Improving crop modeling approaches for supporting farmers to cope with weather risks

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Abstract

Due to changing climate and weather patterns in combination with limitations to extend global arable land area, the pressure on food production systems will increase. Additionally, these future food production systems must feed a rapidly growing world population, whose demand for food rises and becomes increasingly land-intensive. To cope with these challenges, it will be indispensable to increase and stabilize crop yields. This requires, however, a deeper understanding of the factors influencing crop yield variability and a quantification of their relevance under different soil and climate conditions. Besides crop field trials, crop modeling assessments are suitable methods to analyze such yield influencing factors. Therefore, however, these assessments need to be improved in order to appropriately cover the relevant factors influencing yield variability. This dissertation contributes to that research need as we further develop and apply crop models to assess regional wheat and maize yield variability in Germany, Tanzania and on a global scale. For this, we analyze both statistical and process-based crop models in an intra- and inter-comparison and combine the advantages of both model types in a new modeling approach. We use both crop model types to decompose weather and non-weather-related crop yield variability and quantify the weather-related production risks for temperate and tropical production conditions. For achieving this, we apply five steps: (i) First, we develop a statistical crop modeling approach to decompose the influence of weather and agronomic management on winter wheat yields in Germany. (ii) Based on the first step, we expand the statistical methods and apply augmented models for winter wheat and silage maize on a disaggregated level. (iii) Then this model approach is used to investigate an out-of-sample cross validation to demonstrate the models' capability to project future yield changes under climate change. (iv) In a global statistical application, this models' capability of projecting yields is tested for short-term yield forecasts. (v) Finally, we combine statistical and process-based crop modeling to decompose weather-related maize yield losses from losses caused by non-weather factors for the case of Tanzania. Across these five steps, we find that the share of weather-related yield variability is higher in Germany than in Tanzania. Accordingly, crop yield variability in Tanzania is to a higher share attributable to agronomic management and socio-economic influences. For both countries, we find that the share of explained weather-related yield variability is higher on an aggregated level than on the regional level (i.e. districts, counties, or grid cells). This can be explained by heterogeneous management conditions across regions, which are averaged out by the spatial aggregation to national or sub-national levels. Moreover, we demonstrate that our statistical models reproduce the observed yield variability well with a goodness of fit (R^2) mostly higher than 0.80 for Germany, Tanzania and globally. Furthermore, we are able to show that the statistical component of our approach can be used for short-term yield forecasts and to some extent also for climate change projections. Furthermore, the combined statistical-process-based approach can be used for assessing weather-related crop yield losses for insurance purposes. The application of crop models in yield forecast systems and insurance solutions could contribute to develop measures, which support improving food security on a global scale and notably in Sub-Saharan Africa.