

Observation-Constrained Agroecosystem Model Inversion Reveals Continental-Scale Variation of Winter Wheat Traits

Background/Objective

Understanding how crop trait variability shapes genotype \times environment \times management (G \times E \times M) interactions remains a key uncertainty in predicting agricultural performance. Continental-scale crop models often rely on spatially uniform parameters, limiting their ability to represent adaptive variation in phenology, allocation, and yield. To address this limitation, researchers developed an observation-constrained model inversion framework to infer spatially explicit physiological controls for U.S. winter wheat.

Approach

The mechanistic agroecosystem model *Ecosys* was integrated with a deep learning-enabled model-data fusion inversion to infer spatially explicit physiological controls, or trait proxies, for U.S. winter wheat directly from observations. Simulations were constrained by satellite-derived photosynthesis and county yield records from 2008-2022 across \sim 1,000 winter wheat-producing counties.

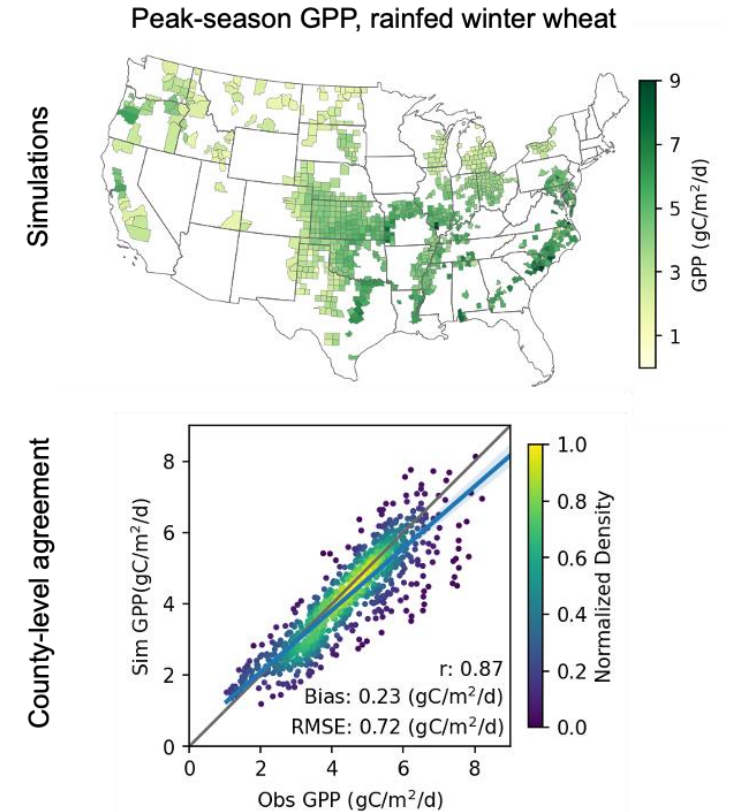
Results

The inversion recovered coherent spatial patterns of maturity group, reproductive capacity, harvest index, and root-shoot allocation. The optimized simulations reproduced observed carbon uptake and yield variability, with gross primary productivity (GPP) $r=0.76-0.88$; phenology bias < 2 weeks; and $> 90\%$ of yields within $\pm 20\%$ of reports. The results revealed distinct physiological profiles aligned with the geographic distributions of major winter wheat market classes. The inferred controls suggest that warmer winters reduce vernalization success in late-maturing cultivars while elevated vapor pressure deficit causes large yield losses in rainfed Hard Red Winter wheat.

Significance/Impacts

This work transforms a process-based crop model into an efficient inference framework, enabling scalable, trait-informed diagnosis of adaptive diversity across ecosystems and offering a transferable pathway to support management and regional breeding prioritization under uncertainty.

Zhang et al. 2026. "Observation-Constrained Agroecosystem Model Inversion Reveals Continental-Scale Variation of Winter Wheat Traits." *Global Change Biology*. DOI: 10.1111/gcb.70936.



County-level peak-season GPP during March-mid June, showing simulated spatial patterns and agreement with satellite-derived reference.