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A Bayesian hierarchical approach to improve model parameter estimates and predictions of silage maize phenology in Germany

Michelle Viswanathan[1], Tobias KD Weber[1], Andreas Scheidegger[2], and Thilo Streck[1]
[1]University of Hohenheim, Institute for Soil Science and Land Evaluation, Biogeophysics (310D), Stuttgart, Germany
[2]Eawag: Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland

Crop models are used to evaluate the impact of climate change on food security by simulating plant phenology, yield, biomass and leaf area index. Plant phenology defines the timing of crucial growth stages and physiological processes that influence organ appearance and assimilate partitioning. It is governed by environmental factors such as solar radiation, temperature and water availability. Plant phenology is not only specific for the crop species, but also depends on the cultivar. Additionally, growth of a cultivar could vary depending on the environment. Common crop models cannot fully capture the influence of the environment on phenology, resulting in cultivar-specific parameters that are environment-dependent. These parameter estimates may be unreliable in case of limited data. Moreover, crucial species-specific information is ignored. On the other hand, in large regional-scale models covering multiple cultivars and environments, information about the cultivars grown is generally not available. In this case, a shared set of parameters for the crop species would suppress within-species differences leading to unreliable predictions.

A Bayesian hierarchical framework enables us to alleviate these problems by honouring the multi-level data structure. Additionally, we can reflect the uncertainty from different sources, for example, model inputs and measurements. In this study we implement a Bayesian hierarchical framework to estimate parameters of the Soil-Plant-Atmosphere System Simulation (SPASS) model for simulating phenological development of different cultivars of silage maize grown over all the contrasting climatological regions of Germany.

We used data from the German weather service on the phenological development stages of silage maize grown across Germany between 2009 and 2019. During this period, silage maize was grown in over 3000 unique location-year combinations. Maize crops were differentiated into early, mid-early, mid-late and late ripening groups and were further classified into cultivars within each ripening group. Within the hierarchical framework, we estimate maize species-specific parameters as well as parameters per ripening group and cultivar, through Bayesian model calibration. We analyse the influence of environmental conditions on parameter estimates, to further develop the hierarchical structure. We perform cross-validation to assess the prediction quality of the parameterized model.

With this approach, we show that robust parameter estimates account for differences between cultivars, ripening groups as well as different environmental conditions. The parameterized model can be used for large-scale phenology predictions of silage maize grown across Germany. These parameter estimates may perform better than independent species- or cultivar-specific estimates, in predicting phenology of future cultivars where specific cultivar characteristics are not known.