Ecosystem modeling: Supermodel or coupling approach?

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Introduction

The Decision Support System for Agrotechnology Transfer-Cropping System Model (DSSAT-CSM) is a widely used modeling package that often simulates wheat yield and biomass well. However, its soil moisture simulation is not always satisfactory.

On the other hand, the Simultaneous Heat and Water (SHAW) model is not able to predict long-term soil water dynamics properly without provision of canopy information. We therefore proposed to use DSSAT-CSM to simulate crop biomass and provide the necessary information for SHAW to improve the prediction of soil water dynamics.

Materials and methods

The Experiment: This model coupling approach was tested using data from three conventionally-tilled wheat rotations (continuous wheat (CW), wheat-fallow (WF) and wheat-wheat-fallow (WWF)) of a long-term cropping systems study located on a Thin Black Chernozemic clay loam near Three Hills, Alberta, Canada. The details of the study were described by Wang et al. (2007).

From 1997, soil water content before seeding at depths of 0–15 cm, 15–30 cm, 30–60 cm, 60–90 cm, and 90–120 cm was obtained by the gravimetric method every year in all treatments. Beginning in 2001, a Delta T ML2 Theta probe was used to measure moisture at 0-6 cm usually once a week in the continuous wheat and wheat-fallow treatments.

DSSAT-CSM: The DSSAT-CSM (Jones et al, 2003) package is a collection of independent programs including 16 crop models and a set of modules for the simulation of the soil temperature, water, carbon and nitrogen balances. Its soil water module is a one-dimensional model which computes the daily changes in soil water content by soil layer due to infiltration, drainage, unsaturated flow and evapotranspiration. The potential evapotranspiration can be calculated by three different methods: Priestley–Taylor, Penman-FAO24 and Penman–Monteith reference method (FAO56).

SHAW Model: The SHAW model, originally developed to simulate soil freezing and thawing (Flerchinger and Saxton 1989), simulates heat, water and solute transfer within a one-dimensional profile which includes the effects of plant cover, dead plant residue and snow. This model has the ability to predict climate and management effects on soil freezing, snowmelt, runoff, soil temperature, water, evaporation, and transpiration. It requires detailed canopy information such as plant height, leaf width and length, dry biomass, leaf area index, effective rooting depth, as well as residue cover and thickness, all of which are provided from the DSSAT model.

Results and discussion

By comparing with soil water content with the 0-6 cm Theta probe measurements under CW simulated results were statistically sound for both models (Figure 1). The SHAW model performed better than DSSAT-CSM, exhibiting better correlation with measurements, higher prediction accuracy and lower bias error. Caution should be taken when comparing models for this depth because the first layer simulated by DSSAT-CSM was 0-5 cm instead of 0-6 cm. For each year, simulated values by DSSAT-CSM fluctuated more and are often too low compared with measurements. The SHAW model improved simulation in terms of both value and trends for each year. Similar results were obtained for the other rotations (data not shown).

Because water contents in the soil profile were only measured 10 times over the nine years by gravimetric method, it is impossible to catch the seasonal changes. Similar to the comparison with Theta probe measurements, the SHAW model also improved simulations of soil water content at 0-15 cm compared with DSSAT-CSM (Fig. 2). At 15-30 cm, the SHAW model using either daily or hourly weather data performed better than DSSAT-CSM (Fig. 2). In contrast to the near-surface depth, water content simulated by DSSAT-CSM changed less over the time and was often overestimated compared with that by SHAW. Surprisingly, the simulated total soil water at 0-120 cm was correlated with measurements at $P<0.05$ for both models. The DSSAT-CSM model tended to overestimate the total water, but the simulation line was often within the range of standard errors of measurement means.

Conclusion

The DSSAT-CSM model simulated biomass production of wheat well under various rotations under conventional tillage, but its prediction of soil water was not satisfactory. Similar to previous studies the model tended to overestimate the drying of the surface layer, and it also overestimated soil water content in the deeper depths (30-120 cm). It is, however, able to provide reasonable canopy information for SHAW, a more sophisticated soil microclimate model, to predict long-term soil moisture dynamics. The SHAW model improved estimation of soil water content at different depths and total water at 0-120 cm in all different wheat rotations and with different phases by improving accuracy and reducing consistent error.

References

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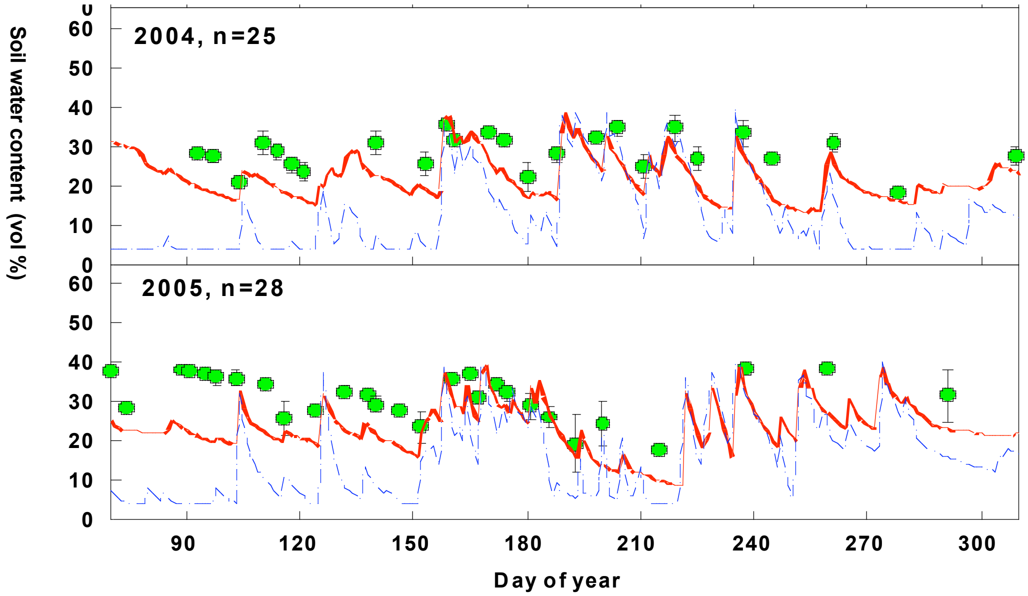

Figure 1. Soil water contents simulated at 0 -5 cm by DSSAT -CSM and at 0 -6 cm by SHAW using hourly weather data and observed at 0 -6 cm using Theta probe in the conventionally tilled continuous wheat in the growing seasons of 2001 -2005 at Three Hills, AB.

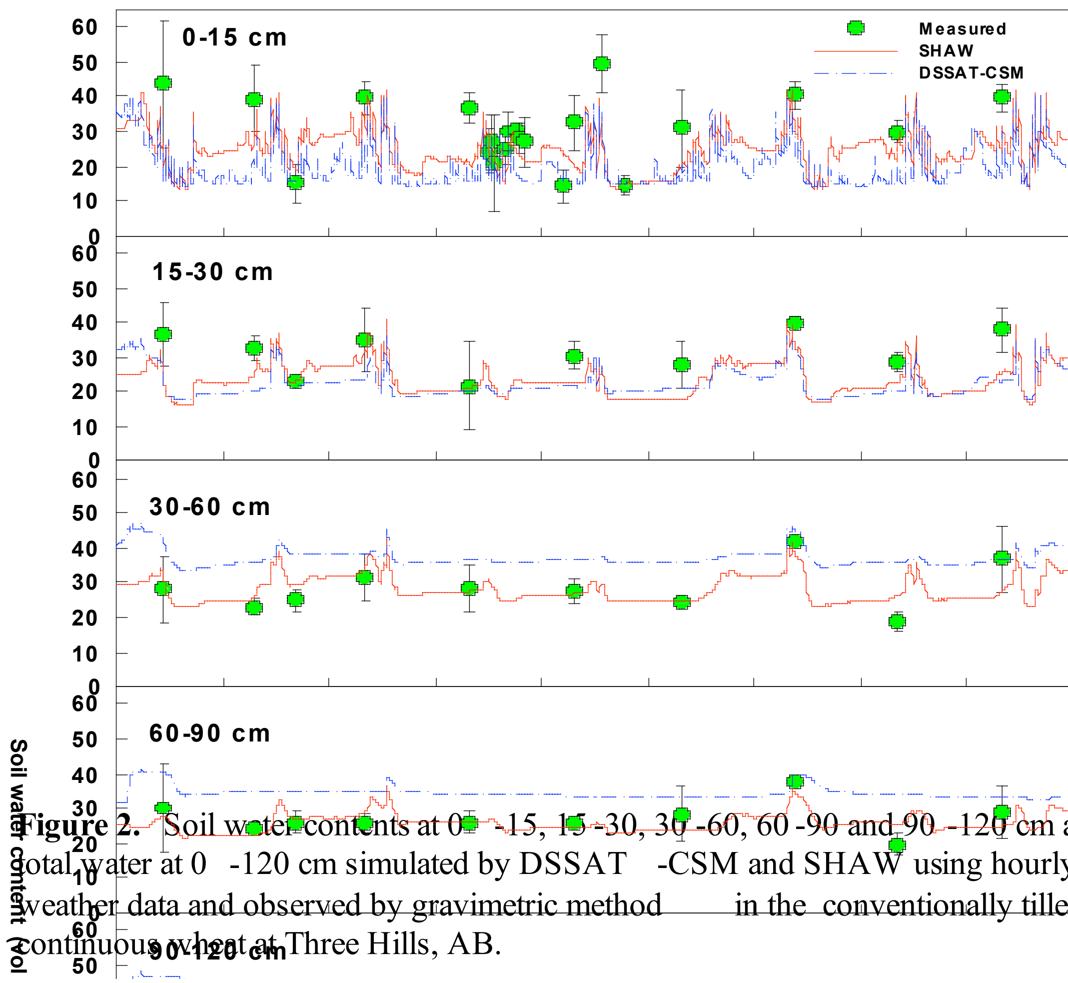

Figure 2. Soil water contents at 0 -15, 15 -30, 30 -60, 60 -90 and 90 -120 cm and total water at 0 -120 cm simulated by DSSAT -CSM and SHAW using hourly weather data and observed by gravimetric method in the conventionally tilled continuous wheat at Three Hills, AB.