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AUTOMATIC CALIBRATION OF CROP GROWTH MODELS FOR PREDICTING CORN ECONOMIC OPTIMUM NITROGEN RATES

Yuxin Miao^{1*}, Xiaoxing Zhen¹, Yanbo Huang^{2*}, Gary Feng²

¹ Precision Agriculture Center, University of Minnesota, USA; ² USDA-ARS Genetics and Sustainable Agriculture Research Unit, USA

*Corresponding Author: ymiao@umn.edu; yanbo.huang@usda.gov

ABSTRACT

The objectives of this study were to 1) evaluate an automatic model calibration strategy; and 2) compare the performance of DSSAT and APEX models for simulation of maize (*Zea mays* L.) growth, plant nitrogen (N) uptake, yield in response to different N application rates and the estimation of the economic optimum N rate (EONR). Detailed data collected from eight site-years of N experiments conducted from 2014 to 2016 in Minnesota and Wisconsin, USA were used in this research. The results indicated that both DSSAT and APEX models performed well at Minnesota sites in maize yield simulation, with manual calibration achieving R^2 of 0.78–0.95, root mean square error (RMSE) of 0.2–1.4 t ha⁻¹, and normalized root mean square error (NRMSE) of 2%–17%. Automatic calibration using a model-independent data assimilation (MIDA) optimizer yielded robust yield prediction results ($R^2 = 0.66$ –0.95; RMSE of 0.3–1.4 t ha⁻¹, and NRMSE of 3–17%). In addition, both DSSAT and APEX models performed well in simulating yield at different N rates and EONR for both preplant and split N application scenarios, although high prediction errors were observed at some site-years. The independent test using Wisconsin data further confirmed the high accuracy of yield prediction for both models using the two calibration strategies (R^2 : 0.79–0.88). It is concluded that MIDA optimizer-based automated model calibration can effectively optimize crop growth model parameters, mitigating the risk of local optima. Both DSSAT and APEX models performed well for simulating maize yield, yield response to N rates and EONR, but improvements are needed for the APEX model for simulating biomass and plant N uptake. The implications for precision agriculture will be discussed.

Keywords: Yield response, Automatic calibration, Nitrogen management, Economic optimum nitrogen rate, Precision nitrogen management

INTRODUCTION

Dynamic process-based crop growth models, which integrate physical and physiological aspects of crop growth and development, are important tools for precision agriculture. However, manual model calibration is time consuming, which limits their applications in precision agriculture. The MIDA (Model-Independent Data Assimilation) optimizer was designed as a highly modular tool, independent of specific models, and friendly to users with limited programming skills and/or technical knowledge of data assimilation algorithms (Huang et al., 2016). However, its performance has only been tested on four ecological models; thus, broader evaluation with comprehensive crop models is needed.

The objectives of this study were to 1) evaluate an automatic model calibration strategy using the MIDA optimizer; and 2) compare the performance of DSSAT and APEX models for simulation of maize growth, plant N uptake and yield in response to different N application rates and EONR.

MATERIALS AND METHODS

Six site-years of N experiments located in Minnesota and two site-years located in Wisconsin were selected in this study. Historically observed weather data from 1990 to 2023 was obtained

from the Iowa Environmental Mesonet (<http://mesonet.agron.iastate.edu/>). Soil information for the dominant soils on each experimental field was obtained from field measurements and the USDA Gridded Soil Survey Geographic Database (gSSURGO) at 30-m resolution. Part of the soil fertility and properties (e.g., Nitrate-N, ammonium N, phosphorus, potassium, organic matter) were measured at three soil depths (0.3 m, 0.6 m, 0.9 m) at/before planting (Kitchen et al., 2017). The soil properties that were not measured in the field were extracted from the SSURGO system. A set of genotype-specific crop parameters for DSSAT and APEX models was calibrated through model calibration procedure in this study using a manual calibration (MC) and an automatic calibration (AC) approach with the MIDA optimizer. The schematic diagram is shown in Figure 1.

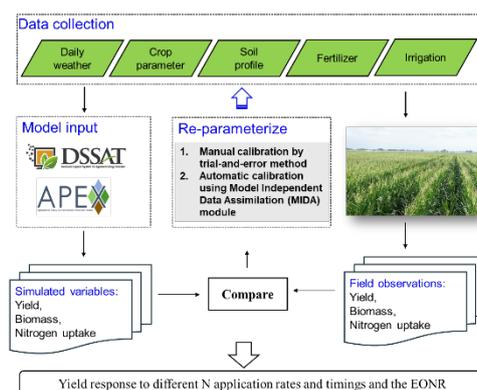


Figure 1. Schematic diagram of crop model calibration and evaluation.

RESULTS & DISCUSSION

Both models performed well for yield prediction, with MC achieving high accuracy ($R^2 = 0.78\text{--}0.95$). The implementation of the MIDA optimizer for AC preserved similar model performance ($R^2 = 0.66\text{--}0.95$), providing an efficient approach to model calibration. Both models successfully captured maize yield responses to N rate and timing. Simulated EONR values by DSSAT model and APEX models closely reflected these observed EONR ranges ($100\text{--}236\text{ kg ha}^{-1}$ for preplant and $116\text{--}281\text{ kg ha}^{-1}$ for split N applications), though discrepancies were shown in certain sites and years. Biomass and plant N uptake simulations highlighted the strengths and limitations of each model. DSSAT outperformed APEX in simulating aboveground biomass and plant N uptake at maturity, with reduced errors after AC (RMSE: $0.7\text{--}3.5\text{ t ha}^{-1}$, NRMSE: $3\%\text{--}17\%$). In contrast, APEX showed greater variability and overestimated biomass at maturity, though both models did not perform well in simulating biomass and plant N uptake at the tasseling stage. The performance of DSSAT and APEX models in yield prediction was further validated using the independent datasets collected from two experimental sites in Lorenzo and Plano in Wisconsin in 2016.

CONCLUSIONS

The MIDA optimizer can be used to automatically calibrate crop growth models, which can facilitate their applications in precision agriculture. Both models performed well for simulating maize yield, its responses to N applications, and EONR, however, . Future efforts should focus on refining AC techniques to account for spatial yield variability under diverse on-farm conditions and improve decision-making for precision crop production.

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