2025 13th International Conference on Agro-Geoinformatics (Agro-Geoinformatics), Boulder, CO, USA, 7-10 July 2025

Coupling radiative transfer models and machine learning for crop trait retrieval in dryland ecosystems

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Radiative Transfer Models (RTMs) such as PROSAIL, which integrates leaf-level (PROSPECT) and canopy-level (SAIL) reflectance simulations, are increasingly employed to support biophysical trait retrieval in crop monitoring applications. In this study, we assess and compare the performance of three PROSAIL configurations—PROSPECT-5 + SAIL, PROSPECT-D + SAIL, and PROSPECT-PRO + SAIL—for estimating Leaf Area Index (LAI) and Canopy Chlorophyll Content (CCC) in dryland maize systems using synthetic Sentinel-2 reflectance data. Results from synthetic test datasets indicate that the PROSPECT-PRO + SAIL configuration achieved superior performance, with LAI retrieved at an R^2 of 0.88 and RMSE of 0.35 m^2/m^2, and CCC estimated at an R^2 of 0.83 and RMSE of 4.1 $\mu g/cm^2$. These outcomes highlight the advantage of using the enhanced biochemical and structural parameterizations in PROSPECT-PRO, especially under semi-arid cropping conditions. Comparative analysis confirms that this configuration consistently yielded the lowest normalized RMSE (nRMSE) for both LAI (9.5%) and CCC (10.7%) across the variants tested. The findings substantiate the added value of improved leaf optical modeling for accurate trait estimation and suggest that PROSPECT-PRO + SAIL provides a robust forward modeling basis for data-driven crop monitoring frameworks.