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RESEARCH ARTICLE

Using the DSSAT model to simulate wheat yield and soil organic carbon under a wheat-maize cropping system in the North China Plain

LIU Hai-long[1], LIU Hong-bin[2], LEI Qiu-liang[2], ZHAI Li-mei[2], WANG Hong-yuan[2], ZHANG Ji-zong[2], ZHU Ye-ping[1], LIU Sheng-ping[1], LI Shi-juan[1], ZHANG Jing-suo[3], LIU Xiao-xia[3]

[1] *Institute of Agricultural information, Chinese Academy of Agricultural Sciences/Key Laboratory of Agri-information Service Technology, Ministry of Agriculture, Beijing 100081, P.R.China*

[2] *Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences/Key Laboratory of Nonpoint Source Pollution Control, Ministry of Agriculture, Beijing 100081, P.R.China*

[3] *Beijing Municipal Station of Agro-environmental Monitoring, Beijing 100029, P.R.China*

Abstract

Crop modelling can facilitate researchers' ability to understand and interpret experimental results, and to diagnose yield gaps. In this paper, the Decision Support Systems for Agrotechnology Transfer 4.6 (DSSAT) model together with the CENTURT soil model were employed to investigate the effect of low nitrogen (N) input on wheat (*Triticum aestivum* L.) yield, grain N concentration and soil organic carbon (SOC) in a long-term experiment (19 years) under a wheat-maize (*Zea mays* L.) rotation at Changping, Beijing, China. There were two treatments including N0 (no N application) and N150 (150 kg N ha^{-1}) before wheat and maize planting, with phosphorus (P) and potassium (K) basal fertilizers applied as 75 kg P_2O_5 ha^{-1} and 37.5 kg K_2O ha^{-1}, respectively. The DSSAT-CENTURY model was able to satisfactorily simulate measured wheat grain yield and grain N concentration at N0, but could not simulate these parameters at N150, or SOC in either N treatment. Model simulation and field measurement showed that N application (N150) increased wheat yield compared to no N application (N0). The results indicated that inorganic fertilizer application at the rates used did not maintain crop yield and SOC levels. It is suggested that if the DSSAT is calibrated carefully, it can be a useful tool for assessing and predicting wheat yield, grain N concentration, and SOC trends under wheat-maize cropping systems.

Keywords: DSSAT, wheat-maize rotation, model evaluation, long-term experiment, yield, soil organic carbon

1. Introduction

Chemical fertilizers contribute to high crop yield and understanding the fate of fertilizers is important for making management decisions about practices for crop production and environmental protection. Long-term fertilization experiments play an important role in determining the effects of long-term fertilization on crop yield and soil fertility. In China, the National Long-term Monitoring Network on Soil Fertility

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LIU Hai-long, E-mail: liuhailong@caas.cn; Correspondence LIU Hong-bin, E-mail: liuhongbin@caas.cn

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and Fertilizer was established in the late 1980s to investigate long-term changes in soil fertility, fertilizer use efficiency and environmental effects of fertilizers for different areas, soil type, and fertilization systems. For example, using the National Long-term Monitoring Network on Soil Fertility and Fertilizer of China, Zhao *et al.* (2011) evaluated the effect of long-term fertilization regimes on nitrate distribution and accumulation in the soil profile, and showed that 24–82% of applied inorganic nitrogen (N) was lost, mostly through ammonia volatilization.

The North China Plain is one of the most important crop production regions in China, and the region accounts for 20% of the national food grain production. The winter wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) rotation system is the dominant cropping system in the region. The best management practice in this wheat-maize cropping system is necessary to improve crop yield and protect the soil and water from erosion and pollution. Although field experiments provide useful information for increasing crop yield and improving field management practices, they are costly and time-consuming, and some parameters are very difficult to measure, such as carbon (C) and nitrogen (N) cycling processes, especially in long-term experiments. Further, the experimental data may have limitations for developing the best practical management practices, because they are influenced by various factors, such as sample size and observation frequency (Sun *et al.* 2013). Dynamic crop growth models were designed to simulate crop growth and soil nutrient dynamic processes in order to quantify the relationships among soil nutrients, crop growth and soil water in the soil-plant-atmosphere system. Thus, they provide an opportunity to investigate the impact of management practices on crop production and the environment, and allow development of best management practices or strategies to improve the crop production. The Decision Support System for Agrotechnology Transfer (DSSAT) model is a cropping system model package (Jones *et al.* 2003), comprising over 28 Cropping Systems Models (CSMs) (Hoogenboom *et al.* 2012), and it is widely used to simulate crop growth, development, and yield on a daily basis (Jones *et al.* 2003; Hoogenboom *et al.* 2012). In recent years, the DSSAT model has been successfully used to simulate the results of long-term experiments (Liu *et al.* 2011; De Sanctis *et al.* 2012; Yang *et al.* 2013). Since the soil organic matter (SOM)-residual component of the CENTURY model was incorporated in DSSAT, it has become more suitable for simulating low-input systems and conducting long-term sustainability analyses (Gijsman *et al.* 2002). For example, Yang *et al.* (2013) simulated the effects of long-term N fertilization on maize yield and soil C and N dynamics in northeast China, and concluded that the DSSAT model with the CENTURY-based soil module can simulate soil N dynamics and predict long-term soil organic carbon (SOC) sequestration well. Musinguzi *et al.* (2014) used the DSSAT-CENTURY model to simulate SOC dynamics in a low-input maize cropping system, and found that the model was a potentially useful tool for predicting SOC dynamics in low-input systems. However, limited information is available about the use of the DSSAT model to study impacts of N fertilizer application on crop growth in the wheat-maize rotation system in the North China Plain region. In this study, the objectives were (i) to evaluate the DSSAT CERES-Wheat crop model together with the CENTURY-based soil model and then to simulate the measured results of a long-term low input wheat-maize rotation experiment, and (ii) to investigate effects of long-term N fertilization on wheat maize yields and soil properties.

2. Materials and methods

2.1. Field experiment

Since 1991, long-term field experiments have been conducted in Changping County, Beijing, China (116°8´24´´E, 40°7´48´´N) as part of National Long-term Monitoring Network on Soil Fertility and Fertilizer of China. Detailed descriptions of the experiments were reported by Liu *et al.* (2010) and Tang *et al.* (2008). In one long-term experiment, a winter wheat and summer maize rotation was carried out, and the plots were separated by cement walls from the soil surface to 80 cm depth to prevent seepage between the plots, particularly during irrigations. Annual average precipitation in the area is 600 mm and annual average air temperature is 12°C. The soil is classified as Fluvo-Aquic (China classification) and Haplic Luvisol (FAO classification) soil (Tang *et al.* 2008). Some soil physical and chemical properties are shown in Table 1.

The experiment included 12 fertilizer treatments with combinations of mineral fertilizers, wheat straw and swine manure. For this study, we selected two treatments, including N0 (no N application) and N150 (150 kg N ha^{-1}). Phosphorus (P) and potassium (K) were applied annually to all plots as 75 kg P_2O_5 ha^{-1} and 37.5 kg K_2O ha^{-1}, respectively, to minimise crop growth limitation arising from deficiencies of these nutrients. Fertilizer applications were conducted before wheat and maize planting. Aboveground biomass was removed from the plots after each harvest. The area of each plot was 200 m^2. In the double cropping rotation, winter wheat was planted between September 29 and October 7 and harvested in mid-June the following year, while summer maize was planted between June 25 and July 3 and harvested in late September. The wheat cultivar used was Zhongyou 9507 from 1990 to 2005, and Zhongmai 12 from 2006 to 2008.

2.2. DSSAT model

In this study, CSM-Wheat and CSM-Maize model (Hoogen-