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A NOVEL ROBUST META-MODEL FRAMEWORK FOR PREDICTING CROP YIELD PROBABILITY DISTRIBUTIONS USING MULTISOURCE DATA[1]

Abstract. There is an urgent need to better understand and predict crop yield responses to weather disturbances, in particular, of extreme nature, such as heavy precipitation events, droughts, and heat waves, to improve future crop production projections under weather variability, extreme events, and climate change. In this paper, we develop quantile regression models for estimating crop yield probability distributions depending on monthly temperature and precipitation values and soil quality characteristics, which can be made available for different climate change projections. Crop yields, historical and those simulated by the EPIC model, are analyzed and distinguished according to their levels, i.e., mean and critical quantiles. Then, the

[1]The development of the robust quantile-based meta-model for predicting probability distributions of crop yields depending on climate scenarios, temperature and precipitation patters, and soil characteristics is supported by the joint project between the International Institute for Applied Systems Analysis (IIASA) and National Academy of Sciences of Ukraine (NASU) on “Integrated robust modeling and management of food-energy-water-land use nexus for sustainable development”. The paper contributes to EU PARATUS (CL3-2021-DRS-01-03, SEP-210784020) project on “Promoting disaster preparedness and resilience by co-developing stakeholder support tools for managing systemic risk of compounding disasters”.

crop yield quantiles are approximated by fitting separate quantile-based regression models. The developed statistical crop yield meta-model enables the analysis of crop yields and respective probabilities of their occurrence as a function of the exogenous parameters such as temperature and precipitation and endogenous, in general, decision-dependent parameters (such as soil characteristics), which can be altered by land use practices. Statistical and machine learning models can be used as reduced form scenario generators (meta-models) of stochastic events (scenarios), as a submodel of more complex models, e.g., Integrated Assessment model (IAM) GLOBIOM.

Keywords: extreme events, climate change, food security, crop yields projections, probability distributions, quantile regressions, robust estimation and machine learning, two-stage STO.

INTRODUCTION

Extreme weather conditions, such as high temperature, heat waves, declining rainfall, prolonged heavy precipitation, can lead to gradual crop yield declines or even abrupt crop production shocks and, therefore, to profit losses, threats to food security and market volatility. Due to climate change, frequency and severity of extreme events is projected to increase [1–6].

There is a need to better understand crop yield responses to weather disturbances, especially, of extreme nature, and relevant land use and soil management practices, i.e., conservation tillage to improve crop yields towards desirable production levels. Crop yield prediction is very challenging in the face of extreme high-impact events. Such events can happen rarely but cause major production losses and require high ex-post adaptation costs and expensive actions. Therefore, gaining earlier information about the likelihood of critical yields and the accounting for the extreme rare-high impact events is essential for farmers, crop insurers, agricultural market managers, for taking informative and timely strategic and operational (long- and short-term) ex-ante and ex-post mitigation and adaptation economic and management decisions.

The two main approaches widely used to assess the impacts of weather, climate change, and soil parameters on crop yields are:

a) process-based simulation models, e.g., EPIC [5–8], which attempt to represent key dynamic processes affecting crop yields, and

b) statistical models, which estimate functional relationships between historical observations of weather, soil characteristics and yields [9–12].

In this paper we develop a hybrid meta-model for generating stochastic crop-yield scenarios based on historical data and on input-outputs of a dynamic process-based crop yield simulation model EPIC [5, 6]. The linkage of the statistical and the process-based approaches into a meta-model for crop yields simulation combines the strengths and avoids the limitations of statistical and bio-physical models if they are used separately.

The crop yields can be distinguished according to their levels, i.e., critical quantiles (5th, 25th, 50s, 75th, and 95th) as well as mean values. Often, the critical quantiles (percentiles) can be identified by the so-called break-even analysis of the crop producer. In this case, the "break-even" yield balances out crop production costs and profits from crops sails at given crop price, which is important for establishing adequate premium and coverage policies of agricultural insurance [13–16].

The meta-model developed in this paper aims at analyzing and predicting probabilities of critical crop yield levels (scenarios) based on monthly temperature and precipitation values, different climate change scenarios (i.e., RCPs), and on soil quality characteristics, which can be altered by soil and water management practices and by weather conditions. In particular, we introduce a quantile-based regression model for the prediction of crop yield percentiles using historical data and inputs/outputs of the EPIC model. The developed crop-yield meta model can be used to generate stochastic crop yield scenarios to be included into more complex Integrated Assessment Models (IAMs), e.g., (stochastic) GLOBIOM model [17–20].