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A Convergent Spectroscopy-based Approach for Vcmax across Leaf Age and Growth Environments

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Understanding the temporal patterns of leaf photosynthetic capacity (the maximum rate of RuBP carboxylation, Vcmax) is critical for determining photosynthetic seasonality and the controls over terrestrial carbon, water, and energy fluxes. However, an efficient method for predicting of Vcmax using the spectroscopy approach across space and time is still lacking. Here, we leverage previous studies which have successfully linked leaf spectroscopy to leaf Vcmax and leaf age respectively, with a specific goal to explore the potential use of leaf spectroscopy as a general means to rapidly estimate and monitor temporal changes in Vcmax. Here we address three questions: (1) whether there exists a convergent relationship between leaf Vcmax and spectroscopy across tropical forest sites, species, leaf age, and growth environments, (2) how well can the spectroscopy approach predict temporal variation in leaf Vcmax compared with the field observed Vcmax-age relationship, and (3) how do spectroscopy-derived Vcmax-age relationships vary across species and growth environments? To address these questions, we used field data collected in two tropical evergreen forests in Panama (n=15 species) and one in Brazil (n=5 species). These data include detailed field measurements of leaf age, full range reflectance spectroscopy (i.e. 350-2500 nm), Vcmax (derived from leaf gas exchange measurements), and growth environments (i.e. sun vs. shade). Our results suggest that leaf reflectance spectroscopy can accurately predict leaf Vcmax at the fully expanded age status across tropical forest sites ($R2=0.7$, $p<0.001$). However, this single-age spectra-Vcmax relationship requires recalibration when it is applied to broader demographic classes (i.e. young, expanding leaf age class). Combining spectroscopy-based leaf Vcmax with spectroscopy-based leaf age, we further constructed the Vcmax-age relationship, which agreed well with field observations, suggesting that the spectroscopy technique is able to capture the temporal trajectories of Vcmax across the entire life cycle of leaves. This will aid development of remote sensing methods to characterize temporal variation of leaf photosynthetic metabolism across spatial and temporal scales, and enable remotely based parameterization and evaluation of Earth system models.