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TRACKING PHOTOSYNTHETIC EFFICIENCY WITH NARROW-BAND SPECTRORADIOMETRY*

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1. BACKGROUND

Narrow-waveband spectroradiometry presents the possibility of detecting subtle signals closely related to the current physiological state of vegetation. In this paper we discuss one such signal related to the epoxidation state of the xanthophyll cycle pigments, violaxanthin, antheraxanthin and zeaxanthin. Recent advances in plant ecophysiology have demonstrated a close relationship between these pigments and the regulatory state of photosystem II in photosynthesis (Demmig-Adams 1990). Our recent field studies of sunflower (*Helianthus annuus*) and oak (*Quercus agrifolia*) have demonstrated that a "xanthophyll signal" can be isolated from the diurnal reflectance spectra of intact canopies. Furthermore, the xanthophyll signal can be used to derive a "physiological reflectance index" (PRI) that closely correlates with the actual photosynthetic efficiency (defined as the photosynthetic rate divided by the incident PAR) in closed canopies (Gamon et al. *in press*). If these signals were detectable in AVIRIS images, they could lead to improved remote estimates of photosynthetic fluxes.

2. MATERIALS AND METHODS

Spectral reflectance was measured by positioning a Spectron spectroradiometer with 15 degree FOV optics (model SE590 with detector model CE390WB-R, Spectron Engineering, Denver, CO) approximately 4 meters above intact sunflower or 2 meters above oak canopies. Reflectance was presented as a "physiological reflectance index" (PRI) analogous in formulation to NDVI, for comparison with physiological measurements.

$$PRI = (R_{531} - R_{ref}) / (R_{531} + R_{ref}) \quad (1)$$

Where "R" indicates reflectance, the subscript "531" indicates the wavelength (in nm) of the xanthophyll signal, and the subscript "ref" indicates a reference wavelength (either 550 or 570 nm).

Physiological assays included leaf-level gas exchange (LI-6200, Li-Cor Inc., Lincoln Nebraska) and chlorophyll and carotenoid determinations by HPLC. Incident photosynthetic photon flux density (PPFD) was used to calculate photosynthetic efficiency from net CO₂ uptake rates.

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$$\text{Photosynthetic efficiency} = \text{Net CO}_2 \text{ uptake rate} / \text{incident PFD} \quad (2)$$

Methods are further described in Gamon et al. 1990 and Gamon et al. *in press*.

3. RESULTS AND DISCUSSION

The PRI correlated well with photosynthetic efficiency in both sunflower and oak (Fig. 1). Photosynthetic efficiency, analogous to the photon (quantum) yield of photosynthesis or the conversion efficiency of PAR to biomass (Monteith 1977), is an indicator of the short-term efficiency of converting PAR to fixed carbon through photosynthesis. This reflectance index may be useful in remotely detecting conditions of reduced photosynthetic activity associated with a number of stresses.

Narrow waveband spectroradiometry could also be used to assess other aspects of physiologically important plant pigments (e.g. chlorophylls, carotenoids and anthocyanins). For example, subtle changes in chlorophyll to carotenoid ratios associated with reduced photosynthetic performance could be detectable with narrow-band reflectance. Narrow-waveband indices of vegetation function may be particularly useful in conditions where broad-band indices are insensitive to current physiological status (e.g. in evergreen vegetation lacking strong diurnal or seasonal changes in canopy display).

Estimation of pigment content from AVIRIS images could lead to improved estimates of photosynthetic fluxes at the landscape scale. In AVIRIS images, pigment contents may be accessible via reflectance indices analogous to the PRI; another approach would be to use a mixture model to isolate component and residual images (Ustin et al. *in press*), which could then be compared with pigment spectra.

In our ground-based studies, validation of physiological interpretations required detailed physiological assays (e.g. of pigment content and photosynthetic flux) that were both expensive and time consuming. These direct "physiological calibrations" of spectral reflectance would be even more difficult at the 20 m scale of the AVIRIS pixel, and atmospheric effects may further obscure relationships between photosynthetic fluxes and spectral reflectance. Ground validation of possible physiological signals in AVIRIS imagery should include flux and reflectance measurements at a range of scales between the leaf and the landscape.

4. ACKNOWLEDGEMENTS

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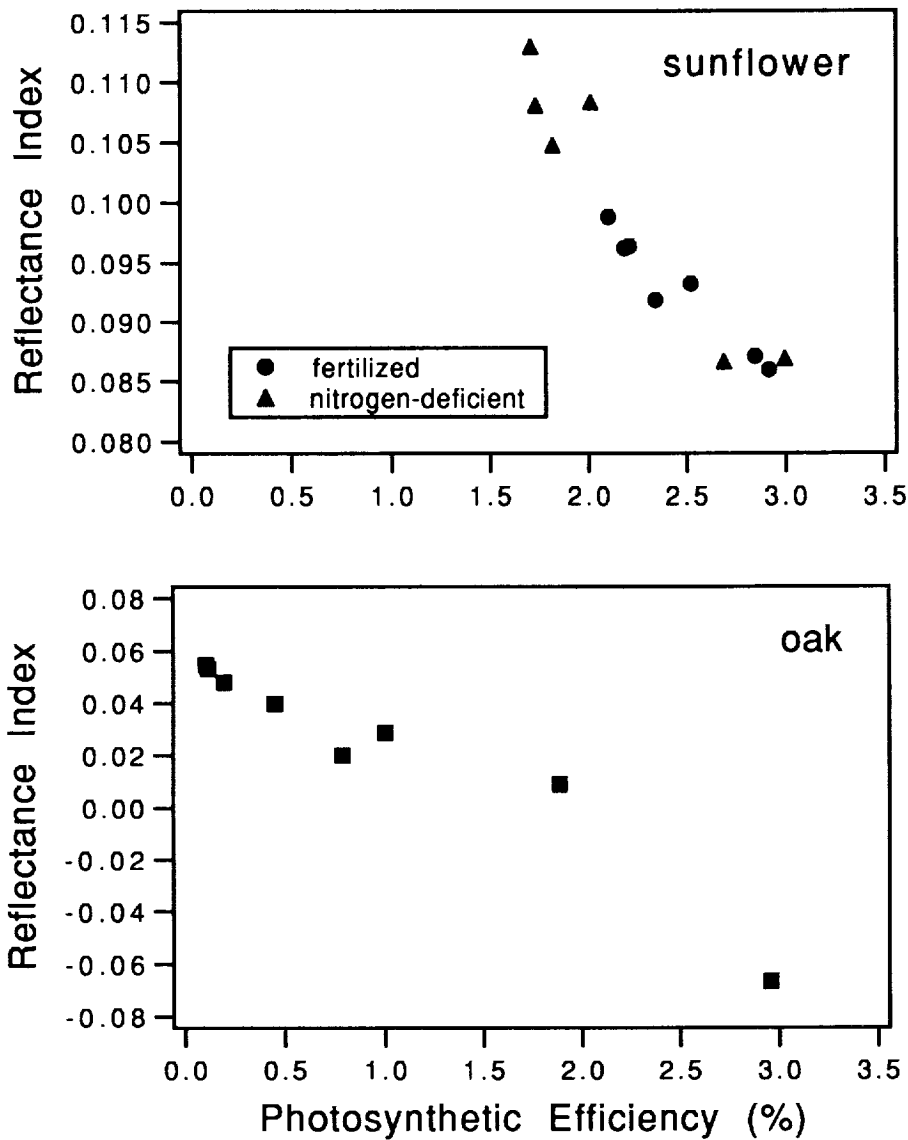


Fig. 1.

Comparison of the physiological reflectance index (PRI; eq. 1) with photosynthetic efficiency (eq. 2) for sunflower (\pm nitrogen) and oak. Reference wavelengths were 550 and 570 nm for sunflower and oak, respectively. Points represent measurements taken at different times in a single day.