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Monte Carlo based parameterization and uncertainty analysis of a coupled crop growth and hydrological model

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Abstract computer simulations are widely used to support decision making and planning in the agriculture sector. The model structure and parameterization are important to achieve reliable results. On the one hand, many 1D crop growth models are using simplified hydrological processes and structures, e.g. by the use of a small number of soil layers or by the application of simple water flow approaches. On the other hand, in many hydrological models crop growth processes are poorly represented. Hence, fully coupled models with a high degree of process representation, would allow analysing the dynamic behaviour of the soil-plant interface in more detail.

We use the Python programming language to link two of such high process oriented independent models and to calibrate both models simultaneously. The Catchment Modelling Framework (CMF) simulates soil hydrology based on the Richards equation and the Van Genuchten-Mualem retention curve. CMF is coupled with the Plant growth Modelling Framework (PMF), which predicts crop growth on the basis of radiation use efficiency, degree days, water shortage and dynamic root biomass allocation.

A Monte Carlo based generalised likelihood uncertainty estimation (GLUE) method is applied to parameterize the coupled model and to investigate the related uncertainty of model predictions. Overall, 20 model parameters (4 for CMF and 16 for PMF) are analysed through 2,000,000 model runs randomly drawn from an equally distributed parameter space. Three objective functions are used to evaluate the model performance, i.e. coefficient of determination ($R^2$), bias and model efficiency according to Nash Sutcliffe (NSE).

The model is applied to three sites with different management in Muencheberg (Germany) for the simulation of winter wheat (Triticum aestivum L.). Field observations for model evaluation include soil water content ant the dry matters of root, storage, stem and leaves.
Best parameter sets resulted in NSE of 0.6 for the simulation of soil moisture across all three plots. The shape parameter of the retention curve n was highly constrained whilst other parameters of the retention curve showed a large equifinality. We plotted 5% and 95% likelihood-weighted prediction limits over all behavioural models. Our uncertainty boundaries for the prediction of water content were lower during moderate soil moisture and higher during wet and dry conditions. The root and storage dry matter observations were predicted with NSEs of 0.94, a low bias of -58 kg ha\(^{-1}\) and an excellent R\(^2\) of 0.98. Dry matters of stem and leaves are predicted with less, but still high accuracy (NSE of 0.79, bias of 178 kg ha\(^{-1}\), R\(^2\) of 0.87). We attribute this slightly poorer model performance due to missing leaf senescence which is currently not implemented in PMF. The most constrained parameters for the plant growth model were the radiation-use-efficiency and the base temperature. The prediction uncertainty of the dry matters of root is constant around 500 kg ha\(^{-1}\), while the uncertainty of the dry matters of storage, stem and leaves varies from 1000 kg ha\(^{-1}\) to 3000 kg ha\(^{-1}\).