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Abstract. The Decision Support for Agrotechnology Transfer (DSSAT) model was a worldwide crop model, and crop accurate simulation of phenology was the premise to realize other functional simulations. The objective of this study was to attempt to calibrate the parameters of wheat phenology coefficients, including cultivar and ecotype coefficients, and develop the winter wheat phenology coefficients of Beijing area. To achieve this goal, field surveys of 7 years in wheat growing seasons in Beijing were carried out during 2005 - 2012. The trail-and-error method and GLUE method were used to calibrate the phenology parameters with 4 growing seasons of 05/06, 06/07, 07/08 and 08/09. Three growing seasons, 09/10, 10/11, and 11/12 were used for validation, and the results showed good agreements between observed date and predicted date. The RMSE of validation data for TS, BT, HD, AN, and MA were 1.63 d, 2.45 d, 3.16 d, 1.83 d, 3.56 d, respectively. Therefore, the calibrated parameters could be used to monitor winter wheat phenology, and could be used for other research as the basis phenology parameters of Beijing area.

Keywords: phenology, DSSAT-CERES, phenology coefficients, winter wheat

1. Introduction

Knowledge of crop phenology is essential for plant physiological indexes, crop production and crop managements[1-2]. Plant growth phase could represent partitioning of the assimilations into the plant organs[3]. Accurate prediction of crop production is closely related with some critical phenology stage, for example anthesis [4]. Besides, phenology is very important in the guidance of crop managements [3].

For most crops models, more than two phases can be used to describe their detail phenological sub-routines in terms of temperature and crop development [5].Phenology is described by the dimensionless state variable development stage in 'School of de Wit' crop models, D. In these models, D is different numbers in different period, it is 0 during emergence, 1 at flowering, and change into 2 during maturity, and the development rate a function of photoperiod and environment temperature [6-7].The CERES model gives a detailed description of phenology simulation. The growth stages of wheat in the CERES model are divided into 9 stages, and vernalization affect is considered as well [8-10]. Water and nutrient can have influence on the development of rate, and STICS considered these affect in phenology simulation[11,5].During 49 growing seasons, performance of eight crop growth simulation models of winter wheat are compared by Reimund et al, and those models are widely used, easily accessible and well-documented and nine models for crop during 44 growing seasons of spring barley[12-13]. The application of rigorous statistical techniques can be used to calibrate sub model of APSIM-Oryza in phenology aspect, and the original method which is put forward by Sarath et al makes it of great easy to do so. [14].

The Decision Support for Agrotechnology Transfer (DSSAT) model was a worldwide crop model, and crop accurate simulation of phenology was the premise to realize other functional simulations. The DSSAT-CERES model shows a detailed description of phenology simulation.CERES-Wheat is used in the simulation of wheat anthesis and production in Southern Sardinia Italy, and Beijing, China, respectively by Dettori (2011) and Wang (2009) [15-16]. Palosuo compared eight crop growth models including DSSAT for anthesis and maturity estimation[5], and the results showed that the phenological stages provided the most accurate estimates using DAISY and DSSAT.By considering terminal spikelet, booting, Xue predicted phenological development of winter wheat via using WE model and CERES-Wheat, in this model, heading, anthesis and maturity are also taken into account[17]. Cultivar coefficients in

DSSAT-CERES, such as P1V, P1D, P5 of wheat, were mainly and generally considered to calibrate the phenology, while other phenology parameters, called ecotype coefficients including P1, P2, P3, P4, were set as default. However, default ecotype coefficients selecting resulted in deviations between simulated and observed phenology data, even though cultivar coefficients were adjusted. calibrate the parameters of wheat phenology coefficients, including cultivar and ecotype coefficients, and develop the winter wheat phenology coefficients of Beijing area.Calibration of the parameters of wheat phenology coefficients, including cultivar and ecotype coefficients, In this study, it is the objective to calibrate the parameters of wheat phenology coefficients, including cultivar and ecotype coefficients, and develop the winter wheat phenology coefficients of Beijing area.

2. Materials and methods

2.1. Study area and phenology investigation

A 7 year field observation was conducted at the Beijing District (40^o00'N ~ 40^o23'N, 116^o27'E ~ 116^o59'E), PR China, during the 2005-2012 growing seasons. The climate of the region is warm moderate semi-humid continental monsoon climate representative, in summer it is hot and rainy, cold and dry in winter, and spring and autumn is short. The mean temperature of the whole year is 10 -12℃, and the mean rainfall is 600mm.

According to Zadoks[18] and Tottman[19], the data of main phenological periods were recorded during 2005-2012 growing seasons. The phenological periods included sowing time (ST), emergence (EM), terminal spikelet initiation (TS), booting (BT), heading (HD), anthesis (AN) and maturity (MA), and detailed data were shown in Table 1.

Table 1. Phenological data of Beijing district for 7 growing seasons

Stage	2006	2007	2008	2009	2010	2011	2012
ST	Sep 25	Sep 28	Sep 25	Sep 28	Sep 25	Sep 27	Sep 25
EM	Oct 2	Oct 5	Oct 2	Oct 5	Oct 2	Oct 4	Oct 2
TS	Mar 12	Mar 6	Mar 6	Mar 9	Mar 22	Mar 13	Mar 22
BT	May 4	Apr 28	May 1	Apr 28	May 6	Apr 30	May 2

HD	May 10	May 6	May 7	May 6	May 14	May 8	May 8
AN	May 15	May 11	May 12	May 12	May 19	May 14	May 13
MA	Jun 17	Jun 15	Jun 18	Jun 15	Jun 20	Jun 19	Jun 18

2.2. Model description and input data set

The DSSAT model successfully used 25 years before by worldwide investigators for various uses[10,20] (Jones et al., 2003; He et al., 2012). The DSSAT model simulates the physiologically ecology process of crops vegetative growth and reproductive growth, crop photosynthesis, respiration, dry-matter distribution and plant growth and aging.[10,21,5].The version 4.5 of DSSAT can simulate more than 29 different kinds of crops, including maize, peanut, soybean, rice , wheat , et al [22]. Notably, accurate forecasting of phenological development is significant in agroecosystem, and is the premise to realize other functional simulations [17,1,23](Xue et al., 2004; Sakamoto et al., 2005; Xu et al., 2009). In DSSAT-CERES-Wheat [3], the growth stages of wheat are divided into 9 stages, while stages 1 to 5 are the main wheat growing stages[23]. The thermal time unit is the kernel of the most phenological development in DSSAT, and photoperiod and vernalization affect are considered the most limiting factor in the crop growth stage between emergence and terminal spikelet initiation as well.

For the sake of run a crop model and appraise a simulation, meteorological data, soil data, crop management information, and experiment data are required [24-25]. Daily weather data, including minimum and maximum air temperature, and precipitation were acquired from China Meteorological Data Sharing Service System (CMDSSS). The website is http://cdc.cma.gov.cn. while solar radiation is obtained from sunshine hours of CMDSSS with the Angstrom formula as used in Allen et al[26].

Each soil horizon of soil data included lower limited volume water content (VWC), soil texture, upper limited VWC at saturation, field capacity, saturated hydraulic conductivity, soil organic carbon, inorganic nitrogen, PH, and bulk density (Table 2). These parameters are obtained from field measurements before sowing time.

Table 2. Soil profile characteristics of the experiment field

Depth (cm)	Sand %	Silt %	Clay %	pH	Org. C %	Total N %	LL %	DUL %	SAT %	BD g/cm^3

0-10	22.6	53.9	23.5	8.00	1.04	0.11	8.8	27.3	51.1	1.66
10-20	22.6	53.9	23.5	8.03	1.04	0.11	8.8	27.3	51.1	1.60
20-40	22.5	54.1	23.4	8.08	1.01	0.10	8.7	27.3	51.3	1.35
40-60	14.9	47.8	37.3	7.94	0.68	0.08	12.3	34.8	54.7	1.16
60-80	14.9	47.8	37.3	7.98	0.66	0.08	12.3	34.8	54.7	1.13
80-100	16.7	43.0	40.3	8.03	0.59	0.07	12.3	34.8	54.7	0.99

Note: Org. C, LL, DUL, SAT, BD represent soil organic carbon, lower limited VWC, field capacity, upper limited VWC at saturation, and bulk density, respectively.

Cultivar parameters were optimized with the GLUE methods[27-28], a brief review of GLUE method is given in He et al. [28-29].The parameters contains vernalization sensitivity coefficient (P1V), photoperiod sensitivity coefficient (P1D), grain filling phase duration (P5), kernel number (G1), kernel size (G2), single tiller weight (G3), and phyllochron interval (PHINT). ecotype coefficients includes duration of end juvenile to terminal spikelet stage (P1), duration of terminal spikelet to end leaf growth stage (P2), duration of end leaf growth to end spike growth stage (P3), and duration of end spike growth to end grain fill lag stage (P4). These parameters were calibrated by the trail-and-error method one by one.

2.3. Statistical analysis

Three statistical indices were used to appraise performance of the model, comparing simulated results with measured data. The first is the mean error (E):

$$\mathrm{E} = \frac{1}{n}\sum_{i=1}^{n}(S_i - M_i)$$

The value of E could show the deviation between analogic and practical measured data. Positive values indicate the simulated data is larger, and vice versa. Meanwhile the lower the absolute value was, the higher the accuracy and precision of the model simulation was considered to be. The second is root mean square errors (RMSE):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - M_i)^2}$$

where S_i and M_i are the analogic and practical measured data, respectively, and

n is the number of treatments. Generally, the RMSE shows a close agreement between measured values and predicted values. The last is the index of agreement (*d*) of Willmott [29]:

$$d = 1 - \frac{\sum_{i=1}^{n}(S_i - M_i)^2}{\sum_{i=1}^{n}(\left|S_i - \overline{M}\right| + \left|M_i - \overline{M}\right|)^2}$$

where $\overline{M}$ is the mean of the n measured data. The value of d ranges from $-\infty$ to 1.0, and the closer the index value is to one, the better the agreement between the simulated and measured data and vice versa.

3 Results

3.1. Thermal unit of phenology stage

The thermal unit (TU) of each phenology stage from 2005 to 2012 was showed in Figure 1. The TU of each phenology stage is the sum of the TU per day of the growth period. As seen in Fig. 1, there was a large difference in the 7 growing seasons result from environmental conditions. The average TU of ST-TS, TS-BT, BT-HD, HD-AN, AN-MA period were 820, 602, 147, 103, 802 degree-days, respectively. The total TU of the 09/10 growing season was the lowest among the 7 seasons, in which the TU of each period except BT-HD period were lower than the average TU of each period of 7 seasons. The TU of each growing stage varied in each year, which represented that thermal unit was one of influence factor to phenology stage.

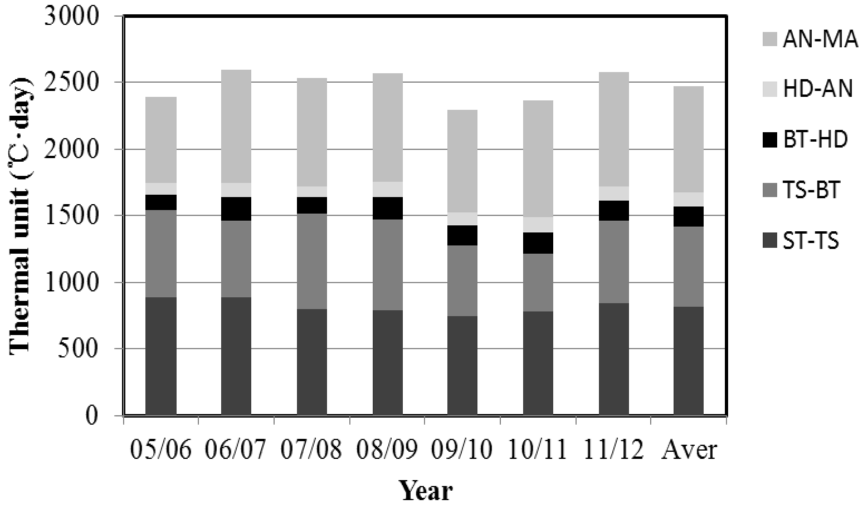

Fig. 1. The thermal unit of each phenology stage from 2005 to 2012

Note: Aver represent the average of thermal unit of each phenology stage.

3.2. DSSAT-CERES model calibration

Four growing seasons, 05/06, 06/07, 07/08, and 08/09, were used to calibrate the DSSAT-CERES phenology parameters. The calibrated parameters of P1, P2, P3, P4, P1V, P1D, P5, were 267 degree-days, 600 degree-days, 175 degree-days, 300 degree-days, 39.99 d, 87.40, 635 degree-days, respectively.

Observed and predicted day after planting (DAP) for TS, BT, HD, AN, MA were showed in table 3 and Figure 2. The results showed that phenology simulation using DSSAT-CERES achieved a good simulation. The DSSAT-CERES model can predict HD, AN, MA better than TS and BT. The best prediction was for MA, which the E, RMSE, and *d* were 0 d, 1.00 d, and 0.97, respectively. The differences of observed and predicted DAP were only 1 d. The E, RMSE, and d for HD were -0.75 d, 1.66 d, 0.90, respectively, and for AN were -2.25 d, 2.50 d and 0.83, respectively. The deviations of observed and predicted DAP were no more than 3 d and 4 d, respectively. The E, RMSE, and *d* for TS were +0.50 d, 4.18 d and 0.73, respectively, and for BT were -3.00 d, 4.24 d, and 0.53, respectively. As the reason, there were large differences of observed and predicted DAP, which were +7 d for TS in 08/09, +6 d for BT in 05/06, and -7 d for BT in 07/08. In brief summary, the DSSAT-CERES model can simulate the phenology after phenology parameters calibrated, and the later periods simulating were better than earlier stage.

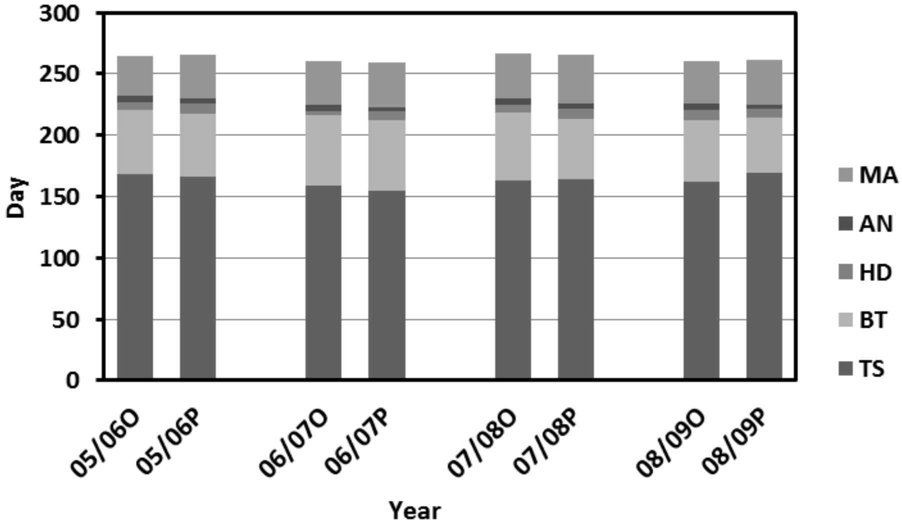

Fig. 2. Phenology parameters calibration with observed (O) and predicted (P) day after planting (DAP) using the DSSAT-CERES model for TS, BT, HD, AN, MA in 4 growing seasons, 05/06, 06/07, 07/08, 08/09 growing seasons

Note: D represented the deviation of predicted DAP and observed DAP.

Table 3. Statistical indices of phenology parameters calibration with observed (O) and predicted (P) day after planting (DAP) using the DSSAT-CERES model for TS, BT, HD, AN, MA in 4 growing seasons, 05/06, 06/07, 07/08, 08/09 growing seasons

Indices	TS	BT	HD	AN	MA
E	0.50	-3.00	-0.75	-2.25	0
RMSE	4.18	4.24	1.66	2.50	1.00
d	0.73	0.53	0.90	0.83	0.97

3.3. Validation of phenology stage simulation with DSSAT-CERES

Three growing seasons, 09/10, 10/11, and 11/12, were used to test the reliability of the DSSAT-CERES model with the calibrated phenology parameters. Validation results were listed in table 4 and Figure 3. The simulation of TS, BT, HD, and AN were in accordance with the observed stage. The E, RMSE, and d values for TS, were 1.33 d, 1.63 d, and 0.98, respectively, for BT were 1.33 d, 2.45 d, and 0.90, respectively, for

HD were 2.67 d, 3.16 d, 0.86, respectively, and for AN were 0.67 d, 1.83 d, 0.94, respectively. There were large differences between observed and predicted MA dates, which the E, RMSE, and d were 1.33 d, 3.56 d, 0.60, respectively. The difference between observed and predicted MA dates for 09/10 growing season was 6 d. The validation results showed that there were good agreement between observed and predicted DAP using the DSSAT-CERES model for each phenology stage.

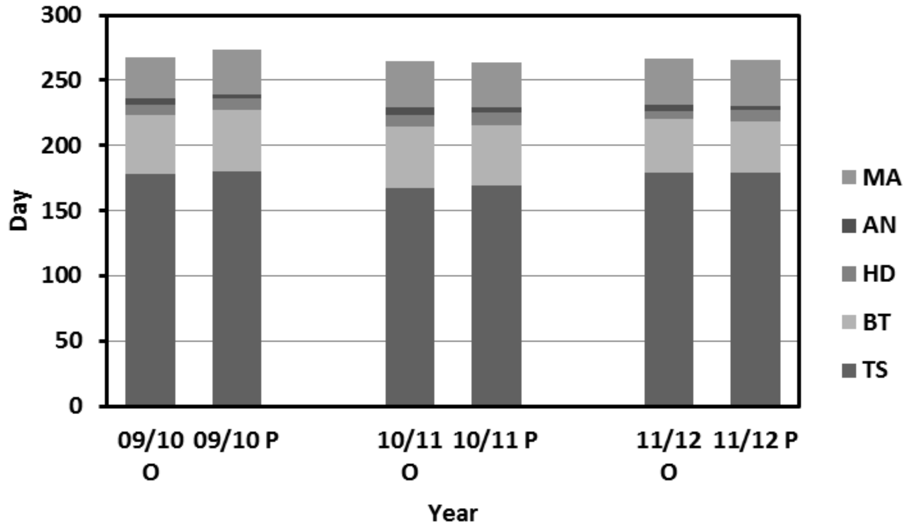

Fig. 3. Validation of observed (O) and predicted (P) day after planting (DAP) using the DSSAT-CERES model for TS, BT, HD, AN, MA in 3 growing seasons, 09/10, 10/11, 11/12 growing seasons.

Note: D represented the deviation of predicted DAP and observed DAP.

Table 4. Statistical indices of observed (O) and predicted (P) day after planting (DAP) using the DSSAT-CERES model for TS, BT, HD, AN, MA in 3 growing seasons, 09/10, 10/11, 11/12 growing seasons.

Indices	TS	BT	HD	AN	MA
E	1.33	1.33	2.67	0.67	1.33
RMSE	1.63	2.45	3.16	1.83	3.56
D	0.98	0.90	0.86	0.94	0.60

4 Discussion

Phenology stage was influenced by external environment factor, including temperature, light, water, and nutrient [30], and temperature and day length were the main driving factor. Fig. 1 showed that the TU of each growing stage varied in each year, which indicated TU was nonlinear with phenology stage [3]. The 09/10 growing season was cooler as compared to the other growing seasons (Table 1), and the TU of 09/10 growing season was much lower than other growing stage.

The research purpose was to attempt to calibrate the parameters of wheat phenology coefficients, including cultivar and ecotype coefficients. The calibrated parameter of P2, 600 degree-days, was much higher than the P2 of CAWH01, USWH01, and UKWH01, which were given parameters in DSSAT 4.5. However, the calibrated P2 was reasonable in consideration of the P2 definition, stage terminal spikelet to end leaf growth period. There were about 6 leaves from terminal spikelet stage to end leaf growth for the winter wheat in North China[19], and a phyllochron, defined as the interval of time between leaf tip appearance PHINT (degree-days), is about 100 degree-days.

The RMSE of each phenology stage were ranged from 1.0 d to 4.24 d for calibrated data, and from 1.60 d to 3.56 d for validation data. They were acceptable results, because there were little differences in determining phenology dates during the actual operation. There were large differences between predicted dates and observed dates for 09/10 growing season, because the 09/10 growing season was cooler than the others. Overall, the calibration and validation results showed that there were good agreement between observed and predicted DAP using the DSSAT-CERES model for each phenology stage.

The study tried to calibrate the phenology parameters, including cultivar and ecotype coefficients. Therein, comparison of calibrated ecotype coefficients and default ecotype coefficients provided by DSSAT should be focused on further investigation.

5. Conclusion

This study was to attempt to calibrate the parameters of wheat phenology coefficients, including cultivar and ecotype coefficients, and develop the winter wheat phenology coefficients of Beijing area. The calibrated parameter of P2 was larger than the default value provided by DSSAT, while it was reasonable in consideration of actual growth progress of winter wheat in Beijing area.

Four growing seasons, 05/06, 06/07, 07/08, 08/09 season, were used as parameters calibration, and three growing seasons, 09/10, 10/11, 11/12 season, were used for validation. The results showed fine agreements between observed and predicted DAP using the DSSAT-CERES model for each phenology stage. The calibrated parameters, as the basis phenology parameters of Beijing area, could be used for other research, such as total above-ground biomass simulation, yield prediction, water and nitrogen balance study.

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