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Selecting crop models for decision making in wheat insurance

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ABSTRACT

In crop insurance, the accuracy with which the insurer quantifies the actual risk is highly dependent on the availability on actual yield data. Crop models might be valuable tools to generate data on expected yields for risk assessment when no historical records are available. However, selecting a crop model for a specific objective, location and implementation scale is a difficult task. A look inside the different crop and soil modules to understand how outputs are obtained might facilitate model choice. The objectives of this paper were (i) to assess the usefulness of crop models to be used within a crop insurance analysis and design and (ii) to select the most suitable crop model for drought risk assessment in semi-arid regions in Spain. For that purpose first, a pre-selection of crop models simulating wheat yield under rainfed growing conditions at the field scale was made, and second, four selected models (Aquacrop, CERES-Wheat, CropSyst and WOFOST) were compared in terms of modelling approaches, process descriptions and model outputs. Outputs of the four models for the simulation of winter wheat growth are comparable when water is not limiting, but differences are larger when simulating yields under rainfed conditions. These differences in rainfed yields are mainly related to the dissimilar simulated soil water availability and the assumed linkages with dry matter formation. We concluded that for the simulation of winter wheat growth at field scale in such semi-arid conditions, CERES-Wheat and CropSyst are preferred. WOFOST is a satisfactory compromise between data availability and complexity when detail data on soil is limited. Aquacrop integrates physiological processes in some representative parameters, thus diminishing the number of input parameters, what is seen as an advantage when observed data is scarce. However, the high sensitivity of this model to low water availability limits its use in the region considered. Contrary to the use of ensembles of crop models, we endorse that efforts be concentrated on selecting or rebuilding a model that includes approaches that better describe the agronomic conditions of the regions in which they will be applied. The use of such complex methodologies as crop models is associated with numerous sources of uncertainty, although these models are the best tools available to get insight in these complex agronomic systems.

1. Introduction

Crop models are essential tools to understand the complexity of cropping systems since they compile knowledge on physiological processes and plant interactions with the environment, which are deemed crucial. In research, models are used to address research problems and interpret experimental results (Rinaldi et al., 2007), to evaluate the impact of alternative management strategies on production (Ventrella et al., 2012) and on the environment (Asseng et al., 1998a), to investigate crop production levels (Van Ittersum et al., 2013) or to predict yields under changing climatic conditions (Asseng et al., 2013). Also in decision-making, crop models are increasingly used, for example, for policy shaping and analysis

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(e.g. CAP greening measures), farmer consultancy (e.g. Hunt et al., 2006) or risk management with early warning systems (e.g. Basso et al., 2013).

In crop insurance, risk is defined as the probability of registering a claim; in the case of drought insurance, a claim is registered when actual yield is lower than the insured yield. Consequently, risk depends on yield variability. The calculated risk is used to set and update premiums, or to design new insurance policies. The accuracy with which the insurer quantifies the actual risk is highly dependent on the availability on high quality actual yield data. However, records on observed yields are not always complete, and the information available for the insurer to calculate the probability and severity of a claim can be biased. This can give rise to unbalanced loss ratios, thereby affecting the actuarial robustness and sustainability of entire insurance systems. In these cases, crop models might be valuable tools to generate data on expected yields for risk assessment when no historical data is available.

However, the uncertainty associated with the use of crop models is large. Many crop and soil water models exist. They differ in aspects such as parameter requirements, time coefficient, simulation of the spatial scale or their either more process-based or more empirically based approach (e.g., Angulo et al., 2014; Kersebaum et al., 2007). Model complexity, the scale of application and the availability of data for model calibration and validation affect the reliability of simulations, especially when simulation purposes differ from those for which the selected model was designed (Kersebaum et al., 2007). In rainfed cropping systems in semi-arid areas, crops are highly dependent on soil moisture along the cropping cycle. The precision of soil water modules in simulating soil water dynamics and the capacity of the crop modules to translate the effects of water stress on crop canopy and biomass growth have an impact on the accuracy of simulated yields. Therefore, crop models should be used with caution, particularly when applied to more resource-limited conditions and when used in decision support systems where environmental, social and economic assets are involved.

Asseng et al. (2013) found a larger uncertainty related to crop models than related to climate models when simulating under future climate projections, and that variation of simulated yield was larger for low-yielding environments. Furthermore, Martre et al. (2014) studied two ensemble-based crop models and concluded that taking the mean or the median of the simulated values estimates better than any single crop model simulations.

Subsequently, a number of questions arise: (i) Which model(s) is/are preferred from the investigated models? (ii) Is the use of the average of several model's outputs better than the use of a single model output? (iii) Given the uncertainties associated to crop model simulations, is it possible to responsibly use crop models in crop insurance analysis and design? And what precautions should be taken when using crop model simulations for decision making regarding model(s) calibration and implementation?

The objectives of this paper were (i) to assess the usefulness of crop models to be used within a crop insurance analysis and design and (ii) to select the most suitable crop model for drought risk assessment in semi-arid regions in Spain. For that purpose first, a pre-selection of crop models simulating wheat yield under rainfed growing conditions at the field scale was made, and second, four selected models were compared in terms of modelling approaches, process description and model outputs. Each selected model calculates aboveground biomass accumulation and soil water balance using different approaches. Likewise, they use alternative assumptions to compute the effect of daily water stress on crop and biomass production. The four crop models were run for winter wheat (*Triticum aestivum* L.) over five growing seasons in NE Spain.

2. Materials and methods

2.1. Models

Four models were pre-selected from the 27 wheat simulation models included in the AgMIP wheat study (Asseng et al., 2013; Martre et al., 2014). The criteria to select them were having (i) a comparable structure in terms of submodules; (ii) different approaches to calculate the daily accumulation of biomass; (iii) different approaches to calculate the daily change in soil water content; and (iv) different approaches to calculate the penalties on crop growth due to water deficit. From all models meeting these criteria, the four more widely used in Spanish conditions were selected: Aquacrop (Raes et al., 2009; Steduto et al., 2012), CSM-CROPSIM-CERES-Wheat (hereafter referred to as CERES-Wheat), available in the package Decision Support System for Agrotechnology Transfer (DSSAT) version 4.5 (Hoogenboom et al., 2012; Jones et al., 2003), CropSyst (Stöckle et al., 2003) and WOFOST (Boogaard et al., 2011; Supit et al., 1994).

With respect to the approach used to calculate the daily accumulation of biomass, Aquacrop calculates biomass production based on water availability through a transpirational water use efficiency coefficient (WUE, g biomass mm^{-1}); CERES-Wheat calculates biomass production rate based directly on radiation through a radiation use efficiency coefficient (RUE, g biomass MJ^{-1}); CropSyst combines the last two approaches, RUE and WUE; and, lastly, WOFOST calculates biomass production rate based on the net carbon assimilation by subtracting maintenance and respiration requirements from gross assimilation of CO_2 (Table 1).

The approaches used to calculate the daily change in soil water content are also different. Aquacrop uses a cascade approach (when no groundwater table is considered as is the case for the semi-arid Spanish regions) that is computed on a 12 layers-subdivided soil; CERES-Wheat uses a cascade approach with potential capillary rise calculated based on soil water diffusivity with a user-defined soil subdivision in layers; in CropSyst, the finite difference approach based on Richard's equation computed on a 20 layers-subdivided soil was selected; and, finally, WOFOST uses a cascade approach (when no groundwater table is considered) that is computed for a homogeneous soil of a single layer. The four models all have submodels for phenology and canopy development, for growth and biomass partitioning, and for the soil water balance.

The differences between the models are found in the detail of the different submodels. Main characteristics of the models are summarized in Tables 1 and 2, and most important equations and approaches are described in detail below.

2.1.1. Aboveground biomass production

CERES-Wheat calculates biomass production rate based directly on radiation through a radiation use efficiency coefficient (RUE, g biomass MJ^{-1}). Aquacrop calculates biomass production based on water availability through a transpirational water use efficiency coefficient (WUE, g biomass mm^{-1}). CropSyst combines the last two approaches, RUE and WUE. Lastly, WOFOST calculates biomass production rate based on the net carbon assimilation by subtracting maintenance and respiration requirements from gross assimilation of CO_2.

Aquacrop computes the daily aboveground biomass (AgB) production $\left(\frac{dAgB}{dt}\text{kg ha}^{-1}\text{ day}^{-1}\right)$ from the potential daily biomass production $\left(\frac{dAgB}{dt}_{POT}\text{kg ha}^{-1}\text{ day}^{-1}\right)$, the so-called water productivity coefficient (*WP*) (given as an input parameter), and the ratio of actual to reference evapotranspiration:

$$\frac{dAgB}{dt} = WP \times \left(\frac{Ta}{ET_o}\right) \quad (1)$$