Agricultural and Forest Meteorology 232 (2017) 163–175

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Uncertainty in canola phenology modelling induced by cultivar parameterization and its impact on simulated yield

Di He[a,b], Enli Wang[b,*], Jing Wang[a,*], Julianne Lilley[b], Zhongkui Luo[b], Xuebiao Pan[a], Zhihua Pan[a], Ning Yang[c]

[a] College of Resources and Environmental Sciences, China Agricultural University, Beijing 100193, China
[b] CSIRO Agriculture and Food, GPO Box 1666, Canberra ACT 2601, ACT, Australia
[c] Beijing Meteorological Service, Beijing 100089, China

ARTICLE INFO

Article history:
Received 23 May 2016
Received in revised form 5 August 2016
Accepted 15 August 2016
Available online 23 August 2016

Keywords:
Parameter uncertainty
Equifinality
Photoperiod
Vernalisation
APSIM-canola

ABSTRACT

Accurate modelling of crop phenology is essential for evaluating how crops respond to future environmental and management changes. However, cultivar parameters are often estimated based on limited data and using a trial-and-error method, leading to uncertainties in simulated phenology and subsequent crop yield. In this paper we evaluated the ability of the APSIM-Canola model to simulate canola phenology and the impact of uncertainty in phenology modelling on simulated grain yield.

We constrained the APSIM-Canola model to experimental data to derive the parameters controlling canola flowering and maturity dates using a Bayesian optimisation method, by minimising the RMSE between simulated and recorded pre- and post-flowering durations. The dataset covered observations for 10 cultivars, 35 site-years, with maximum of seven sowing dates each year from four canola growing regions in China.

Our results demonstrated that multiple combinations of parameters could lead to the same simulation accuracy of canola phenology (equifinality) due to insufficient information/understanding to separate vernalisation and photoperiod sensitive phases. This could potentially lead to incorrect cultivar characterisation and wrong yield simulations. Our results further showed that the critical photoperiod below which canola phenological development slows down is likely to be 20 h instead of the 16.3 h currently used in the APSIM model. With this correction, the model was able to accurately simulate canola phenology across environments, and the impact of equifinality on simulated yield was small. Cultivar differences in terms of phenology could be accurately described by only three parameters in APSIM, i.e., vernalisation sensitivity, photoperiod sensitivity, and thermal time required for grain-filling period.

1. Introduction

Crop phenology, i.e., the timing of the key growth stages and physiological processes, controls the life cycle of crops and the partitioning of assimilates between different crop organs. It also determines the timing of various agronomic management practices. Accurate modelling of crop phenology is therefore essential for evaluating management options and how crops respond to future environmental and management changes (Menzel et al., 2006; Wang et al., 2013). However, some of the key model parameters that specify cultivar phenological differences in current crop models cannot be directly measured (Liu et al., 2010, 2013). Very often, these cultivar parameters are estimated based on limited data or determined using trial-and-error method (Wang et al., 2013). In spite of the importance of phenology, the potential uncertainties in simulated phenology caused by parameter estimation and the potential impact of such uncertainty on simulated crop yield have not been properly addressed.

Canola (*Brassica napus* L. or *Brassica juncea*) ranks among the top three oilseed crops in the world, accounting for 18% of the global crop oil production in 2013 (Rondanini et al., 2012; FAO, 2015). The rising demand for biofuels has further promoted canola production (Fargione et al., 2008; Rondanini et al., 2012) and relevant research including the use of modelling to evaluate the impact of agricultural management on canola production (Shabani et al., 2013; Zeleke et al., 2014), and potential and achievable canola yields across regions (Christy et al., 2013; Lilley et al., 2015). China produces ∼20% of the canola seed in the world, with an average

* Corresponding authors.
E-mail addresses: Enli.wang@csiro.au (E. Wang), wangj@cau.edu.cn (J. Wang).

http://dx.doi.org/10.1016/j.agrformet.2016.08.013
0168-1923/

annual production of 6.20 M t (1961–2013) (FAO, 2015). One recent study has demonstrated the usefulness of modelling to simulate canola phenology and to evaluate the impact of sowing dates on canola yield in the Yangtze River Basin of China (Wang et al., 2012). In order to meet the demand for modelling canola phenology and growth, it is critical to examine the potential uncertainty in simulated phenology and the subsequent impact on simulated canola yield.

Several recent studies have tried to address uncertainty in crop modelling. A multi-model ensemble approach has been proposed to quantify uncertainty in simulated crop yields (Asseng et al., 2013; Bassu et al., 2014). Wang et al. (2015b) further showed significant uncertainty in simulated maize phenology due to structural differences between current crop models. However, few attempts have been made to quantify the uncertainty caused by model parameterization, particularly for canola (Robertson et al., 2002).

The objectives of this study are to: (i) critically evaluate the capacity of the APSIM farming systems model (Holzworth et al., 2014; Robertson and Lilley, 2016) to simulate phenology of both spring and winter canola; (ii) examine the robustness of APSIM-Canola phenology parameters derived from observed phenology; (iii) quantify the uncertainty in simulated canola phenology and its impact on simulated canola yield in the main canola production regions of China.

2. Materials and methods

2.1. Study sites, climate, and sources of crop and weather data

Nine sites located in the main canola production regions of China were chosen in this study, including Leshan, Yuxi, Jiangkou, and Guiyang in the Upper Yangtze River Basin, Wuhan and Changsha in the Middle Yangtze River Basin, Nanjing in the Lower Yangtze River Basin, and Wuchuan and Tianzhu in the Northern Region (Fig. 1). The Yangtze River Basin is largely characterised by subtropical humid monsoon climate and the prevailing farming system is canola-rice double cropping, where winter canola is sown in autumn (September–November) and harvested in spring (March–May). The Upper Yangtze River Basin has complex terrain with mixed subtropical and alpine climate. The Northern Region has a temperate continental monsoon climate with cold winter and warm summer, where spring canola is planted in spring (March–May) and harvested in autumn (September–November) in a single-cropping system.

At all sites, canola phenological stages, i.e. time of sowing, emergence, 50% plants first flowering, and maturity, were recorded for multiple years depending on locations (Table 1 and Fig. 1). Crop data in the Upper Yangtze River Basin were obtained from agro-meteorological observation stations belonging to the China Meteorological Administration (CMA). At each of these stations, there was a cropping field to observe crop growth, development, and yield with consistent CMA data collection standards. Crop data in Wuhan, Changsha, Nanjing, and Tianzhu were extracted from the published articles of Liu (2008), Liao and Guan (2001), Tang (2006), and Xie (2012), respectively. Crop data of Wuchuan site were measured at Wuchuan experimental station in Hohhot, Inner Mongolia. (Shen et al., 2013; Yang, 2014). The canola cultivars planted in the experiments and their key differences are listed in Table 2.

In all the experiments, weeds, pests and diseases were properly controlled, and fertilizers were applied to eliminate any nutrient deficiency to canola growth. At the Wuchuan site, canola was grown under rainfed conditions (without irrigation), while at all other sites the canola crop was grown under water stress-free conditions, either due to sufficient rainfall or through supplementary irrigations to meet crop water demand.

Historical daily weather data from 1971 to 2009 for Nanjing, from 1987 to 2010 for Changsha, and from 1960 to 2010 for all the other sites, were obtained from CMA, including maximum and minimum temperatures (°C), rainfall (mm), and sunshine hours (h). Sunshine hours were converted into daily global radiation using the Angstrom equation (Black et al., 1954; Wang et al., 2015a).

Soil hydraulic properties and other soil parameters used for simulations of canola phenology, biomass growth and yield for each site were obtained from the China Soil Scientific Database (http://www.soil.csdb.cn/). Plant available water holding capacity (PAWC) of the soil ranged from 133.8 to 247.5 mm, and canola rooting depth was from 80 to 100 cm at selected sites.

2.2. The APSIM-Canola model

APSIM version 7.6 was used in this study. APSIM simulates canola development, biomass growth, and grain yield in response to temperature, photoperiod, radiation, soil water, and nitrogen conditions with a daily time-step (Robertson et al., 1999; Robertson and Lilley, 2016). For phenological development, the duration from sowing to maturity is divided into eight phases, i.e., sowing to germination, germination to emergence, emergence to the end of juvenile stage (EndJuv), EndJuv to floral initiation (FI), FI to flowering (FL), FL to start grain-filling (StGF), StGF to end of grain-filling (EndGF), and EndGF to maturity (Fig. 2). Except for the first and last phases that are short and assumed to last only for one day, each phase requires a certain cumulative thermal time (CTT) to complete. The CTT required from germination to emergence is proportional to sowing depth. CTT from emergence to EndJuv decreases with accumulated vernalisation days, with the rate of decrease dependent on vernalisation sensitivity of the cultivar. CTT from EndJuv to FI decreases with increasing photoperiod, with the rate of decline dependent on photoperiod sensitivity of the cultivar. For phases FI to FL, FL to StGF, and StGF to EndGF, the developmental rate only depends on the rate of thermal time accumulation (Robertson et al., 2002; Robertson and Lilley, 2016).

Cultivars may differ significantly in their sensitivity to vernalisation and photoperiod, and in the length of grain-filling period (i.e. CTT from StGF to EndGF). Little genotypic variation was found for the length of phases FI – FL and FL – StGF (Robertson et al., 2002). In APSIM, it is assumed that phenological development of canola is not influenced by water and nutrient stresses, except for extreme conditions that may kill the crop. This is in general consistent with our recorded phenology under different water supply conditions in the experiments. Although limited individual studies indicated that water stress might accelerate or delay maturity (Tesfamariam et al., 2010; BirunAra et al., 2011), the impact of water and nutrient stress on canola phenology is still inconclusive. Therefore, we did not consider any impact of water and nutrient stress on phenological development of canola.

2.3. Derivation of cultivar parameters

For a given canola cultivar, 10 parameters in total determine the phenological development of canola from emergence to maturity in APSIM (Fig. 2 and Table 3). The first three determine the vernalisation sensitivity, i.e. the maximal cumulative vernalisation days required to complete the vernalisation process (VD_{max}) and the minimum and maximum cumulative thermal time required to complete the juvenile phase from emergence ($CTT_{Juv,min}$, $CTT_{Juv,max}$). The next four determine the photoperiod sensitivity, i.e., the thermal time target from end of juvenile stage to floral initiation at the maximum and minimum critical photoperiod ($CTT_{FI,min}$, $CTT_{FI,max}$, DL_{max}, DL_{min}). Two thermal time targets (CTT_{FL}, CTT_{StGF}) are used to specify the time needed from floral initiation to flowering and from flowering to the start of grain-filling.