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# Estimating genetic parameters of DSSAT-CERES model with the GLUE method for winter wheat (*Triticum aestivum* L.) production

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ABSTRACT

Crop growth models integrate genotype, environment and management and can serve as an analytical tool by which to study the influences of these factors on crop growth, production, and agricultural planning. Parameter calibration is the primary step taken before the local application of crop growth models. In this study, experimental field data were collected by way of a five-year (2008–2013) set of field experiments at a field site in Beijing, China. The DSSAT-CERES model was calibrated by integrating the generalized likelihood uncertainty estimation (GLUE) method and a systematic approach, and used experimental data relating to two seasons 2009/2010 and 2012/2013. The calibrated model was evaluated for its prediction performance using experimental data relating to the three seasons 2008/2009, 2010/2011 and 2011/2012. The results showed that the GLUE method can accurately estimate the genotype parameters of wheat; that the simulated leaf area index (LAI), aboveground biomass (AGB), aboveground nitrogen (AGN) and grain yield (GY) were close to the measured values; and that the DSSAT-CERES-Wheat model can be used to schedule wheat seed sowing dates, and optimize N fertilizer application in areas around Beijing. In general, the DSSAT-CERES-Wheat model was proved to be a useful decision-making tool for winter wheat production in the Beijing area.

## 1. Introduction

Winter wheat (*Triticum aestivum* L.) is a staple cereal crop and an important source of calories and protein for most of the domestic population in the North China Plain (Reynolds et al., 2012). The prediction of growth status and grain yield (GY) is essential for crop management and policy making at both regional and national scales (Kowalik et al., 2014). Winter wheat growth and GY fluctuate from year to year due to variations in temperature, rainfall, soil conditions, crop genotype, crop management and other events (Lee et al., 2013). Therefore, in order to accurately predict wheat yield prior to harvest, it is necessary to consider these influential factors simultaneously.

Crop simulation models simulate crop growth and development, and predict crop yields based on weather, soil conditions, crop genotype and management data. They can help improve our understanding of the relationships that exist between crops and the environment (Crout et al, 2014). Various models have been developed for different crops, such as DSSAT (Jones et al., 2003), APSIM (Keating et al., 2003), AquaCrop (Vanuytrecht et al., 2014) and STICS (Brisson et al., 2003). These models have become useful and effective tools within the fields of irrigation and fertilizer (nitrogen) management (Asseng et al., 2012; He et al., 2012a,b), grain yield and quality forecasting (Asseng et al., 2002; Asseng and Milroy, 2006; de Wit and van Diepen, 2007), plant growth estimation (Araya et al., 2010; Thorp et al., 2012), precision agriculture (Thorp et al., 2008), breeding programs (Jeuffroy et al., 2014; Vazquez-Cruz et al., 2014) and climate change evaluation (Angulo et al., 2013; Fan and Shibata, 2014). The CERES-Wheat model is integrated within the Decision Support System of Agrotechnology Transfer modelling system (DSSAT; V 4.5) and is a well-known crop model developed for the simulation of winter wheat growth (Jones et al., 2003; Thorp et al., 2012).

However, parameter calibration is a prerequisite step prior to the

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local application of crop growth models (Jiang et al., 2011). The common trial-and-error method selects the optimum combination of parameters through repeated and varied attempts until the instrument ceases its attempts to find a optimum solution. This method is simple and frequently used but is not an effective technique, especially when the number of parameters included within it is large (Hsiao et al., 2009). Various kinds of systematic algorithms have been used for model parameter estimation, such as the simplex method (Inoue et al., 1998), simulated annealing method (Soldevilla-Martinez et al., 2014), genetic algorithm (He et al., 2012a,b), Bayesian methods (Ceglar et al, 2011), and the particle swarm optimization method (Li et al., 2015). The generalized likelihood uncertainty estimation (GLUE) method, as a commonly used method situated within the Bayesian methods, estimates model parameters from both prior information and experimental data (Brun et al., 2006), and has been integrated into the DSSAT software as a general method of parameter estimations for cultivar of different crops (Hoogenboom et al., 2010; He et al., 2010). The DSSAT-GLUE method software only considers cultivar parameters related to crop growth stages and grain characteristics, whereas parameters relevant to process variables, such as dry matter accumulation and leaf area, are not considered. However, these process related parameters are significant in terms of our understanding of crop growth and development, and subsequently for guiding field management.

Therefore, the objectives of this work were to: (1) use the GLUE method to estimate the genotype parameters of the CERES-Wheat model, including parameters not only related to crop growth stages and grain characteristics but also to process variables, and; (2) evaluate the prediction performance of the calibrated CERES-Wheat model in order to simulate leaf area index (LAI), aboveground biomass (AGB), aboveground N uptake (AGN) and grain yield.

## 2. Materials and methods

### 2.1. Experimental site

Field experiments were conducted during five consecutive growing seasons; 2008/2009, 2009/2010, 2010/2011, 2011/2012 and 2012/2013 at the Xiaotangshan Experimental Site (40.17°N, 116.43°E), Beijing, China. The soil and crop management practices at the site were representative of those in the region. The soil is fine-loamy, with a nitrate nitrogen ($NO_3$-N) content of 3.16–14.82 mg kg$^{-1}$, an ammonium N ($NH_3$-N) content of 10.20–12.32 mg kg$^{-1}$, an Olsen phosphorus content of 3.14–21.18 mg kg$^{-1}$, an exchangeable potassium content of 86.83–120.62 mg kg$^{-1}$, and an organic matter content of 15.84–20.24 g kg$^{-1}$ in the uppermost 0–30 cm layer. This area has a typical semi-humid continental monsoon climate, with hot rainy summers, cold dry winters, and short springs and autumns.

The experiments undertaken during 2008–2013 involved various wheat cultivars, N application rates and sowing dates (Table 1). The size of each experiment plot was 100 m$^2$. Plot management followed local common practices for wheat production in this region, namely sprinkler irrigation at the jointing, booting and early filling period, and pesticide and herbicide control at the early filling period. These were implemented during each growing season. All varieties at the same treatment, sowing date or nitrogen fertilizer application, were averaged to calculate the DSSAT-CERES model. The main reasons are: (1) the DSSAT-CERES model was used for local application, and crop parameters are localized; (2) wheat cultivars are all local promoted varieties and some characteristics, e.g., period of duration, tiller capability, are pretty similar to each other.

### 2.2. CERES-Wheat model and genotype parameter estimation

The CERES wheat model in DSSAT V4.5 is a typical example of a process-based wheat model that uses carbon, nitrogen (N) and water balance principles to simulate crop growth stages, total aboveground biomass, yield, and water and nitrogen balances (Jones et al., 2003; Thorp et al., 2008, 2010; Palosuo et al., 2011). Wheat growth stages proceed through nine growth stages based on the temperature response function and genetic information contained within the CERES-Wheat model (Hanks and Ritchie, 1991; Wang and Engel, 1998). The model is a classical RUE (radiation use efficiency) model, which simulates daily photosynthesis as a function of incoming solar radiation, leaf area index (LAI), plant population, canopy extinction coefficient and RUE (Confalonieri et al., 2009; Thorp et al., 2010). Assimilated carbon is proportionally partitioned into various plant organs, including leaves, stems, roots, and grain, at different growth stages. Canopy N accumulation is simulated based on crop N demand and available N in the soil. The crop N demand affects plant growth, target N concentrations and critical N concentrations. The nitrogen concentrations of different plant organs vary with the plant growth stage. Available N uptake from soil depends on soil $NH4^{+}$-N and $NO_3{}^{-}$-N concentrations, soil water levels and root growth (Liu et al., 2011; DeJonge et al., 2012). Grain dry matter is derived by way of photosynthesis during the grain filling stage and re-translocation from pre-stored dry matter (Asseng et al., 2002; Asseng and Milroy, 2006).

In order to run the CERES-Wheat model and evaluate a simulation, four types of input data were required: meteorological data, soil characteristics, crop management information and plant genetic information (Hoogenboom et al., 2012). Estimation of plant genetic parameters is a prerequisite step prior to any local application of a model (Jiang et al., 2011). Boote (1999) proposed a systematic approach by which to calibrate a model for a new crop or new cultivar, or for a particular dataset. This systematic approach was interpreted as follows: (1) most model parameters have their physical meaning, and the specific category of each parameter was classified as its meaning; (2) one class of parameters was calibrated, and the sequence was followed by the model structure, e.g., crop development was the first step to be simulated in the DSSAT-CERES and parameters related with crop growth stages were the first step to calculate. The Boote systematic approach solved the parameter calibration of how to reduce the number of parameters to include in the model, where to start, and what sequence of parameter

**Table 1**
Details of field experiments on winter wheat conducted over five consecutive growing seasons (commencing 2009–2013) in Beijing, China.

| Treatment name | Year | Cultivars | Sowing date | N level (kg N ha$^{-1}$) |
|---|---|---|---|---|
| 2009 | 2008/2009 | Nongda195, Jing9428, Yannong19 | Sep. 28th | 160 |
| 2010-S1 | 2009/2010 | Nongda195, Jing9428, Jingdong13 | Sep. 25th | 160 |
| 2010-S2 | 2009/2010 | Nongda195, Jing9428, Jingdong13 | Oct. 5th | 160 |
| 2010-S3 | 2009/2010 | Nongda195, Jing9428, Jingdong13 | Oct. 15th | 160 |
| 2011 | 2010/2011 | Nongda195, Jing9428, Yannong19 | Oct. 3rd | 230 |
| 2012 | 2011/2012 | Nongda195, Jing 9428, Jingdong22 | Sep. 25th | 190 |
| 2013-N1 | 2012/2013 | Nongda211, Zhongmai175, Jing9843, Zhongyou206 | Sep. 28th | 0 |
| 2013-N2 | 2012/2013 | Nongda211, Zhongmai175, Jing9843, Zhongyou206 | Sep. 28th | 105 |
| 2013-N3 | 2012/2013 | Nongda211, Zhongmai175, Jing9843, Zhongyou206 | Sep. 28th | 210 |
| 2013-N4 | 2012/2013 | Nongda211, Zhongmai175, Jing9843, Zhongyou206 | Sep. 28th | 420 |