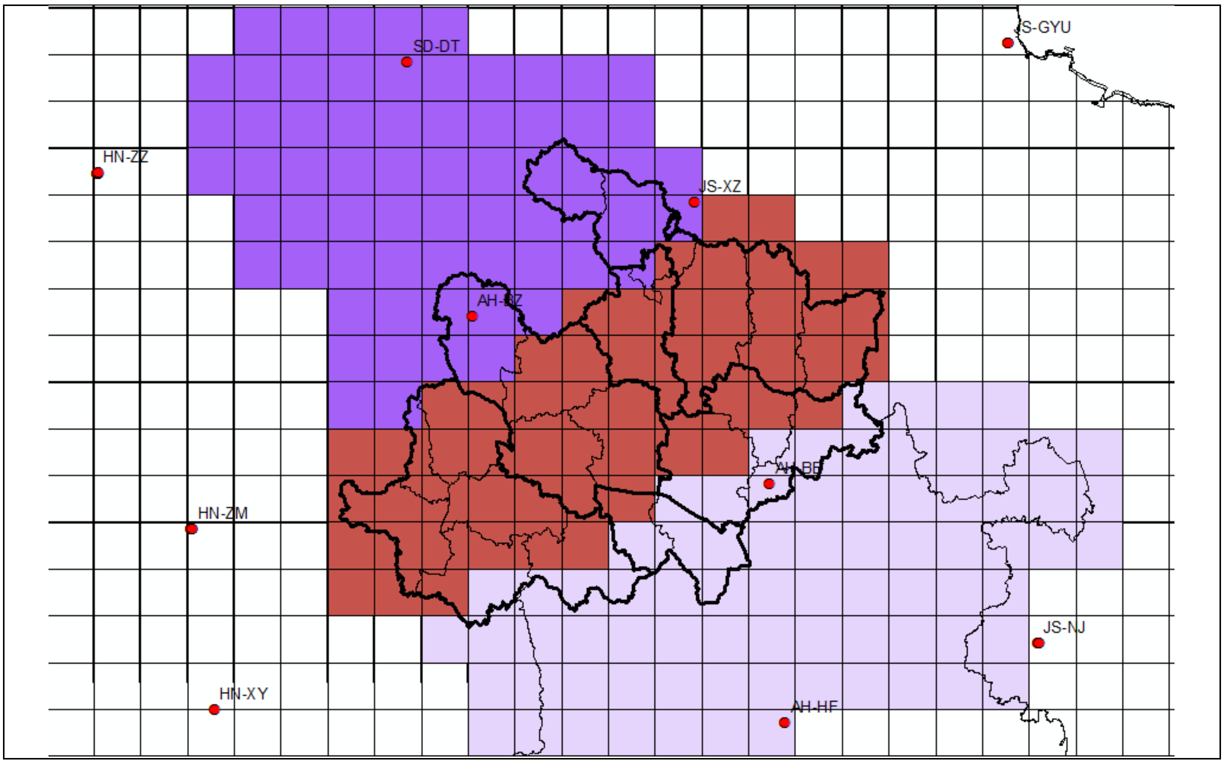


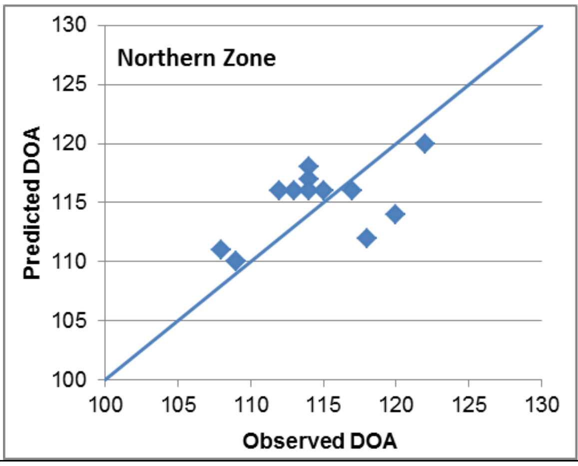
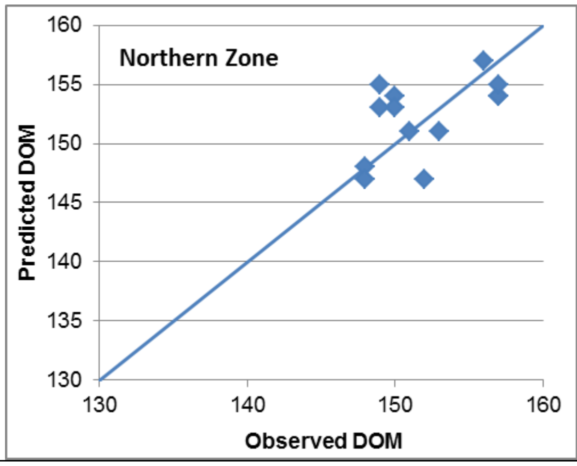
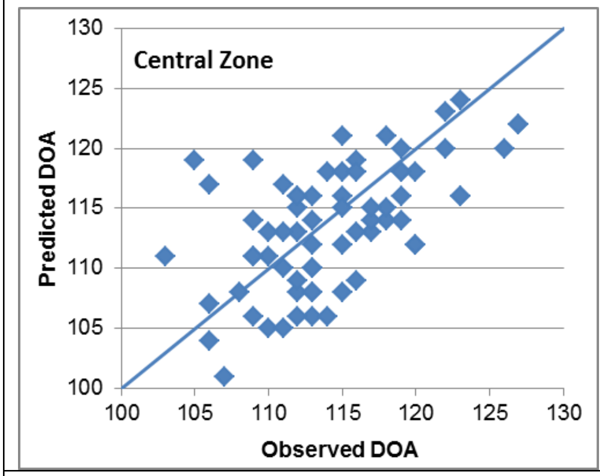
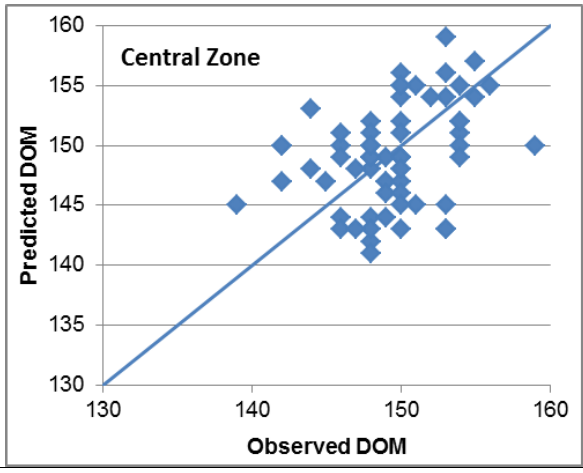
Figure 6: The division of three climate zones for regional calibration.

2.3.2. Calibration results

Table 8 gives the calibrated values of TSUM1 and TSUM2 for the three regions (north, central and south). Fig. 20 shows the comparison between the observed phenology and the calibrated ones, indicating in general a good agreement in trends though scattering existing.

Table 4: Recalibrated parameters Tsum1 and Tsum2 and the performance of prediction on DOA and DOM for the three zones of the northern Anhui region. (Default values of Tsum1 and Tsum2 are 1100 and 975 respectively)

Zone	Nr of sources	Tsum1	Tsum2	DOA	DOM
		°C day	°C day	RMSE (day)	RMSE (day)
North		791.2	763.9	3.3	3.2
Central		794.8	715.6	4.8	4.3
South		758.2	706.4	5.1	3.4

DOA	DOM
Northern Zone	
	
Central Zone	
	
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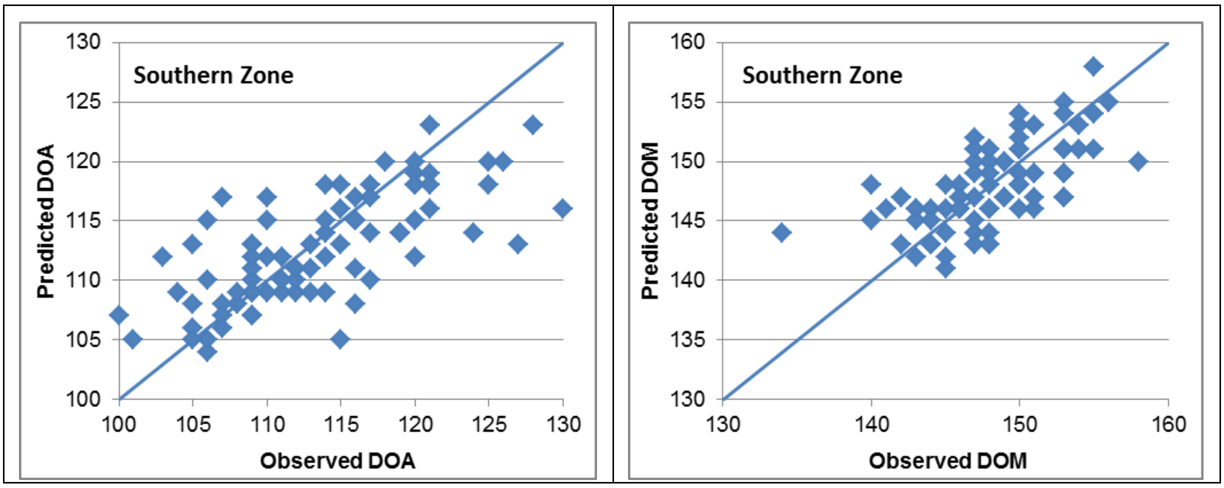

Figure 7: The comparison between the predicted and observed DOA (left column) and DOM (right column) in each zone of the northern Anhui.

3. Conclusions and recommendations

The databases that have been collected for Anhui province provide an excellent start for the setup of the WOFOST model for winter-wheat in Anhui. First of all, the detailed observations from the Fengqiu experimental site allow a very detailed calibration including complex parameters in the WOFOST model. Second, the regional phenological observations for each county allow making spatial adjustments to a limited number of parameters and allow defining the crop calendar (crop sowing) over the entire region which has to be implemented in CGMS.

Analysis of the data for the Fengqiu site showed that the quality and number of observations is variable between years, cultivars and experiments. In general, the data for the Zhengmai9023 cultivar is considerably better than the for the later XinMai19 cultivar. Moreover, the phenological characteristics of the Xinmai19 cultivar deviate quite strongly from the phenological characteristics that were derived from the regional phenological observations. Therefore, the detailed calibration of WOFOST focused on the Zhengmai9023 cultivar which is probably more representative of the wheat cultivar that is predominantly cultivated in Anhui. The Xinmai19 cultivar may be a new cultivar which has not yet seen widespread cultivation in Anhui.

The results from the calibration of the phenology at Fengqiu demonstrate that the observed phenological stages can be reasonably reproduced by the model and that the values for TSUM1, TSUM2, DLC and DLO are considerable different from the default values. Also the critical and optimal day length (DLC: 10.09 hour and DLO: 13.95 hour) are quite close to the shortest day length at the latitude of Anhui (10 hour) and the day length around flowering in Anhui (14 hours).

The calibration results for biomass and LAI show variable results: For the first two experimental seasons (2003-2004 and 2005-2006) the simulated curves well fit the observed data. However, the results for the two other experiments show less satisfactory results, although the figures also demonstrate that the data quality is less good in those years. For calibrating the final crop yield, we encountered a technical problem with CALPLAT which failed calibrating the relevant parameter (FOTB). The result is that the current calibration results underestimate the final crop yield. Calibration of this parameter may still be needed also given the short grain filling period in Anhui.

The data from phenological observations from the 11 counties was used successfully to regionalize the detailed calibration from the Fengqiu site. Using the phenological observations we identified a gradient in the sowing date of the wheat, with later sowing from north to south Anhui. Therefore, the area was split into three zones for which a sowing date was estimated from the data. After calibrating the phenological parameters in WOFOST (only TSUM1 and TSUM2) for each zone individually, we found that the values of the phenological parameters are slightly shifting to lower values from the northern to the southern zone in Anhui. In general, the variability in the phenological observations can be reasonably explained by WOFOST.

Finally, we can conclude that the CGMS/WOFOST has now been set up well for Anhui and sufficient data could be used to calibrate the different parameters of the model and to make a spatial implementation of it. The validation of the system still has to be executed by comparing results from CGMS/WOFOST with the regional yield statistics for the different counties in Anhui. These results will be reported in the CGMS piloting report for Anhui.