Crop Monitoring as an
E-agricultural tool in
Developing Countries

REPORT ON CROP DATABASE IN ANHUI

V2.0

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2.0	20/12/2013	42	Executive summary, conclusion added. Some revisions to the text.	Allard de Wit

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ACRONYMS & CLOSSARY

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:

- 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.

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.

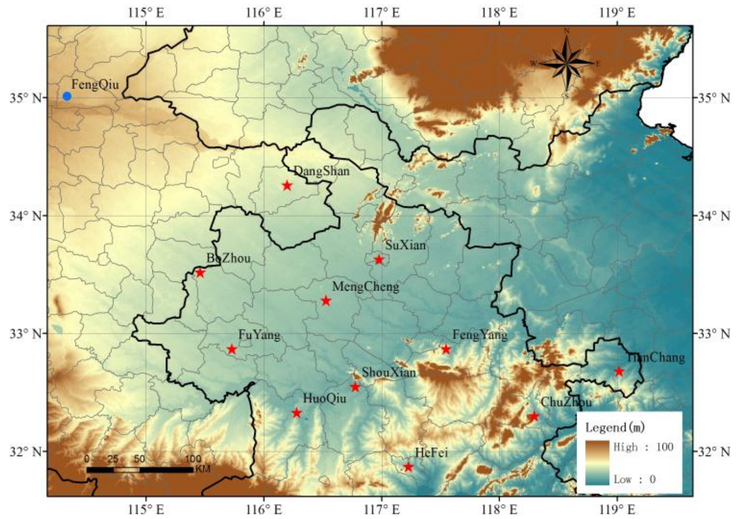


Figure 1: The study area with location of counties in Anhui province and Fengqiu experimental site.

2. Crop data in Anhui

2.1. Intensive crop experimental data at Fengqiu site

Intensive crop experiments were carried out at Fengqiu Comprehensive Agroecology Experiment Station (35°1' N, 114°4' E), Chinese Academy of Sciences, located in Fengqiu county of Henan province. This station is located in the North China Alluvial Plain (Huang-Huai-Hai-Plain) and in the northwest of the Anhui study area (**Fig. 1**). The location is characterized by a sub-humid climate with a mean annual temperature of 14°C and a mean annual precipitation of 615 mm.

The data were collected between 2003 and 2011. The experiments were carried out in 6 plots and with 4 different cultivars of winter wheat with time (year) (**Table 1**). The crops in each plot were applied by 3 different practices in fertilization and water supply, say, optimized practice (with optimal fertilization and water supply), no fertilization and water limited practice. However, in practice the differentiation between potential and water-limited conditions is sometimes difficult to make depending on the actual rainfall amount.

The crop phenology were observed including emergence, regreening, tillering, jointing, heading, anthesis, milking, dough, grain filling and maturity. Planting density (number of plants per square meter), mean crop height, crop leaf area index, number of tillers in each phonological stage, total above ground fresh biomass weight, stem dry biomass weight, leaf dry weight, total aboveground dry weight were also measured.

Four cultivars were planted during the experimental period: Zhengmai9023, Kenong199, Xinmai19 and Zhengmai336. As shown in Table 1, Zhengmai9023 was cultivated between 2003 and 2007, continued by Xinmai19 between 2007 and 2011. Three treatments (optimised fertilization and water supply condition, no fertilization and water limited condition) were applied to these two cultivars for each year. Kenong199 was planted for 2007-2008 under water limited condition only. In total 6 field plots for each cultivar were made in the same year.

Differences in phenological stages under different treatments are found not obvious, both for Zhengmai9023 and Xinmai19.

Table 1: List of crop data collected at Fengqiu experimental station.

Cultivar	Treatment	Plots	Period	Note
Zhengmai9023	No fertilization	2	2005 – 2007	DOP,DOE and DOM are missing
	Water limited	6	2005 - 2007	DOP,DOE and DOM are missing
	Optimisation	3, 4	2003 - 2007	DOP missing

Kenong199	No fertilization Water limited Optimisation	x 6 x	2007 - 2008	DOT, DOJ, DOH, DOF, DOD were ovserved
Xinmai19	No fertilization Water limited Optimisation	1, 2 5, 6 4	2007 - 2011 2008 – 2011 2007 - 2011	DOP, DOG, DOE, DOM missing DOP, DOG, DOE, DOM missing DOP, DOG, DOE, DOM missing
Zhengmai336	No fertilization Water limited Optimisation	2 x 4	2011 2011 2011	DOT only DOT only DOT only

Since Kenong199 and Zhengmai336 were only cultivated for one year with incomplete record for one year growing cycle, we decided to use Zhengmai9023 and Xinmai19 for calibration. Some fundamental properties of the crop phenology and yields were described in the following sections. All the values shown below are the average of all plots for each treatment in the same year.

2.1.1. Crop phenology

Three different treatments (optimisation, no fertilization, water limited) didn't make difference in the crop phenology bot for Zhengmai9023 and Xinmai19 (Figs 2, 3).
Zhengmai9023 and Xinmai19 showed very similar properties in crop phenology as seen in Fig. 4.

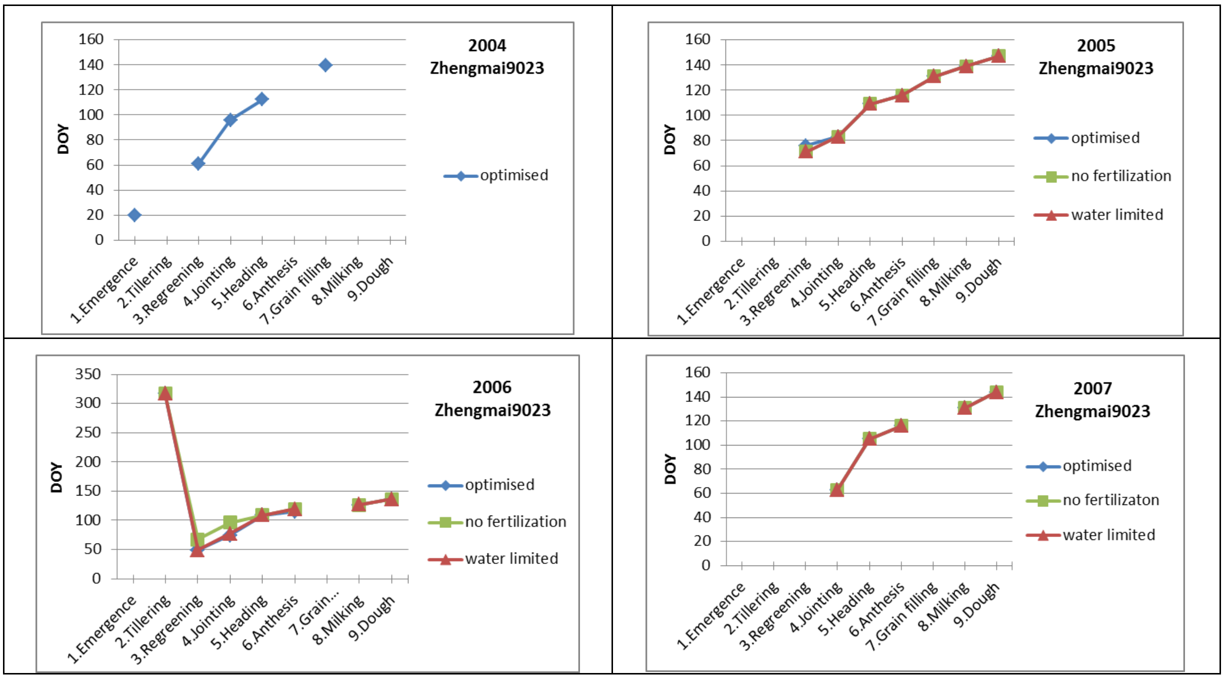


Figure 2: Crop phenology of winter wheat Zhengmai9023 under different treatments at Fengqiu experimental site.

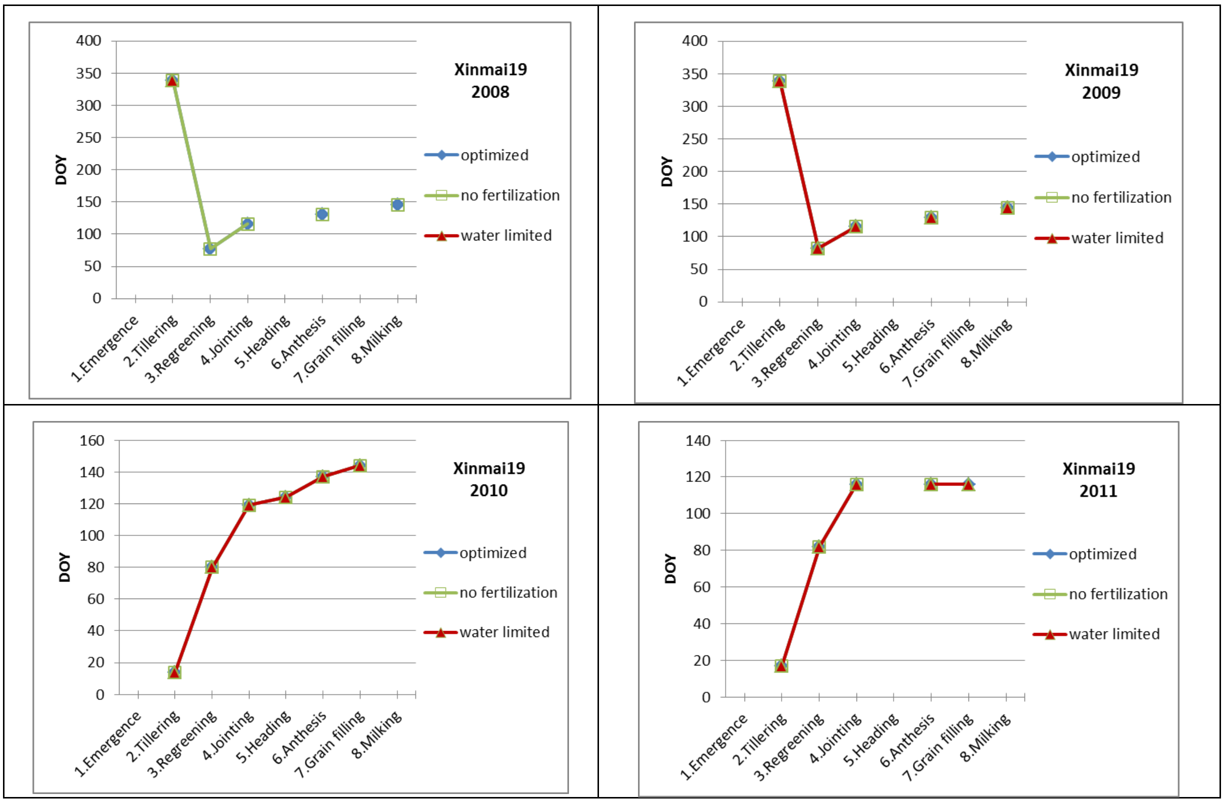


Figure 3: Crop phenology of winter wheat Xinmai19 under different treatments at Fengqiu experimental site.

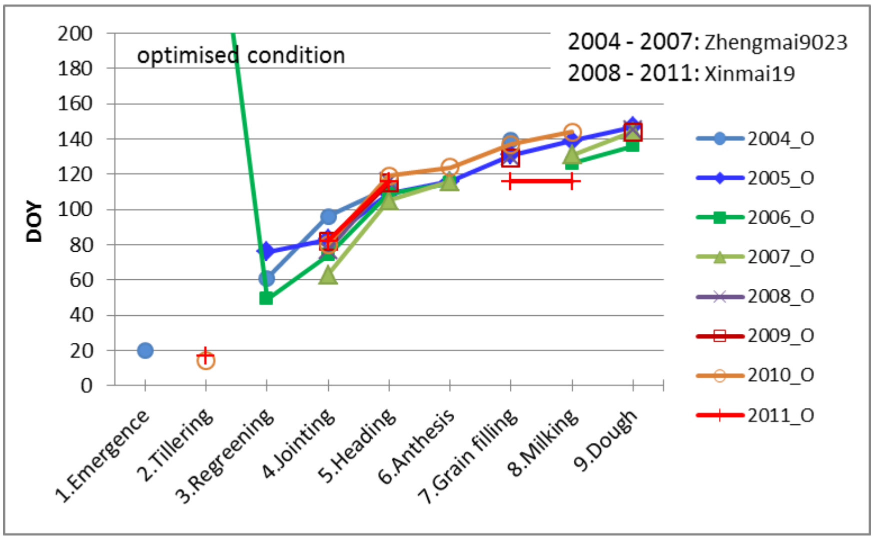


Figure 4: Crop phenology of winter wheat Zhengmai9023 and Xinmai19 under optimised condition at Fengqiu experimental site.

2.1.2. Crop growth and yield

LAI, total aboveground fresh weight (g/m^2), stem dry weight (g/m^2, leaf dry weight (g/$m^{2)}$, and total aboveground dry weight (g/m^2) were measured. Data of LAI and total aboveground dry weight (g/m^2) are described below. Impact on the LAI due to different treatments on the two cultivars of winter wheat are obvious (Figs. 5 and 6). In particular, large deviation under the "no fertilization" treatment from "optimised" condition were found. Abnormal observations of LAI were found in 2005 and 2007 for Zhengmai9023 (Fig. 5 b and d) and in 2010 for Xinmai19 (Fig. 6c), where the LAI values under "water limited" condition were even larger than those under "optimised" condition. This might be attributed to the uncertainties in the observation.
Fig. 7 gives the comparison of the LAI for the two cultivars under the same condition of "optimised", indicating that the LAI values were quite divers among different years.

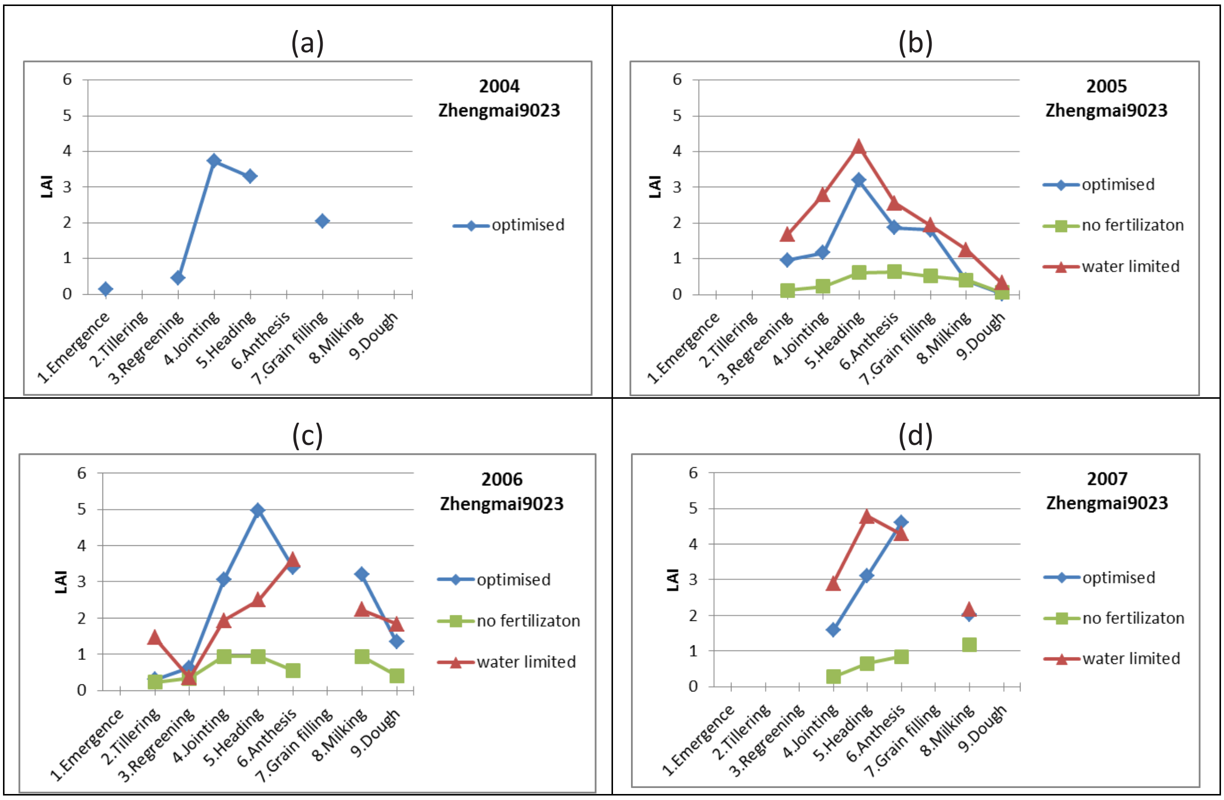


Figure 5: LAI of winter wheat Zhengmai9023 under different treatments at Fengqiu experimental site: (a) 2004; (b) 2005; (c) 2006; and (d) 2007.

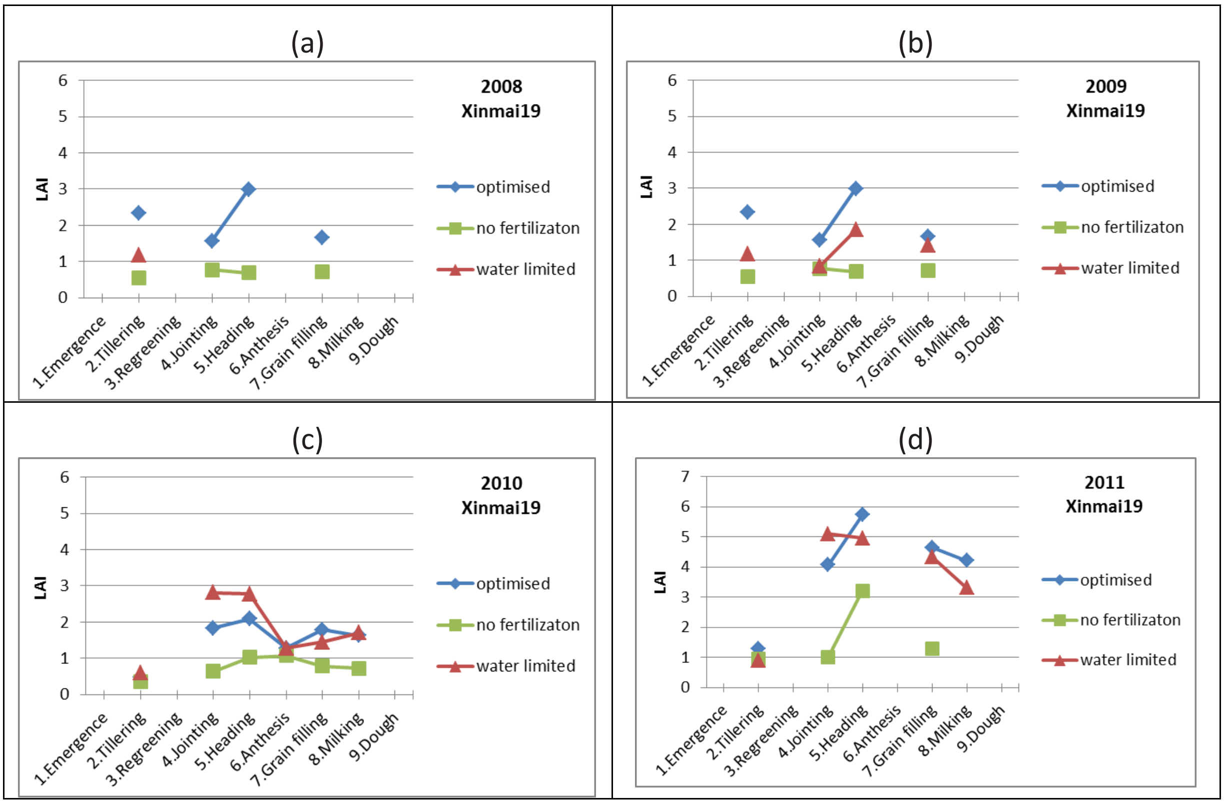


Figure 6: LAI of winter wheat Xinmai19 under different treatments at Fengqiu experimental site: (a) 2008; (b) 2009; (c) 2010; and (d) 2011.

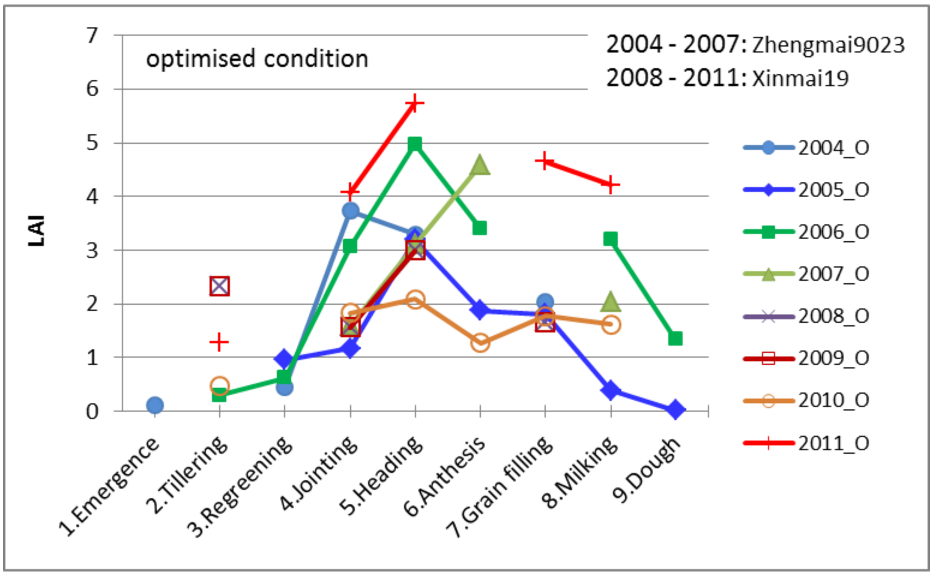


Figure 7: LAI of winter wheat Zhengmai9023 and Xinmai19 under optimised condition at Fengqiu experimental site.

Difference in the “total aboveground dry weight” between the “water limited” and “optimised” conditions are not significant. On the contrary, yield under “no fertilization” condition are significantly deviated from the “optimised” condition (Figs. 8 and 9). Abnormal values were found in 2007 for Zhengmai9023, where yield at ‘heading’ stage under “water limited” condition seemed too high (Fig. 8d).
Similar to LAI, yield in different years under the “optimised” condition showed very large differences (Fig.10).

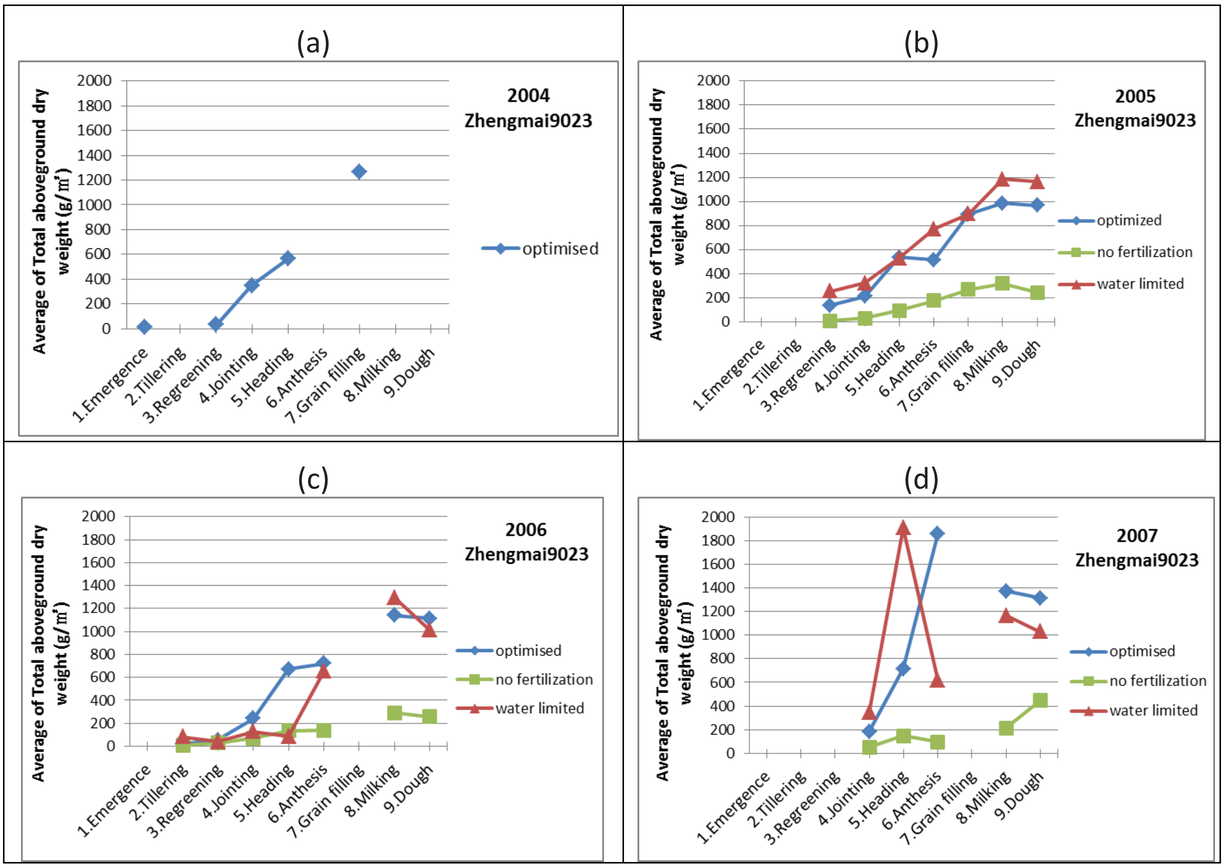


Figure 8: Total above ground dry weight of winter wheat Zhengmai9023 under different treatments at Fengqiu experimental site: (a) 2004; (b) 2005; (c) 2006; and (d) 2007.

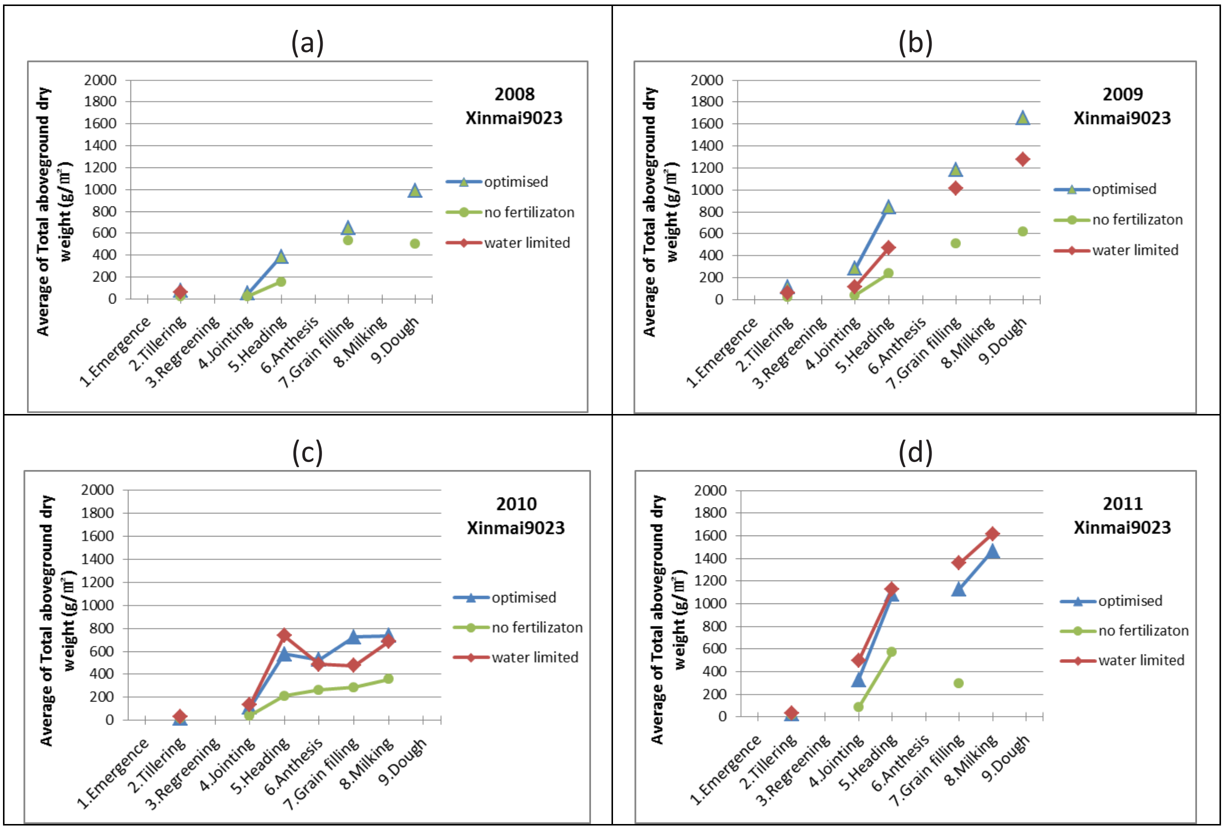


Figure 9: Total above ground dry weight of winter wheat Xinmai19 under different treatments at Fengqiu experimental site: (a) 2008; (b) 2009; (c) 2010; and (d) 2011.

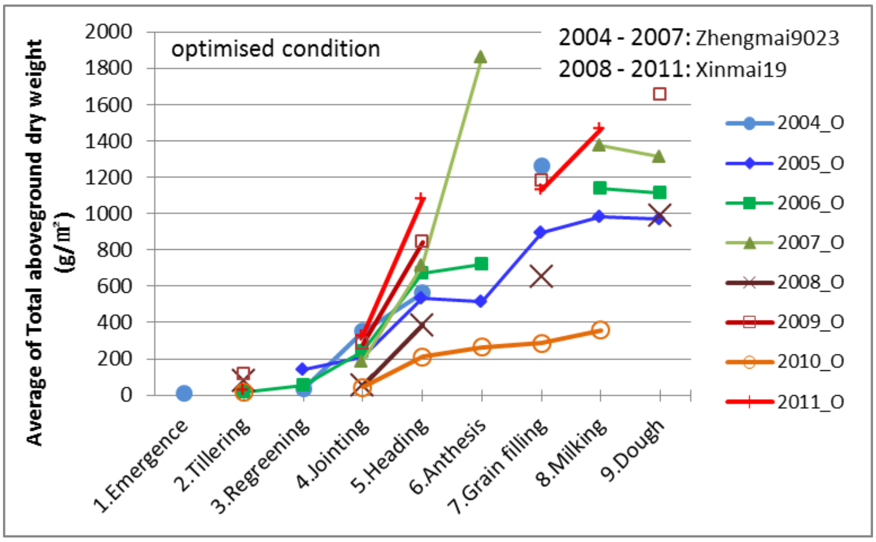


Figure 10: Total above ground dry weight of winter wheat Zhengmai9023 and Xinmai19 under optimised condition at Fengqiu experimental site.

2.2. Winter wheat calendar data in Anhui

Calendar data of winter wheat with different genotypes from 11 counties in the northern Anhui province were collected by the project partner Anhui Institution for Economic Research (AIFER). The spatial distribution of the 11 counties along with the DEM are shown in **Fig. 1**. Most sites are located in the Huaibei Plain. The elevation difference in this region is less than 100m.

The data were collected between 1992 and 2012 over 11 counties, some counties with shorter record period (Dangshan, Tiangchang, Huoqiu: 2002 - 2012). **Table 2** gives the information of record length of the crop data for each county.

Nine growing stages in winter wheat phenology were observed in these 11 counties including sowing, emergence, tillering, stop growing, regreening, jointing, heading, milking, and maturity. All the stages are expressed as day of the year (DOY) at their average starting days, for example day of planting (DOP), day of emergence (DOE), day of maturity (DOM), etc.

Table 2: Description of counties in Anhui province where the winter wheat calendar data are collected.

ID	Location	Province	Latitude	Longitude	Altitude	Time span	Nr of effective years
58015	Dangshan	Anhui	34.26	116.2		2002 - 2012	6
58102	Bozhou	Anhui	33.52	115.46		1992 – 2012	21
58118	Mengcheng	Anhui	33.28	116.53		1992 – 2012	21
58122	Suxian	Anhui	33.63	116.98		1992 – 2012	21

58203	Fuyang	Anhui	32.87	115.73	1992 – 2012	21
58214	Huoqiu	Anhui	32.33	116.28	2002 - 2012	10
58215	Shouxian	Anhui	32.55	116.78	1992 – 2012	21
58222	Fengyang	Anhui	32.87	117.55	1992 – 2012	21
58236	Chuzhou	Anhui	32.3	118.3	1992 – 2012	21
58240	Tianchang	Anhui	32.68	119.02	2002 - 2012	11
58321	Hefei	Anhui	31.87	117.23	1992 – 2012	21

The DOP and DOE showed clear gradient in this region with earlier days in the north and later days in the south (**Fig. 2**). On average, the range of DOP is varying between DOY 283 (belonging to the most northern county Dangshan) and DOY 297 (belong to the most southern county Hefei) (**Table 2**). The trend in the DOM in this region is not as significant as the DOP and DOE, ranging between 145 and 152. The length of growth (defined as the days between the planting day and the day of maturity) showed decreasing gradient from the north to the south (from 233 days to 208 days) though with some saltation in between (**Fig. 2**).

There are missing observations in all the stages unequally for each county in different years. The available years of data for each phenology stage in each county are shown in Table 2 indicating the quality of the dataset. For calibration (see section 3) the missing observations in phenological stages are interpolated using available stages immediately before and after the missing stages. The standard deviations of all the phenological stages in each county are also given in **Table 2** indicating the variation of each stage along the record years, the variation is partly due to climate conditions and partly due to the observation errors of the dataset.

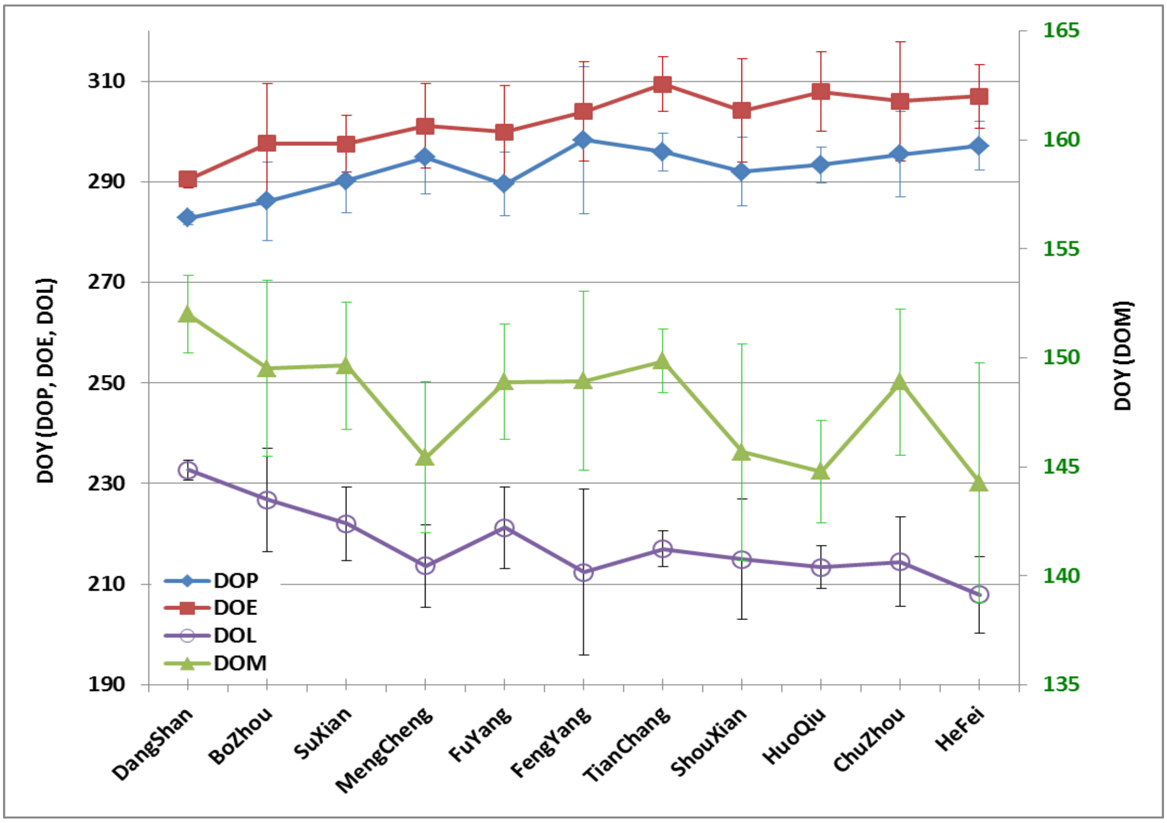


Figure 11: The mean DOP, DOE, DOM and DOL in each county averaged over the period when data were available. Error bars indicate the standard deviations of the statistic periods.

Table 3: Mean DOP, DOE and DOM in each county averaged over the period along with the standard deviations .

Location	DOP	Nr.* yrs	DOE	Nr. yrs	DOH	Nr. yrs	DOm	Nr. yrs	DOM
Dangshan	283 ± 1.3	4	291 ± 1.7	4	112 ± 2.6	6	135 ± 3.1	5	152 ± 1.8
Bozhou	286 ± 7.8	18	298 ± 11.9	20	108 ± 4.6	19	136 ± 4.9	20	150 ± 4.0
Mengcheng	295 ± 7.2	16	301 ± 8.4	18	105 ± 5.0	19	134 ± 3.4	17	145 ± 3.5
Suxian	290 ± 6.3	19	296 ± 5.6	19	108 ± 4.9	20	138 ± 2.5	17	150 ± 2.9
Fuyang	290 ± 6.3	18	299 ± 9.3	18	108 ± 6.6	20	137 ± 3.4	16	149 ± 2.7
Huoqiu	293 ± 3.6	9	308 ± 7.8	10	104 ± 5.7	9	134 ± 2.8	9	145 ± 2.3
Shouxian	292 ± 6.8	16	304 ± 10.2	18	103 ± 6.7	20	133 ± 5.4	17	146 ± 5.0
Fengyang	298 ± 14.6	20	304 ± 9.9	18	107 ± 6.8	20	135 ± 4.8	19	149 ± 4.1
Chuzhou	296 ± 8.4	19	306 ± 11.9	21	104 ± 5.2	18	137 ± 3.3	16	149 ± 3.4

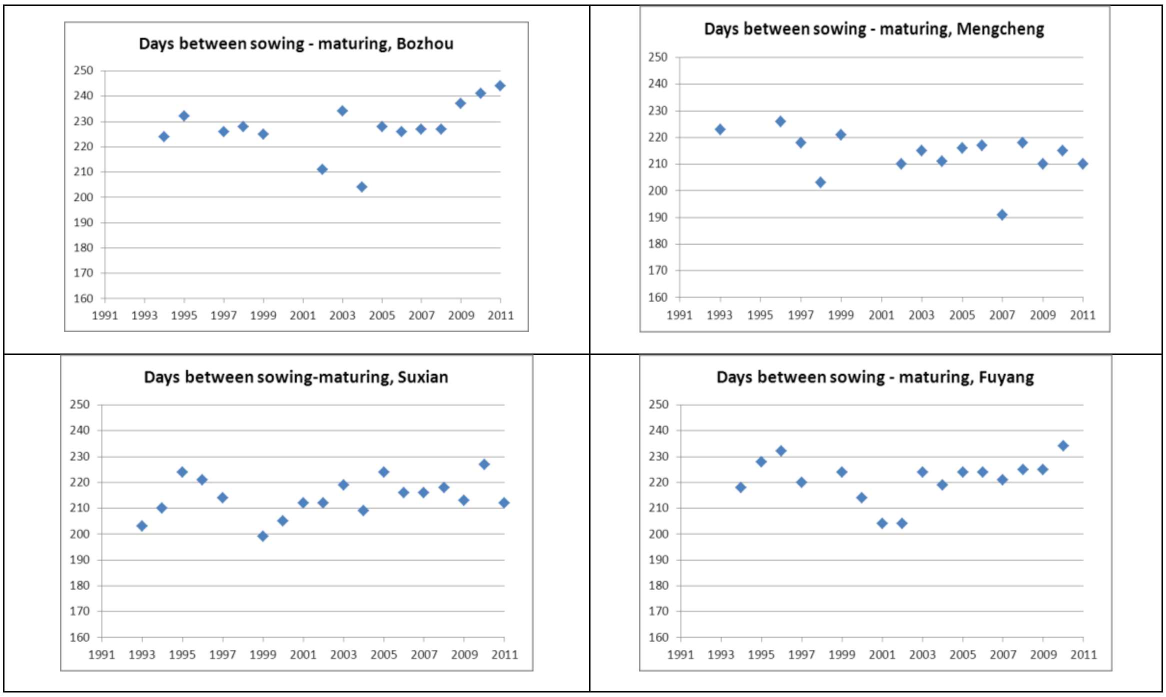
Tianchang	296 ± 3.8	10	309 ± 5.4	10	104 ± 5.1	9	135 ± 5.0	7	150 ± 1.5
Hefei	297 ± 4.8	19	307 ± 6.4	20	102 ± 9.2	19	130 ± 5.1	16	144 ± 5.5

** Nr. yrs denotes the number of available observation.*

The days of growing length (DOL) at each county showed annual variation (**Table 4**). The largest variation is at Fengyang county (Fig.12f), where the minimum and maximum days of growing season are found as 175 days and 238 days, respectively, and with mean and standard deviation as 209 and 14 days. Excluding the three counties with shorter records (Dangshan, Huoqiu and Tianchang), Suxian and Hefei have the most stable range in growth length.

Table 4: Range of growing period of winter wheat in ten counties in northern Anhui province. Nr of samples indicates number of years with complete records of DOL.

	Dangshan	Bozhou	Mengcheng	Suxian	Fuyang	Huoqiu	Shouxian	Fenyang	Chuzhou	Tianchang	Hefei
max	235	244	226	235	234	220	229	**238**	**227**	224	**220**
min	230	204	191	206	204	207	196	**175**	**190**	213	**196**
mean	233	227	214	222	221	213	216	**212**	**215**	217	**208**
Std	2.1	10.2	8.3	7.3	8.1	4.3	8.0	**16.5**	**8.9**	3.6	**7.6**
Nr of years	3	15	15	18	16	8	13	18	14	7	16



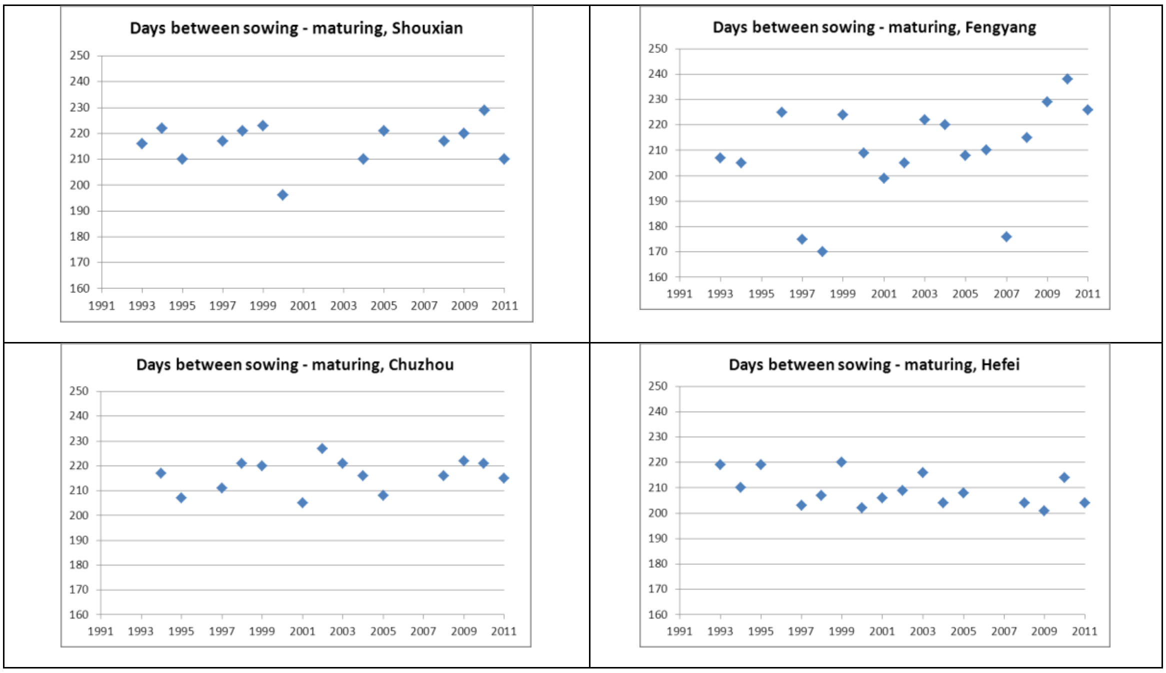


Figure 12: Days between sowing and maturity at the eight counties with long records of crop phenology (1992 - 2011). The three sites with shorter records are not shown.

Since the length of growing period was strongly correlated with the sum of air temperatures, the degree days (e.g. temperature sum of growing period, base temperature is taken as 0°C) is calculated at each county to evaluate the climate zones. The large contrast in the DOL, DOP and DOE between the north (Dangshan as 2169 degree days) and south (Hefei as 2373 degree days) part of the region clearly attribute to the large gradient in the climate conditions presented by the degree days of the growing period as shown in **Figs. 13 and 14** (here the degree days is calculated as the temperature sum taking the base temperature as 0 °).

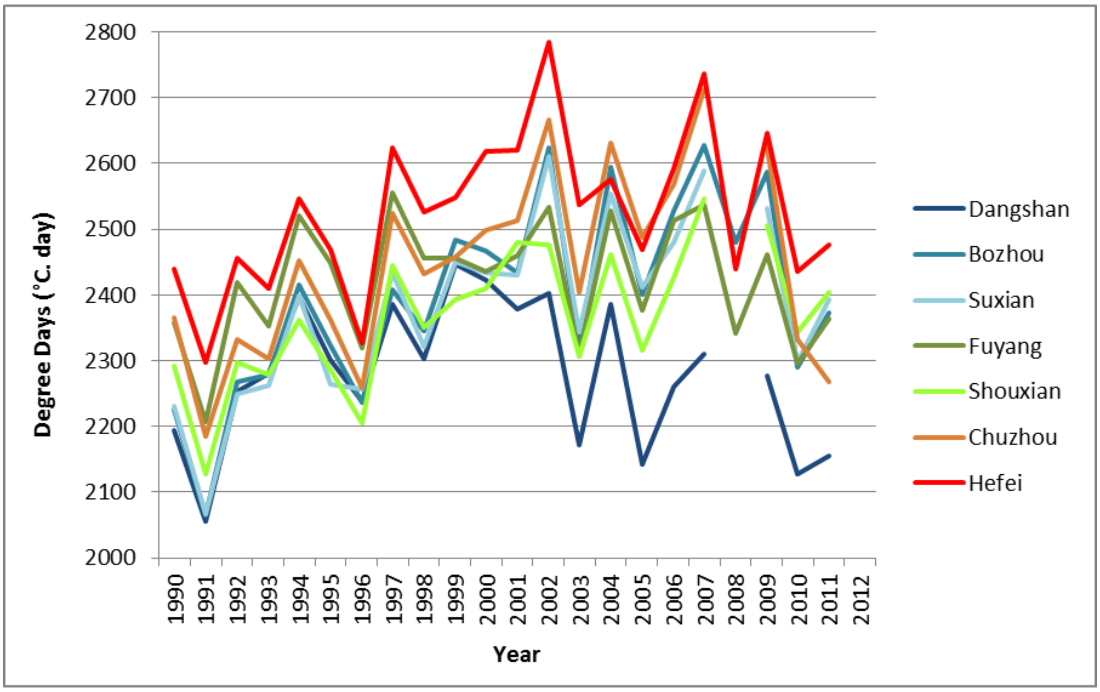


Figure 13: Annual variation of cumulative temperature from 1 January to 30 June of each year for the 7 counties where the meteorological data are available.

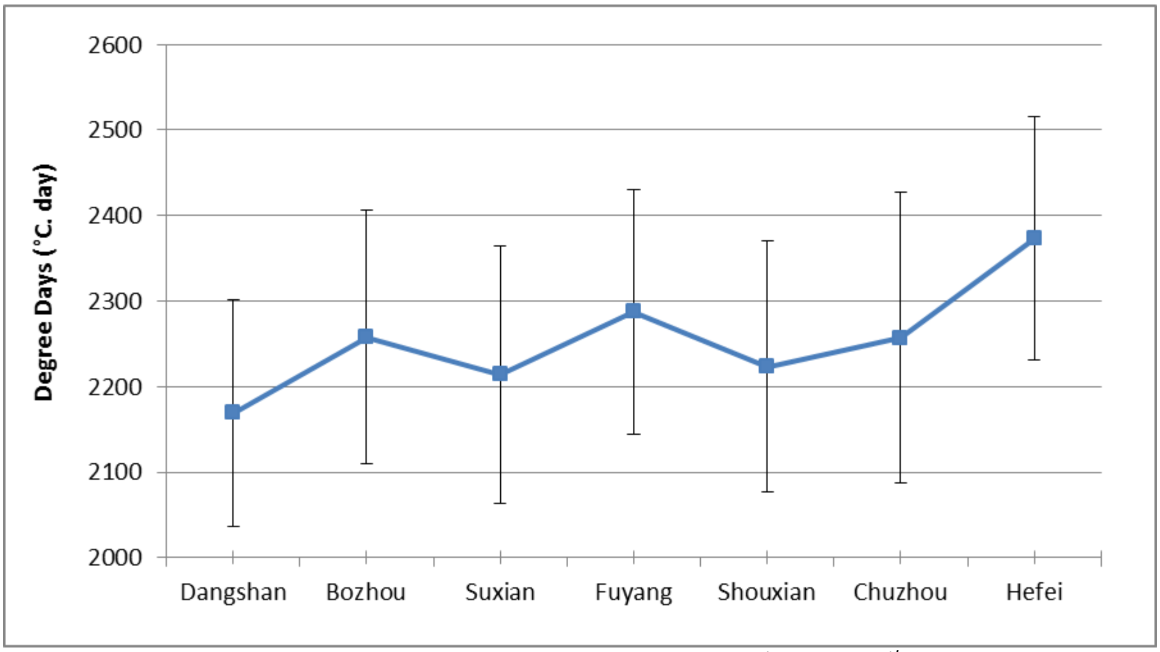


Figure 14: Mean degree days during the growing season (1st Jan – 30th June) between 1990 – 2012 at the 7 counties of Anhui province. Error bars indicate the standard deviation over the statistic period.

2.3. Yield statistics data

Yield statistics and cultivated area of winter wheat over 6 regions (district, NUTS Level 1) were collected for the period between 2000 and 2011 (Fig. 20). The 6 regions together with their belonging counties are listed in Table 13 (the 6 NUTS Level 1 regions are highlighted by bold).

Table 5: The six regions and their belonging counties where the winter wheat yield statistics were collected.

NUTS				
NUTS_CODE	**NUTS_NAME**	**NUTS_LEVEL**	**BELONGS_TO**	**BELONGS_TO_NAME**
34	Anhui province	0	2	Lower Yangze
3403	**Bengbu District**	**1**	**34**	**Anhui province**
340301	Bengbu city	2	3403	Bengbu District
340321	Huaishan county	2	3403	Bengbu District
340322	Wuhe county	2	3403	Bengbu District
340323	Guzhen county	2	3403	Bengbu District
3404	**Huainan District**	**1**	**34**	**Anhui province**
340401	Huainan city	2	3404	Huainan District
340421	Fengtai county	2	3404	Huainan District
3406	**Huaibei District**	**1**	**34**	**Anhui province**
340601	Huaibei city	2	3406	Huaibei District
340621	Suixi county	2	3406	Huaibei District
3412	**Fuyang District**	**1**	**34**	**Anhui province**
341201	Fuyang city	2	3412	Fuyang District
341221	Linquan county	2	3412	Fuyang District
341222	Taihe county	2	3412	Fuyang District
341225	Funan county	2	3412	Fuyang District
341226	Yingshang county	2	3412	Fuyang District
341282	Jieshou city	2	3412	Fuyang District
3413	**Suzhou District**	**1**	**34**	**Anhui province**
341301	Suzhou city	2	3413	Suzhou District
341321	Dangshan county	2	3413	Suzhou District
341322	Xiaoxian	2	3413	Suzhou District
341323	Lingbi county	2	3413	Suzhou District
341324	Sixian	2	3413	Suzhou District
3416	**Bozhou District**	**1**	**34**	**Anhui province**
341601	Bozhou city	2	3416	Bozhou District
341621	Guoyang county	2	3416	Bozhou District

NUTS				
NUTS_CODE	**NUTS_NAME**	**NUTS_LEVEL**	**BELONGS_TO**	**BELONGS_TO_NAME**
341622	Mengcheng county	2	3416	Bozhou District
341623	Lixin county	2	3416	Bozhou District

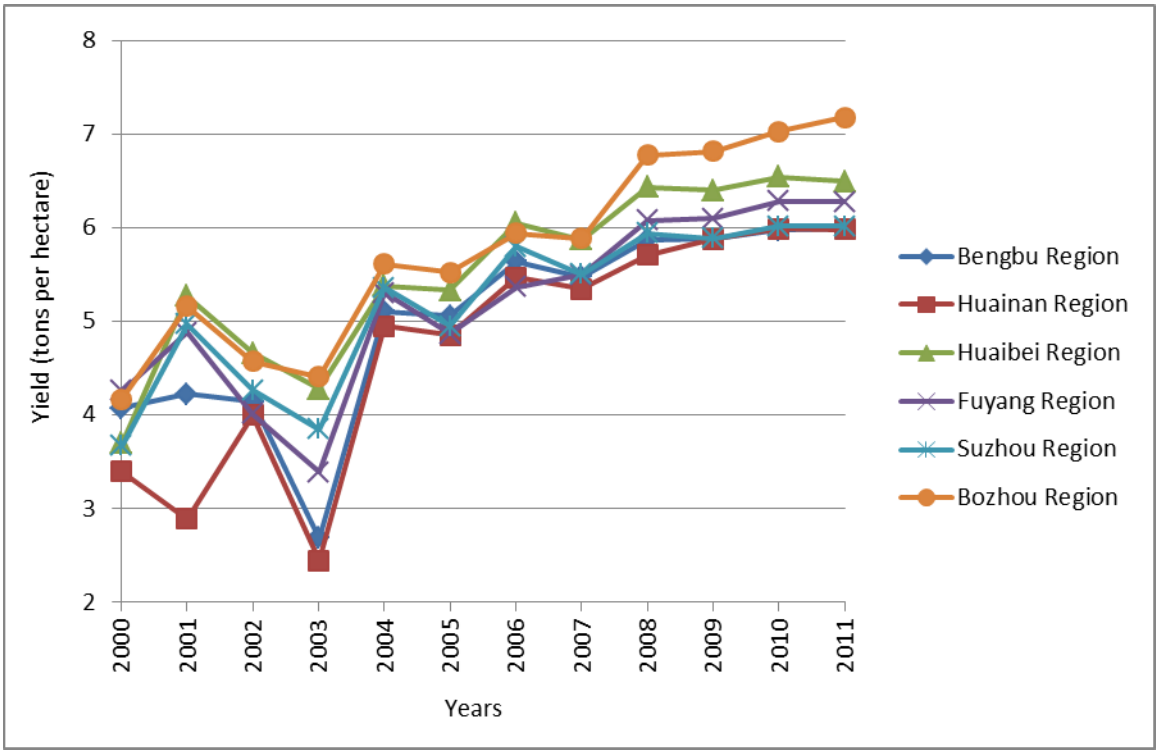


Figure 15: Yield statistics over 6 regions in the northern Anhui province between 2000 and 2011.

3. Anhui CGMS calibration

3.1. Calibration using the comprehensive experimental data from Fengqiu station

3.1.1. 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).

3.1.2. Calibration results

3.1.2.1. 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 6: 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

3.1.2.2. Parameters optimization

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

Table 7: 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			

3.1.2.3. 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)

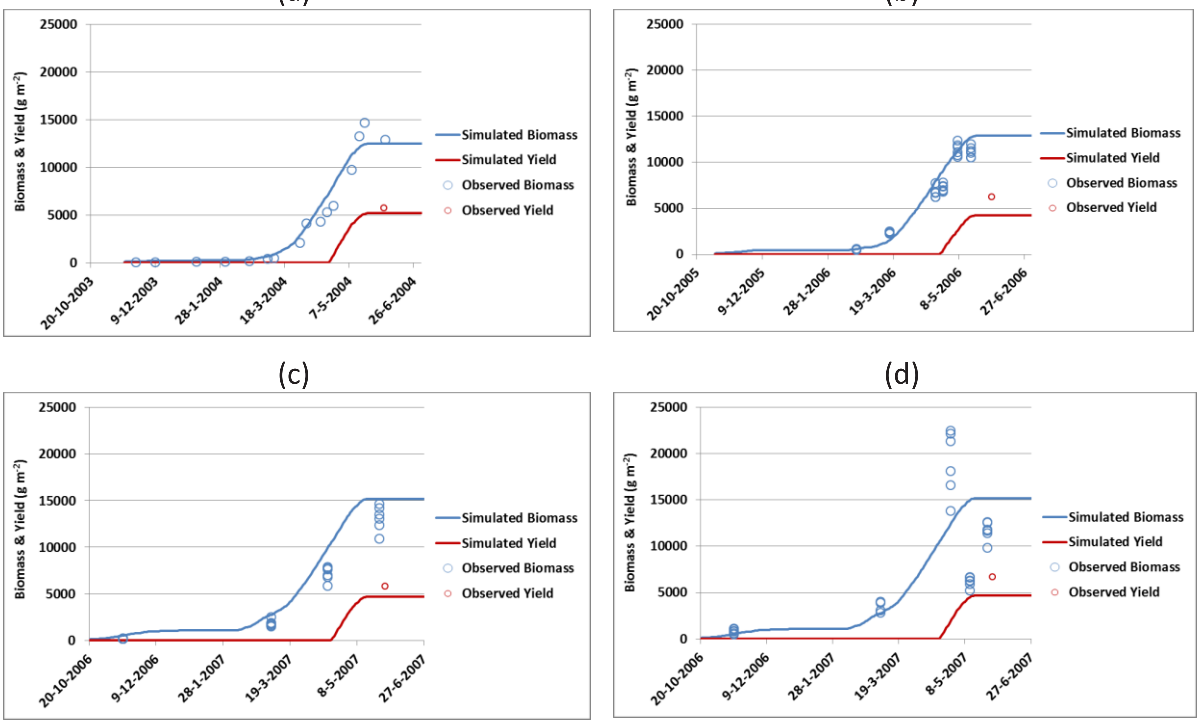
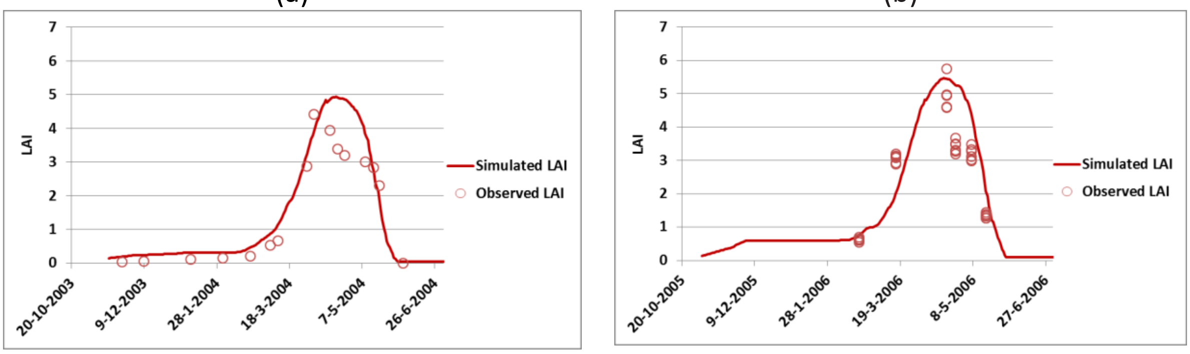


Figure 16: Comparison of the simulated biomass and yield against the observations for winter wheat crop at Fengqiu experimental site in different years.

(a) (b)



(c) (d)

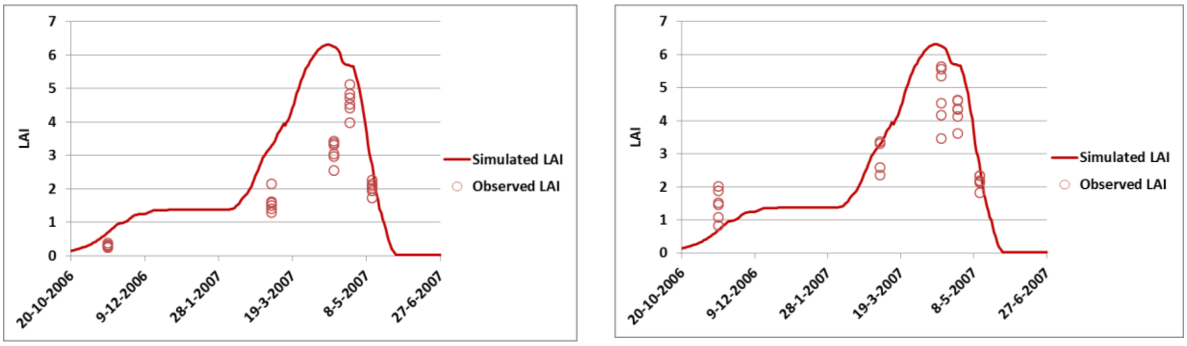


Figure 17: Comparison of the simulated leaf are index against the observations for winter wheat crop at Fengqiu experimental site in different years (same data as in Fig. 15).

3.2. Calibration using the crop phenology data from northern Anhui

3.2.1. 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.

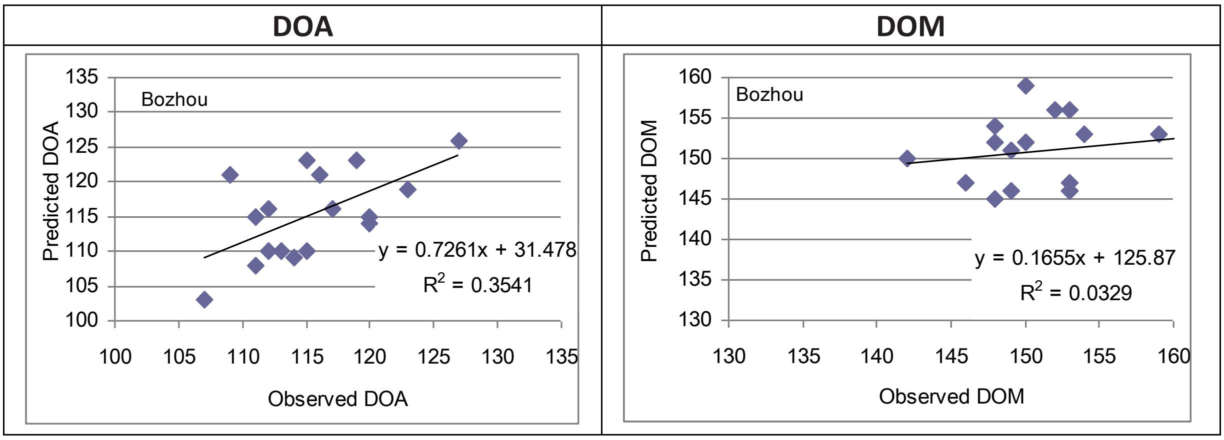
3.2.2. Calibration results and predicted anthesis and maturity dates at each county

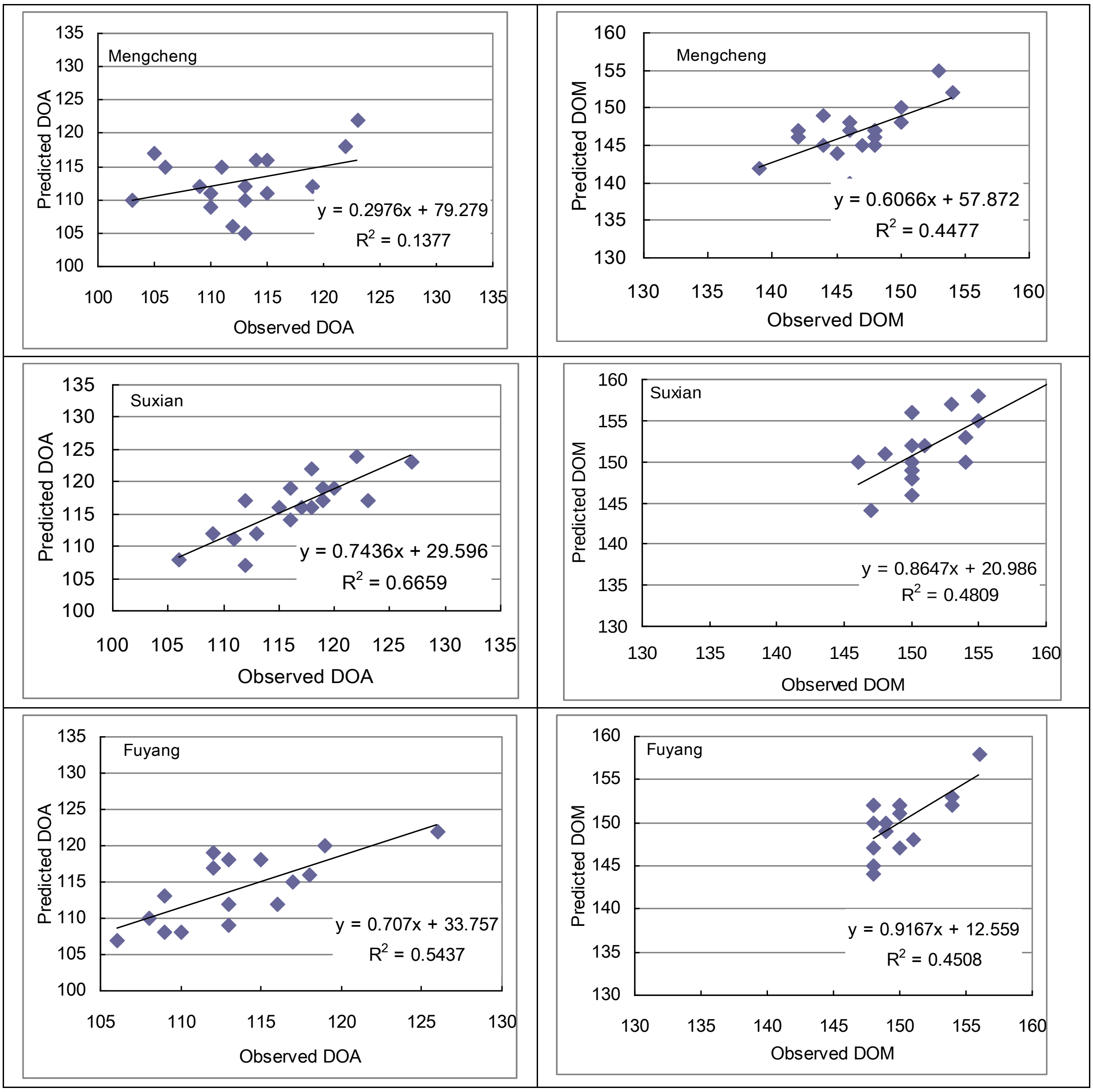
The calibrated Tsum1 and Tsum2 for each county together with the errors in the predicted DOA and DOM are listed in **Table 7**. The calibrated Tsum1 and Tsum2 have the mean values of 787.1 ^{o}C day (default as 1100) and 700.8 ^{o}C day (default as 750) with their standard deviations as 47.6 and 45 ^{o}C 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

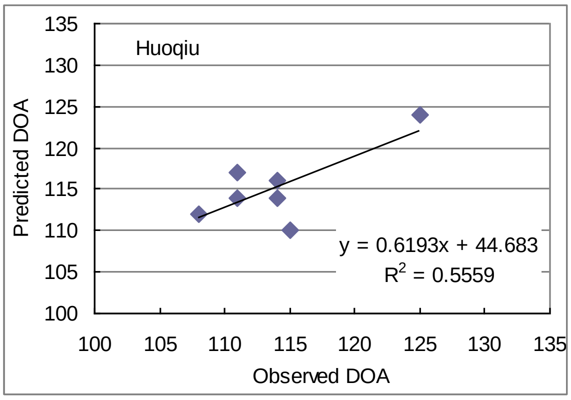
0.138 and 0.744. For the predicted DOM, the RMSE of the ranges between 2.88 and 5.43 days, the coefficient of determination R^2 is between 0.033 and 0.882. Comparison between the predicted and the observed DOA and DOM in each county are shown in **Figs. 17**. **Fig. 18** gives the results taking the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

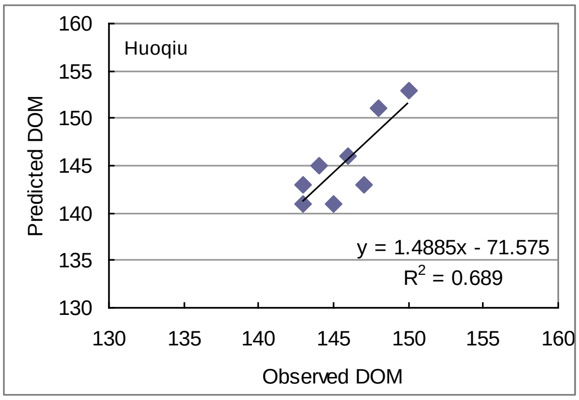
Table 8: Recalibrated parameters Tsum1 and Tsum2 and the performance of prediction on DOA and DOM for each county in the northern Anhui region.

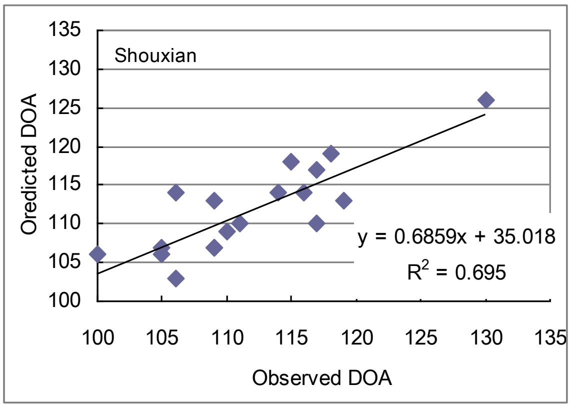
ID	County	Tsum1	Tsum2	DOA			DOM		
		°C day	°C day	RMSE (day)	R^2	Slope	RMSE (day)	R^2	slope
58015	Dangshan								
58102	Bozhou	838.9	736.0	5.2	0.354	0.726	5.43	0.033	0.166
58118	Mengcheng	753.0	673.6	5.41	0.138	0.298	2.88	0.448	0.607
58122	Suxian	815.3	720.7	2.98	0.666	0.744	3.08	0.481	0.865
58203	Fuyang	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						

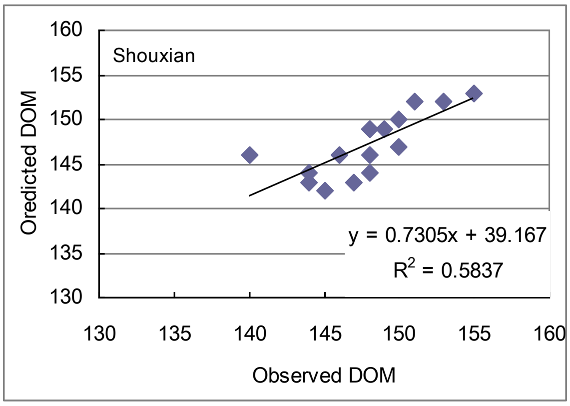


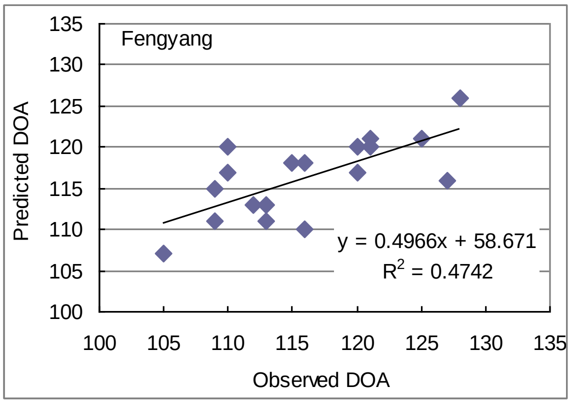

Mengcheng
Predicted DOA
Observed DOA
y = 0.2976x + 79.279
R2 = 0.1377
Mengcheng
Predicted DOM
Observed DOM
y = 0.6066x + 57.872
R2 = 0.4477
Suxian
Predicted DOA
Observed DOA
y = 0.7436x + 29.596
R2 = 0.6659
Suxian
Predicted DOM
Observed DOM
y = 0.8647x + 20.986
R2 = 0.4809
Fuyang
Predicted DOA
Observed DOA
y = 0.707x + 33.757
R2 = 0.5437
Fuyang
Predicted DOM
Observed DOM
y = 0.9167x + 12.559
R2 = 0.4508

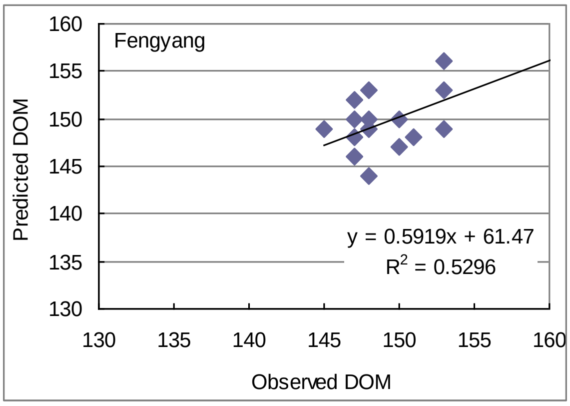

Huoqiu
y = 0.6193x + 44.683
R2 = 0.5559
Predicted DOA
Observed DOA


Huoqiu
y = 1.4885x - 71.575
R2 = 0.689
Predicted DOM
Observed DOM


Shouxian
y = 0.6859x + 35.018
R2 = 0.695
Oredicted DOA
Observed DOA


Shouxian
y = 0.7305x + 39.167
R2 = 0.5837
Oredicted DOM
Observed DOM


Fengyang
y = 0.4966x + 58.671
R2 = 0.4742
Predicted DOA
Observed DOA


Fengyang
y = 0.5919x + 61.47
R2 = 0.5296
Predicted DOM
Observed DOM

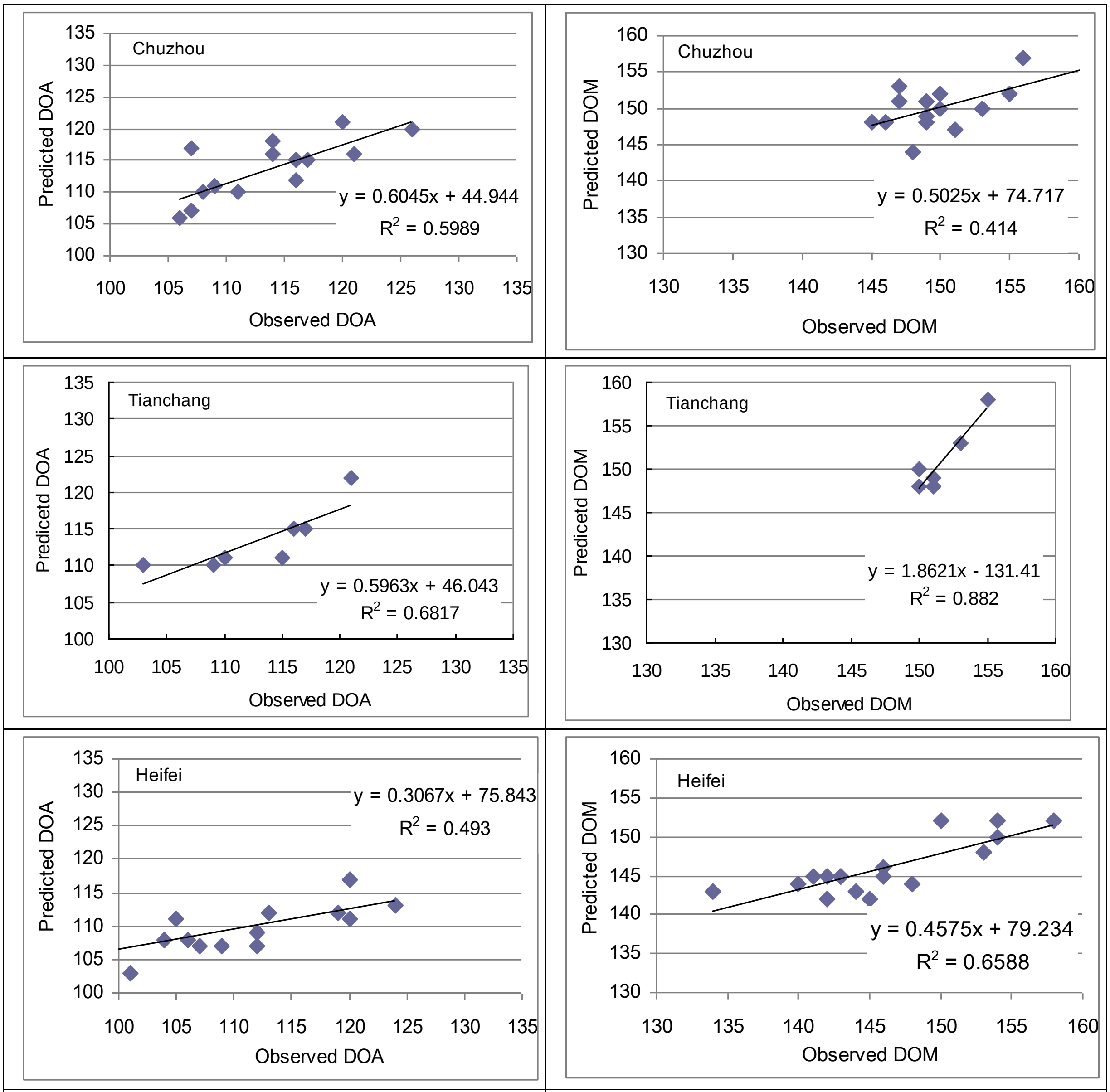


Figure 18: The comparison between the predicted and observed DOA and DOM of each county in northern Anhui.

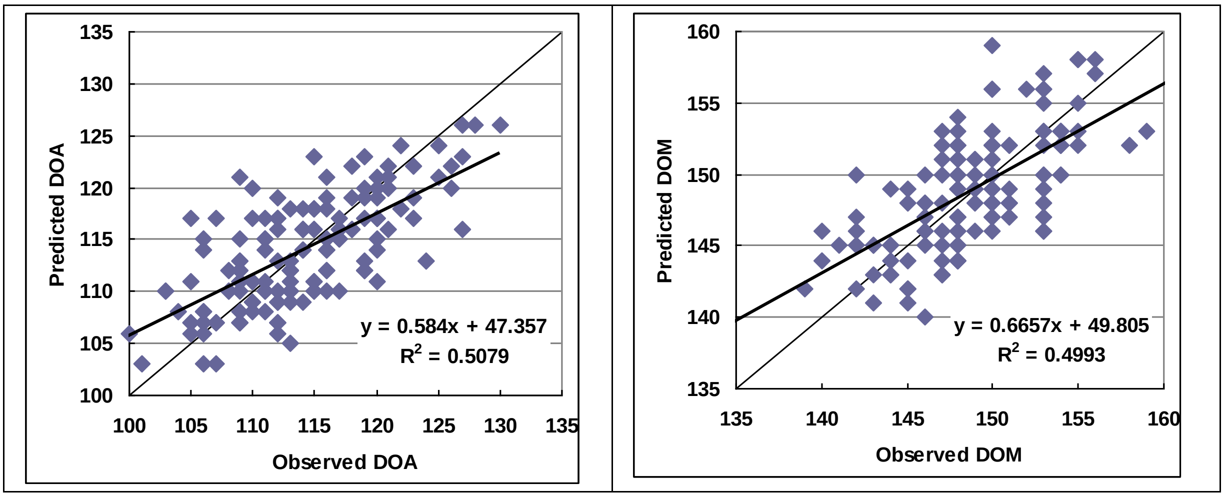


Figure 19: The comparison between the predicted and observed as the whole in northern Anhui.

3.3. Regional Calibration of CGMS-Anhui

3.3.1. 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.

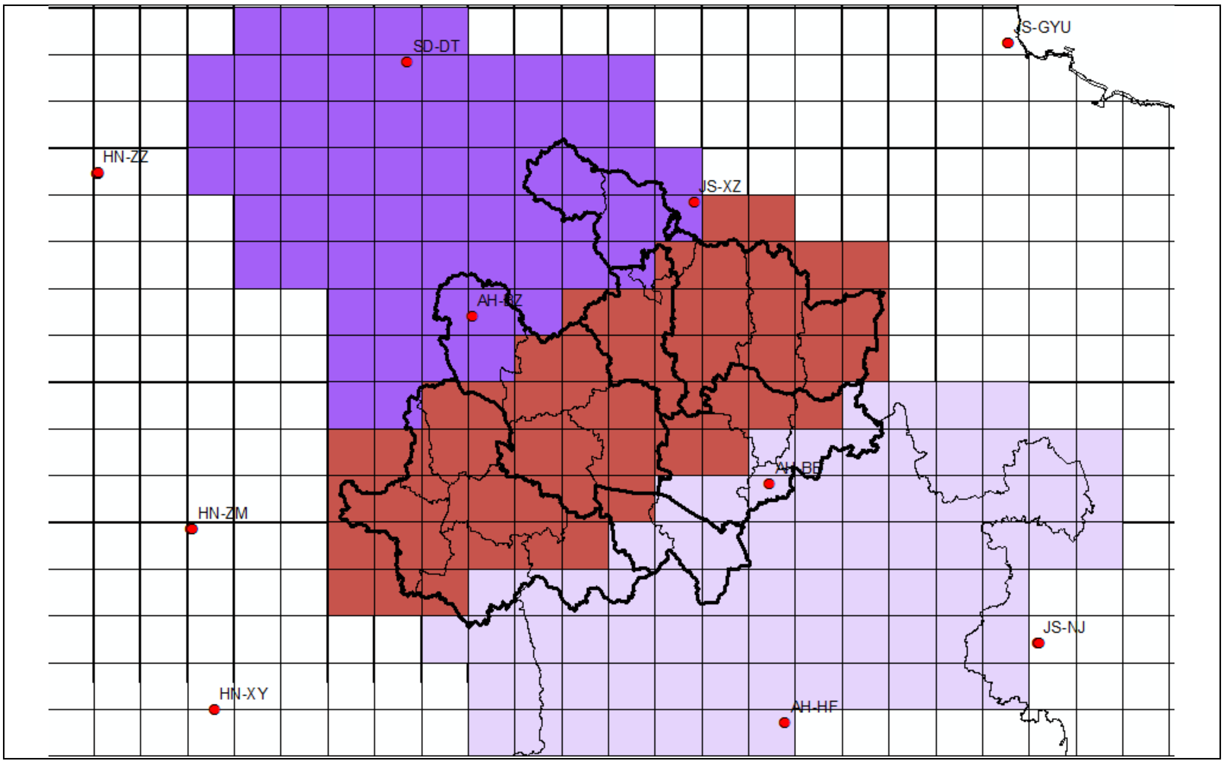


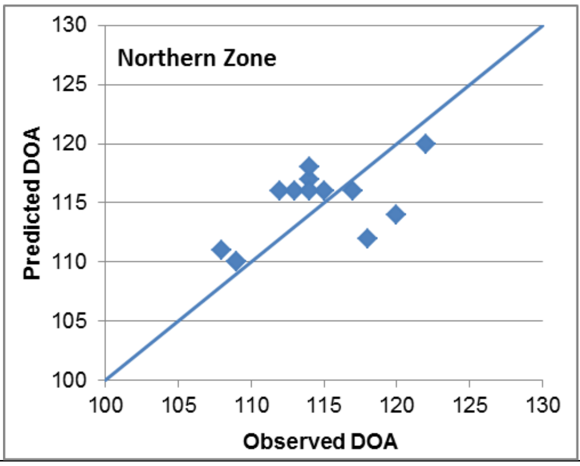
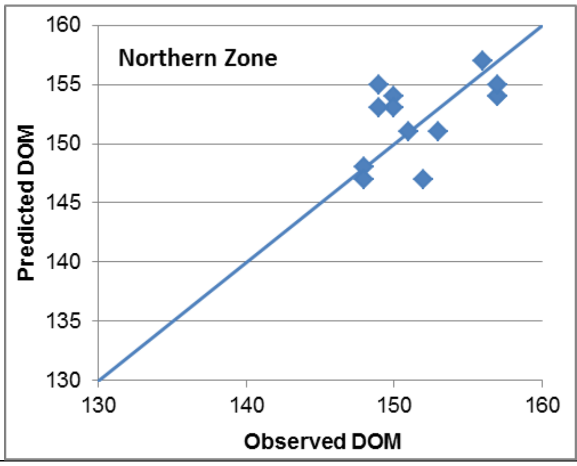
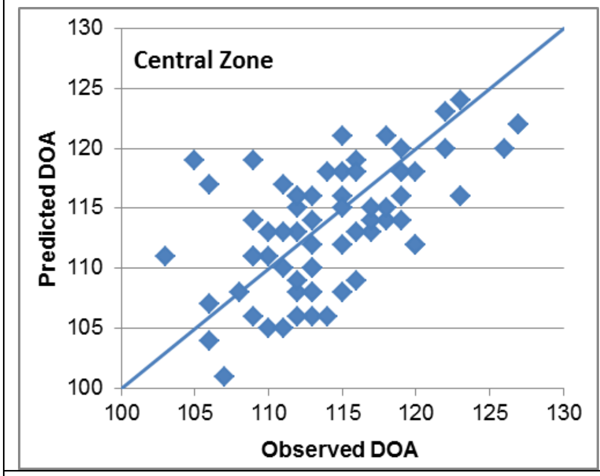
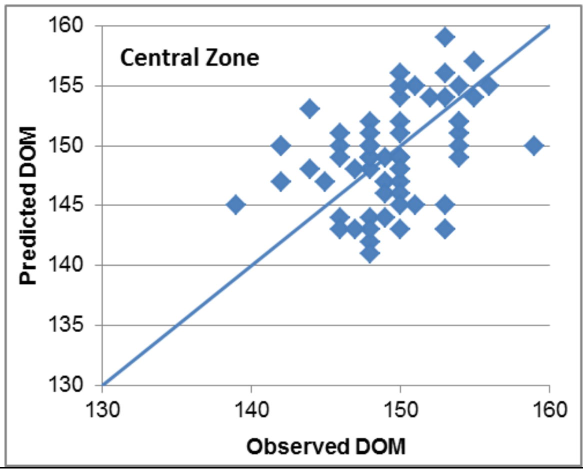
Figure 20: The division of three climate zones for regional calibration.

3.3.2. 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 9: 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	
	
Southern Zone	

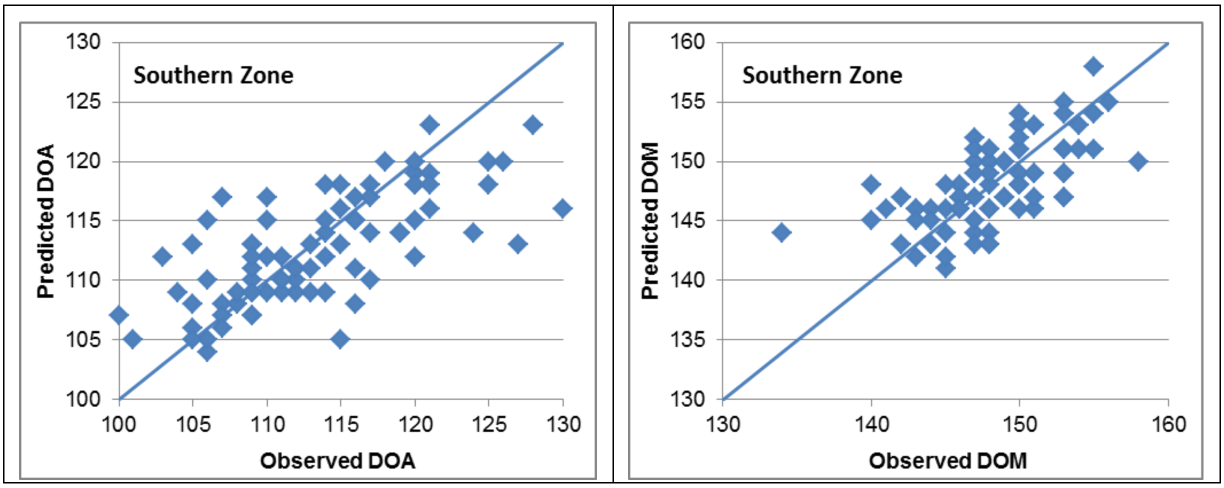


Figure 21: The comparison between the predicted and observed DOA (left column) and DOM (right column) in each zone of the northern Anhui.

4. 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.