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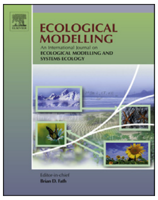

Development, uncertainty and sensitivity analysis of the simple SALUS crop model in DSSAT

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ABSTRACT

Simplified approaches to modeling crop growth and development have recently received more attention due to increased interest in applying crop models at large scales for various agricultural assessments. In this study, we integrated the simple version of SALUS (System Approach to Land Use Sustainability) crop model in the widely-used Decision Support System for Agrotechnology Transfer (DSSAT) to enhance the capability of DSSAT to simulate additional crops without requiring detailed parameterization. An uncertainty and sensitivity analysis was conducted using the integrated DSSAT-simple SALUS model to assess the variability in model outputs and crop parameter ranking in response to uncertainties associated with crop parameters required by the model. The influence of year, production level, and location on the effect of crop parameter uncertainty was also investigated.

Parameter uncertainty resulted in a high variability in modeled outputs. Simulated potential aboveground biomass ranged from 1.2 t ha^{-1} to 38 t ha^{-1} for maize and 4 t ha^{-1} to 26.5 t ha^{-1} for peanut and cotton, all locations and years considered. The degree of variability was dependent upon the production level, the location, the year, and the crop. Ranking of crop parameters was not significantly affected by the year of study but was strongly related to the production level, location, and crop. The model was not sensitive to parameters related to prediction of the timing of germination and emergence. The most influential parameters were related to leaf area index growth, crop duration, and thermal time accumulation. Findings from this study contributed to understanding the effects of crop parameter uncertainty on the model's outputs under different environmental conditions.

1. Introduction

Recently crop models have been adopted at scales larger than field levels to assess bi-directional feedbacks between the atmosphere and croplands (Faivre et al., 2004; Bondeau et al., 2007; Osborne et al., 2007; Adam et al., 2011). Some studies have suggested that when operating at larger scales, crop models may be less sensitive to some detailed crop growth processes that were designed for simulating individual plants (Adam et al., 2011; Ewert et al., 2011). In addition, gaps in knowledge of detailed crop parameters for many crops limit the application of complex crop models in global assessment studies (Stehfest et al., 2007). Many modeling communities agree that accommodating a wide range of crops in generic models will not only increase the applicability of the models but also contribute to structuring knowledge common to these crops (Jones et al., 2003; Wang et al., 2002). However, while these generic models have been adopted worldwide, many of them, including the CERES family (Jones and Kiniry, 1986), the CROPGRO family (Boote et al., 1998) and WOFOST (Supit et al., 1994) exhibit a significant level of details and therefore restrict their use in situations where inputs and parameters required by the model, are not available.

In this study, we integrated in DSSAT (Decision Support System for Agrotechnology Transfer) a robust model yet simple in its parameterization, the simple crop model currently present in SALUS (System Approach to Land Use Sustainability). SALUS (www.salusmodel.net, Basso et al., 2006, 2010) derives from the well-established and validated CERES suite of models with the goal of quantifying the impact of management strategies and their interactions with the soil–plant–atmosphere system on yield and carbon (C), nitrogen (N), and phosphorus (P) dynamics. It contains two modeling approaches, a simple crop model and a complex model. The simple crop model is based on a predetermined leaf area index (LAI) curve that is described in this paper. The complex crop model calculates LAI using cultivar coefficients. The model accommodates various crop rotations, planting dates, plant populations, irrigation, organic and inorganic fertilizer application, and tillage practices. It also simulates plant growth and soil conditions during growing seasons and fallow periods. A version of the model runs on the Internet with simple interfaces (for farmers and extension services) and

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has spatial capabilities. SALUS presents new algorithms for simulating kernel number, plant population effects on bareness and prolificacy, surface runoff, soil water redistribution, upflow from the water table and includes a spatial component for water routing across the landscape (Basso, 2000; Batchelor et al., 2002). SALUS has been tested for soil carbon dynamics (Senthilkumar et al., 2009) crop yield (Basso et al., 2007), plant N uptake and phenology (Basso et al., 2010, 2011), nitrate leaching (Giola et al., 2012; Syswerda et al., 2012), water use efficiency (Ritchie and Basso, 2008) and transpiration efficiency (Basso and Ritchie, 2012).

The simple SALUS crop model (which will be referred to as SALUS-Simple) is based on the modeling approaches used by EPIC (Erosion Productivity Impact Calculator, Williams et al., 1989) and ALMANAC (Agricultural Land Management Alternatives with Numerical Assessment Criteria, Kiniry et al., 1992) to estimate LAI and plant biomass during the season. The current version of the model describes water-limited production with 20 plant parameters and can in principle be parameterized for a range of annual crops and grasses from literature or available data. Comparison between ALMANAC (which calculates LAI and dry matter similarly to SALUS-Simple) and CERES showed that the two models had similar capabilities to simulate variability in maize grain yield across nine U.S. locations (Kiniry et al., 1997).

The implementation of SALUS-Simple in DSSAT led to a number of specific research questions: does the model behave as expected under different environments? What plant parameters exert the largest influence on major model outputs? How do uncertainties in plant parameters translate into variability in these model outputs? Do all the parameters in SALUS-Simple need to be estimated for each maturity group in a species?

A global uncertainty and sensitivity analysis was conducted to address these questions. Since an uncertainty and sensitivity analysis has not been conducted on the SALUS-Simple crop model previously, little is known about the relationship between uncertainties in the plant parameters and variability in key model outputs. Uncertainty and sensitivity analysis is recommended and widely used during model development (Monod et al., 2006). It has been applied for various objectives including verifying model behavior (Confalonieri et al., 2010b), identifying important crop parameters (Pathak et al., 2007) and ranking these parameters with respect to their importance in yield formation (Richter et al., 2010). A detailed review of uncertainty and sensitivity analysis methods was provided by Saltelli et al. (2004), Helton (1993) and Helton et al. (2005). A comparison of the most common sensitivity analysis methods was recently discussed by Confalonieri et al. (2010a).

The goal of this paper was to describe the SALUS-Simple crop model integrated in DSSAT and investigate responses of the model's outputs to crop parameter uncertainty under different environmental conditions. Specific objectives were to: (i) quantify the effect of changes in crop parameters within their ranges of uncertainty, on final biomass, final grain yield and season length of maize, peanut, and cotton; (ii) identify parameters in SALUS-Simple that have the most influential effects on model outputs, and hence need to be estimated with high accuracy; (iii) highlight differences in the effects of crop parameter uncertainty on model outputs under various environmental conditions and at potential and water-limited production levels.

2. Materials and methods

2.1. Overview of the SALUS-Simple crop model

The SALUS-Simple crop model simulates the potential production of an annual crop using less than 20 crop parameters with

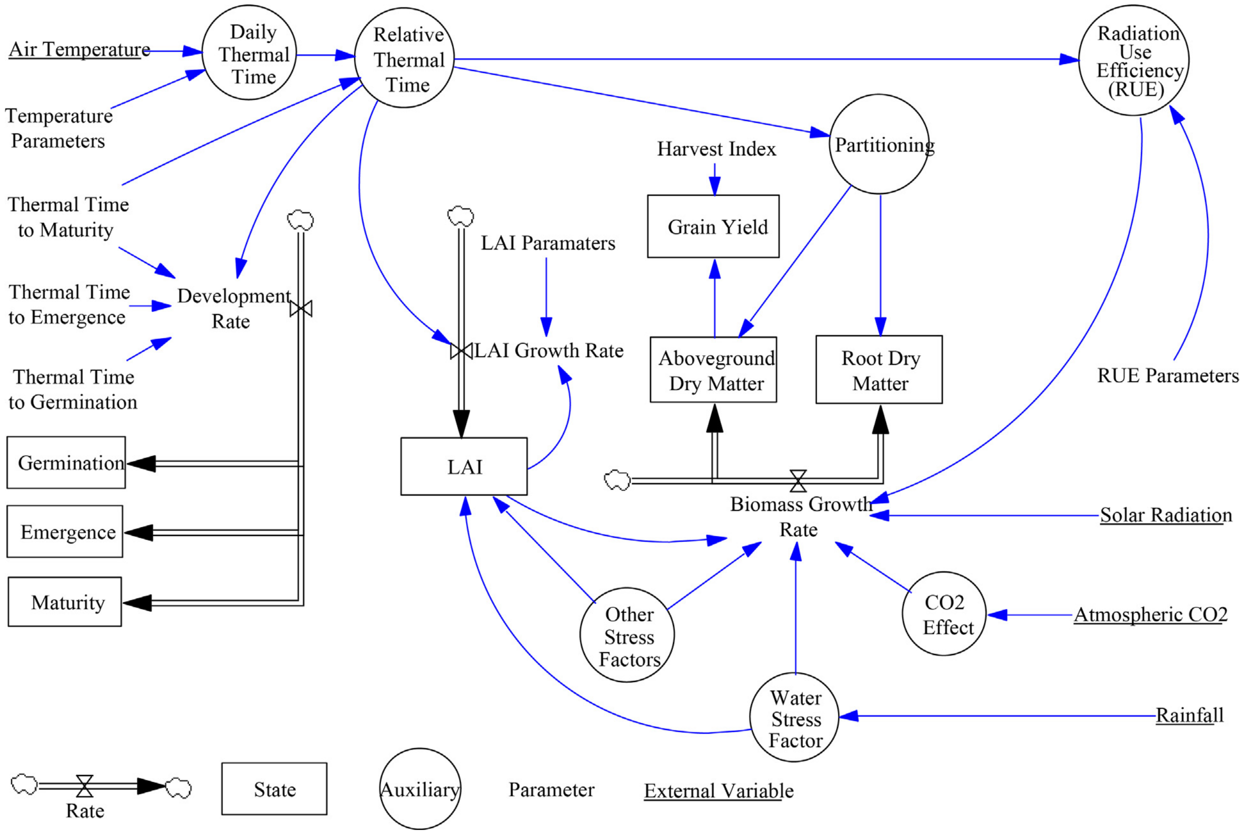

Fig. 1. Diagram depicting the SALUS-Simple model with the main crop growth and development processes.