

A Hybrid Biophysical-Machine Learning Framework for Diurnal Surface Energy Flux Estimation Using Proximal Sensing

Background/Objective

Evapotranspiration (ET) is a fundamental component of the water balance of agricultural systems. Direct observation of ET may be cost prohibitive, but models such as the Surface Temperature Initiated Closure (STIC1.2) model may serve as a viable low-cost option. However, STIC1.2 is constrained by limitations in the temporal frequency of satellite observations and the availability of in situ measurements. This work seeks to remove these limitations by utilizing high frequency in situ proximal thermal sensing observations alongside machine learning (ML) techniques for flux estimation with STIC1.2.

Approach

Data were collected at the Sustainable Advanced Bioeconomy Research site in Iowa in 2021 and 2022 for both annual and perennial crops and both C3 and C4 photosynthesis pathways. Proximal remote sensors, eddy covariance, weather, and energy balance sensors enabled half-hourly STIC evaluations. Three hybrid STIC variants replacing costly in situ energy balance measurements with ML or biophysical estimates were tested. Shapley Additive Explanations were applied to latent energy flux (LE) residuals to diagnose model error sources.

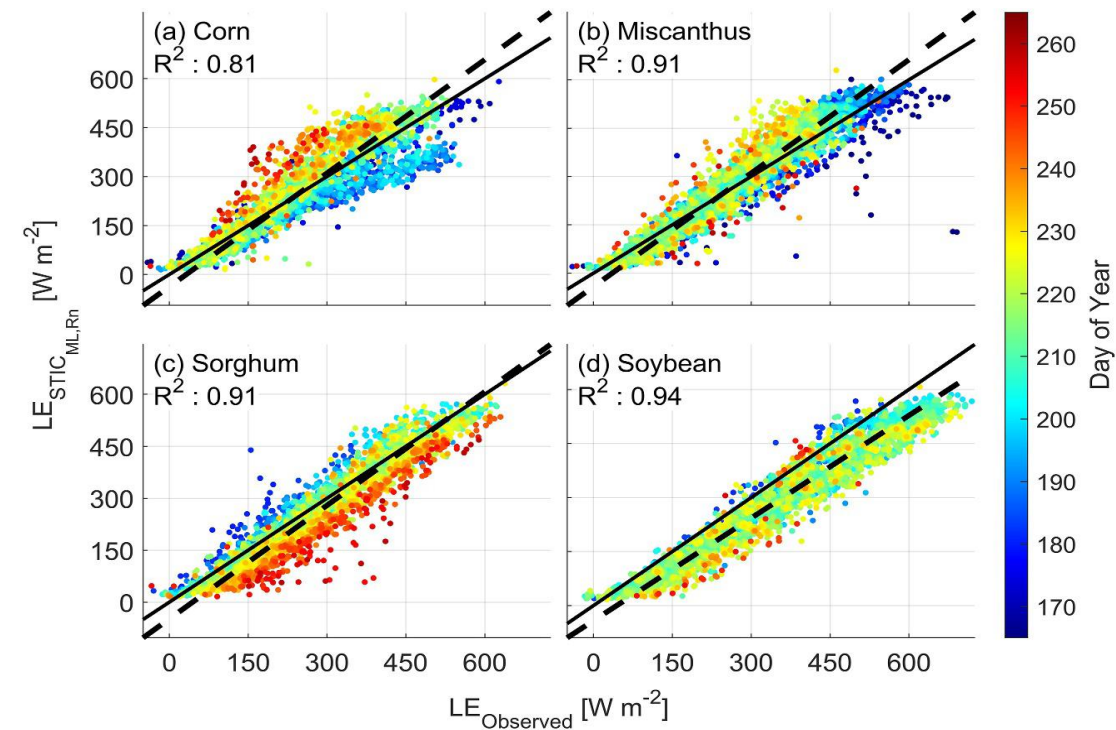
Results

STIC(ML,Rn) achieved $R^2 = 0.81\text{--}0.94$ across all 4 crops, comparable to the reference model ($R^2 = 0.89$), with no energy balance sensors required. Explainable ML revealed that radiation inputs drive $>50\%$ of remaining LE errors, with canopy phenology and wind speed contributing $\sim 24\%$, providing a roadmap for the next generation of model development.

Significance/Impacts

This work provides a pathway for future model development and underscores the utility of ML explainability methods for residual analysis when applied within a domain-informed interpretive framework.

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STIC(ML,Rn) predicted vs. LE for (a) corn, (b) miscanthus, (c) sorghum, and (d) soybean. Points are colored by day of year, errors are largest early and late in the season when canopy conditions are changing rapidly. Dashed line = 1:1, solid line = regression fit.