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FOLIAR BIO-PHYSICAL AND SPECTRAL PROPERTIES ASSOCIATED WITH LIGHT ENVIRONMENT IN A MATURE POPLAR STAND

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ABSTRACT

This study evaluates the ability of reflectance (R) and chlorophyll fluorescence (ChlF) parameters to express the differences in foliar properties associated with varying light environment. In the summer of 2007 a tall crane was used to acquire foliar reflectance measurements and collect samples from sunlit and shaded tree crowns, from the upper and lower canopy of a mature tulip poplar (*Liriodendron Tulipifera* L.) forest. Leaf-level photosynthesis, R, ChlF spectra and kinetics and bio-physical parameters were measured on excised samples.

The differences in the light environment greatly affected the spectral and biophysical data, especially the photosynthetic parameters (Amax, LUE, photochemical quenching, Qp, Qn, Qp/Qn). For sunlit foliage, ChlF kinetics (Fo, Fm, Fs, and Fv/Fm) were significantly lower than shaded foliage. Our analysis indicated that some of the tested spectral bio-indicators (e.g. PRI1, RE2, G035, Dmax) were strongly associated with LUE and differed significantly depending on the light environment. ChlF as compared to R indices followed more closely the trends in LUE, which emphasizes the application of ChlF for the timely detection of changes in vegetation physiology and carbon dynamics.

Index Terms — vegetation reflectance (R), chlorophyll fluorescence (ChlF), light use efficiency (LUE), spectral bio-indicators, Photochemical Reflectance Index (PRI), Photosynthetic capacity (Amax, $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$),

1. INTRODUCTION

In the context of climate change, it has become critical to understand the dynamics of ecosystem carbon uptake through diurnal and seasonal changes and in response to varying environmental conditions [1, 2]. A remote sensing approach to capture the temporal dynamics of useful parameters related to ecosystem carbon balance is essential to enable synoptic information at a variety of temporal and

spatial scales. Remote sensing offers also the opportunity for long term monitoring at various space and time scales. Some of the spectral approaches and developed indicators, especially those using high spectral resolution data, have proved useful for the detection of changes in chlorophyll, nitrogen and foliar structural constituents, however an universal spectral approach have been difficult to identify [4, 5, 6, 7, 8, 9, 10, 11]. Forest canopy structure varies relatively slowly, while individual trees constantly respond to changes in their micro environment. Both phenological and physiological changes in the foliage may result in spectral changes. A measure of ecosystem carbon uptake is the photosynthetic light use efficiency (LUE, CO_2 uptake per unit PAR absorbed), originally developed in agronomy to describe the seasonal production of biomass by crops [3]. A reflectance indicator, commonly associated with LUE, The Photochemical Reflectance Index (PRI), utilizes the physiological change captured at 531 nm in conjunction with a reference band at 570 (550 or 680) nm, in the form of a normalized difference index [12, 13, 14, 15]. Vegetation ChlF parameters have also been used to determine plant photosynthetic function and efficiency, in response to a suite of varying environmental conditions [15, 16, 17, 18].

This study tests the ability of spectral reflectance and ChlF indicators, suggested by previous studies, to detect the physiological differences between sunlit and shaded forest canopies, especially the differences in foliar LUE. While the difference in the morphology of sunlit vs. shaded foliage is clearly established, research is needed to determine if the foliar spectral R and ChlF characteristics also differ.

2. METHODS

In the summer of 2007, a tall crane equipped with man-basket was used to acquire canopy *in situ* spectral measurements and to collect samples from sun and shade leaves, from the upper (30 m) and lower (20 m) strata of a 60 year old tulip poplar (*Liriodendron tulipifera* L.) canopy, at the Smithsonian Environmental Research Center (SERC)

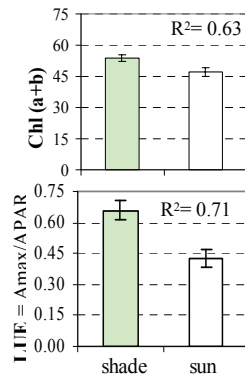


Figure 1. Differences in foliar chlorophyll content and LUE, associated with light environment.

in Edgewater, MD, USA. *In situ* spectral measurements and foliar samples were collected first from the sunlit upper and lower portions of a tree crown, and then from the shaded upper and lower portions. This sequence of measurements was repeated twice during the day, resulting in morning (am) and afternoon (pm) set of measurements from two tree crowns. Foliar samples were excised from the tree canopy following the *in situ* spectral measurements, whole leaves (stem attached) were placed in water vials and transported to and adjacent laboratory for the following biophysical measurements: photosynthesis, optical properties (reflectance, transmittance, and absorbance spectra), ChlF kinetics, pigment contents, leaf area, fresh weight (FW), and dry weight (DW). Measurements of photosynthetic function and ChlF kinetic parameters (F_s , F_m , F_v/F_m) were collected using Li-Cor 6400 Photosynthetic System fitted with a leaf fluorometer chamber (Li-Cor, Lincoln, NE). Photosynthetic capacity (A_{max} , $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) was determined under a saturating 1000 ppm CO_2 concentration. Shaded leaves were measured at a PAR level ranging from 700-1400 $\mu\text{mol photons m}^{-2} \text{ s}^{-1}$ while for sunlit foliage PAR levels ranged from 1200-1600 $\mu\text{mol photons m}^{-2} \text{ s}^{-1}$ as determined by *in situ* PAR observations. Foliar optical properties were measured using a spectro-radiometer ASD FieldSpec®Pro (Analytical Spectral Devices, Inc., Boulder, CO) *in situ* from leaves in the canopy and on the excised samples, using an integrating

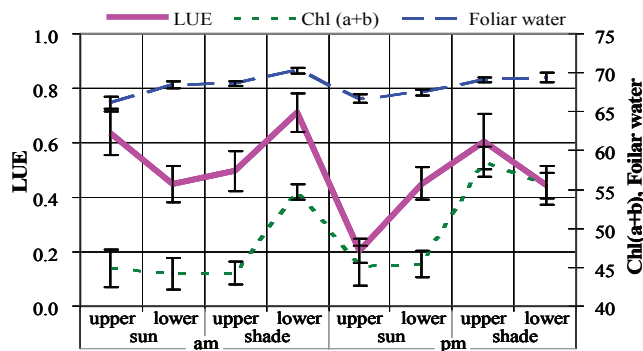


Figure 2. Variation in Light use efficiency (LUE), leaf total chlorophyll and water contents associated with the differences in the light environment, canopy strata and time of data acquisition during the day.

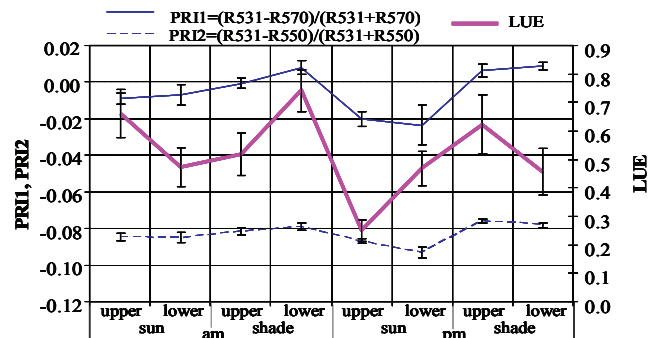


Figure 3. The trends in PRI1 and PRI2 differed in association with light environment, and in general followed the trends established for LUE.

sphere Li-Cor 1800, Li-Cor, Inc. The spectra were corrected for the temporal variation in the light illumination. Light use efficiency (LUE) was calculated as $LUE = A_{max}/APAR$, where A_{max} and $APAR$ are the maximum photosynthetic rate and absorbed photosynthetically active radiation, measured on the foliar samples.

Statistical analyses (ANOVA and Correlation analysis) were conducted using SYSTAT 11. High spectral resolution (3 nm) foliar R, ChlF spectra and F kinetics, obtained over the range of light conditions, were evaluated statistically for correlations to foliar morphology, pigment content, photosynthetic function, LUE and to determine the spectral regions and indices with higher sensitivity to the differences in light environment. Correlations between spectral and biophysical data were sought.

3. RESULTS

3.1 Biophysical properties

The differences in the light environment (sun vs. shade) greatly affected the spectral and biophysical data, especially the photosynthetic parameters (e.g. A_{max} , stomatal conductance, Q_p , Q_n , Q_p/Q_n , photochemical quenching.).

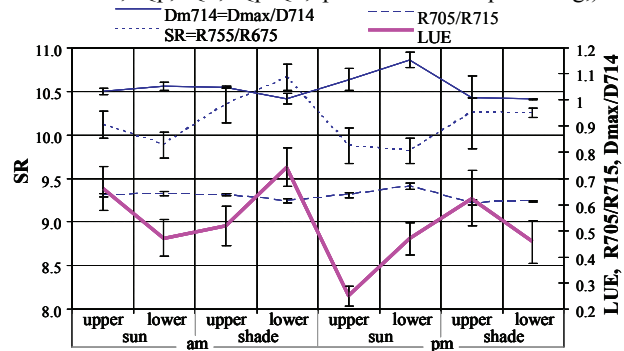


Figure 4. Reflectance indices, separating best samples from different light environments. This indices were more successful in following the trends in LUE, than the traditionally associated with LUE PRI1, PRI2 and PRI3.

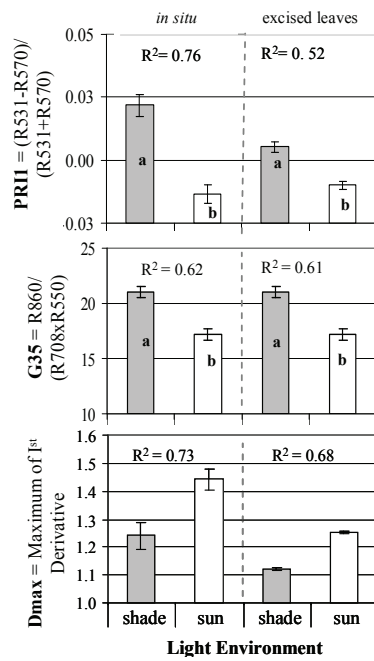


Figure 5. Reflectance indices discriminating optimally the different light environments.

Fm, Fs, and Fv/Fm) were significantly higher for the shaded leaves.

Foliage location within the canopy (upper vs. lower strata) and time of data acquisition (am vs. pm) were of secondary importance (Fig. 2).

3.2 Optical properties

Photosynthetic capacity (A_{max} , $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) was positively related to R intensity in the 450-800 nm region,

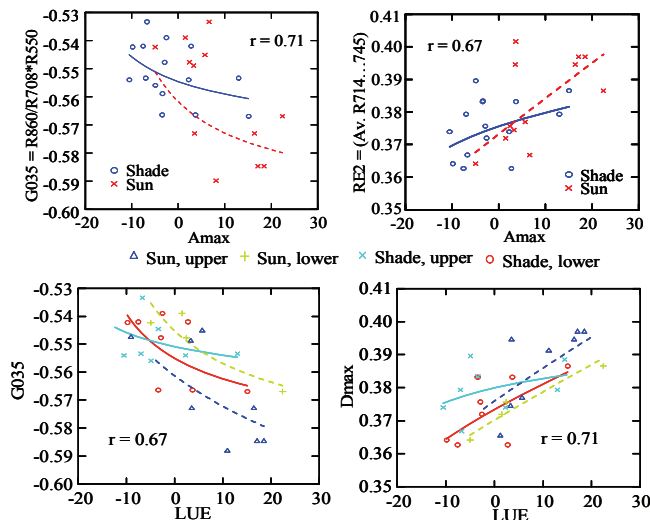


Figure 6. Strong relationships were established between some of the reflectance indices associated with multiple bio-physical factors (e. g. G35, RE2, Dmax) and LUE.

Leaf area, pigment and water content and light use efficiency (LUE) were significantly reduced for sunlit as compared to shaded foliage (Figure 1 and 2). Higher foliar pigment and water content were associated with higher LUE. In general, chlorophyll and water content were higher for shaded vs. sunlit foliage, but the differences were much less pronounced as compared to the difference in LUE data associated with light environment. ChlF kinetic parameters (e.g. Fo,

with stronger correlations at 530 nm ($r=0.62$), 690 nm ($r=0.75$) and 730 nm ($r=0.77$). Stomatal conductance ($\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) was also positively correlated to R, at lower levels (maximal correlation at 740 nm, $r^2=0.57$). Pigment content and leaf structural parameters (FW/DW and foliage location in the canopy) were negatively related to R (450-800 nm).

Some of the spectral indices strongly associated with the biophysical parameters (fig. 5.), significantly differed depending on light condition. Stronger relationship to LUE, and separation of light environments were established for the reflectance *in situ* measurements, as compared to the measurements on excised samples. The reflectance indices commonly associated with LUE include PRI1, PRI2 and PRI3 [2]. They utilize the narrow spectral bands (531 nm, normalized to 550, 570 or 680 nm) effected by the xanthophyll cycle, a regulatory mechanism controlling the dissipation of excess absorbed by the vegetation light energy [2]. In the current study only PRI1 and PRI2 followed the trends established for LUE (Fig.3), with PRI1 having a higher correlation to LUE ($r = 0.62$).

In this study, the reflectance indices Dmax, G35, SR, Dmax/D714 and R705/R715 [4, 6, 7, 12, 18], performed well for separation of light environment (Fig. 5), followed the trends in LUE and showed stronger correlation to LUE than PRI1 (Fig. 4). These indices, affected by the changes in a larger number of bio-physical variables than PRI, are not associated commonly with LUE. The strong relationship among physiological variables such as foliar pigment and water content, photosynthetic rate and PAR, which in many cases change in unison and effect simultaneously LUE, may provide an explanation. The derivative Dmax from spectra measured *in situ* and from excised samples performed comparably.

Analyses of the absorbance and transmittance data, as well as an assessment of the *in situ* collected fluorescence data are currently on the way.

3.3 Fluorescence properties

Steady state ChlF (Fs) and the induction kinetic parameters

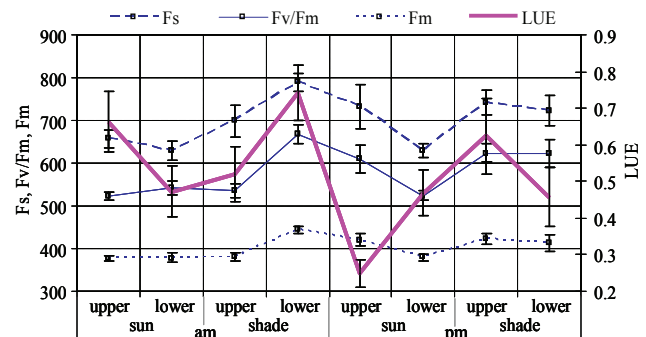


Figure 7. Steady state ChlF (Fs) and the ChlF kinetic parameters Fm and Fv/Fm followed the trends in LUE more closely, as compared to the calculated reflectance indices (Fig. 3 and Fig. 4).

Fm and Fv/Fm significantly differed in association with both, light environment and canopy strata (Fig. 7). They closely followed the trends in LUE and their correlation to LUE was stronger ($r=0.83$) than R parameters (Fig. 6), demonstrating the capability of ChlF for detecting minor changes in vegetation physiological condition and assessing differences in LUE.

4. CONCLUSION

For sunlit as compared to shaded foliage leaf area was significantly lower and photosynthetic rates higher, while the pigment contents did not significantly differ. ChlF kinetic parameters (e.g. Fo, Fm, Fs, and Fv/Fm) were significantly higher for the shade leaves. The differences in the light environment (sun vs. shade) greatly affected the spectral and biophysical data, especially the photosynthetic parameters (e.g. Amax, LUE, photochemical quenching, Qp, Qn, Qp/Qn). The upper vs. lower strata location of the foliage within the canopy was of secondary importance. A preliminary analysis indicates that some of the published spectral indices, such as PRI1, RE2, G035, Ro, Dmax, CII, were strongly associated with photosynthetic parameters and differed significantly depending on the light environment. ChlF parameters followed more closely the trends in LUE, than the calculated R indices, which emphasizes the need for establishing ChlF monitoring capabilities, to better understand the dynamics in C cycling and vegetation physiology.

An additional season of data collections and further analysis of the spectral data and the collected fluorescence and bio-physical variables are planned to validate the established spectral bio-indicators of LUE.

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