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Monte Carlo Based Calibration and Uncertainty Analysis of a Coupled Plant Growth and Hydrological Model

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Computer simulations are widely used to support decision making and planning in the agriculture sector. On the one hand, many plant growth models use 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 plant growth processes are poorly represented. Hence, fully coupled models with a high degree of process representation would allow a more detailed analysis of the dynamic behaviour of the soil-plant interface.

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

The Monte Carlo based Generalised Likelihood Uncertainty Estimation (GLUE) method was applied to parameterize the coupled model and to investigate the related uncertainty of model predictions to it. Overall, 19 model parameters (4 for CMF and 15 for PMF) were analysed through 2 x 10^6 model runs randomly drawn from an equally distributed parameter space. Three objective functions were used to evaluate the model performance, i.e. coefficient of determination (R^2), bias and model efficiency according to Nash Sutcliffe (NSE).

The model was applied to three sites with different management in Muencheberg (Germany) for the simulation of winter wheat (*Triticum aestivum L.*) in a cross-validation experiment. Field observations for model evaluation included soil water content and the dry matters of roots, storages, stems and leaves. Best parameter sets resulted in NSE of 0.57 for the simulation of soil moisture across all three sites. The shape parameter of the retention curve n was highly constrained whilst other parameters of the retention curve showed a large equifinality. The root and storage dry matter observations were predicted with a NSE of 0.94, a low bias of 58.2 kg ha^{-1} and a high R^2 of 0.98. Dry matters of stem and leaves were predicted with less, but still high accuracy (NSE=0.79, bias=221.7 kg ha^{-1}, R^2=0.87). We attribute this slightly poorer model performance 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. Cross validation helped to identify deficits in the model structure, pointing out the need of including agricultural management options in the coupled model.