Predicting Spatiotemporal Soil Organic Carbon Responses to Management Using EPIC-IIASA Meta-Models

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The management of Soil Organic Carbon (SOC) is a critical component of both nature-based solutions for climate change mitigation and global food security. Agriculture has contributed substantially to a reduction in global SOC through cultivation, thus there has been renewed focus on management practices which minimize SOC losses and increase SOC gain as pathways towards maintaining healthy soils and reducing net greenhouse gas emissions. Mechanistic models are frequently used to aid in identifying these pathways due to their scalability and cost-effectiveness. Yet, they are often computationally costly and rely on input data that are often only available at coarse spatial resolutions. Herein, we build statistical meta-models of a multifactorial crop model in order to both (a) obtain a simplified model response and (b) explore the biophysical determinants of SOC responses to management and the geospatial heterogeneity of SOC dynamics across Europe. Using 35 years of multifactorial, spatially-explicit simulation data from the gridded Environmental Policy Integrated Climate-based Gridded Agricultural Model (EPIC-IIASA GAM), we build multiple polynomial regression ensemble meta-models for unique combinations of climate and soils across Europe in order to predict SOC responses to varying management intensities. We find that our biophysically-determined meta-models are highly accurate ($R^2 = .97$) representations of the full mechanistic model and can be used in lieu of the full EPIC-IIASA GAM model for the estimation of SOC responses to cropland management. Model stratification by means of climate and soil clustering improved the meta-model’s performance compared to the full EU-scale model. In regional and local validations of the meta-model predictions, we find that the meta-model accurately predicts broad SOC dynamics while it often underestimates the measured SOC responses to management. Furthermore, we find notable differences between the results from the biophysically-specific models throughout Europe, which point to spatially-distinct SOC responses to management choices such as nitrogen fertilizer application rates and residue retention that illustrate the potential for these models to be used for future management applications. While more accurate input data, calibration, and validation will be needed to accurately predict SOC change, we demonstrate the use of our meta-models for biophysical cluster and field study scale analyses of broad SOC dynamics with basically zero fine-tuning of the models needed. This work provides a framework for simplifying large-scale agricultural models and identifies the opportunities for using these meta-models for assessing SOC responses to management at a variety of scales.