

Sensitivity of Sentinel-2 red-edge bands to leaf chlorophyll concentration in winter wheat

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Introduction: Chl_{a+b} empirical estimation

Several ***narrow-band VI***, obtained from high spectral resolution reflectance data in the ***red-edge***, have proved to be sensitive at the canopy scale to ***leaf chlorophyll concentration*** [***Chl_{a+b}***] a valuable indicator of nutritional stress;

A few ***broad –band VI***, based on ***green, red and NIR*** reflectance, have been proposed with the same objective;

However, there is currently ***little agreement*** on which VI, both among narrow and broad-band indices, has the strongest relationships with [***Chl_{a+b}***]

The availability of **Sentinel-2 high spectral resolution data with 20m spatial resolution in the red-edge and 10 m in the visible-NIR** can significantly improve the accuracy of [**Chl_{a+b}**] empirical estimation at the canopy scale;

The present work addresses the **comparison between the sensitivity to [**Chl_{a+b}**] of several narrow band and broad-band VI, obtained from Sentinel 2 VIS/red-edge/NIR bands**, in winter wheat field trials with different nitrogen fertilization levels.

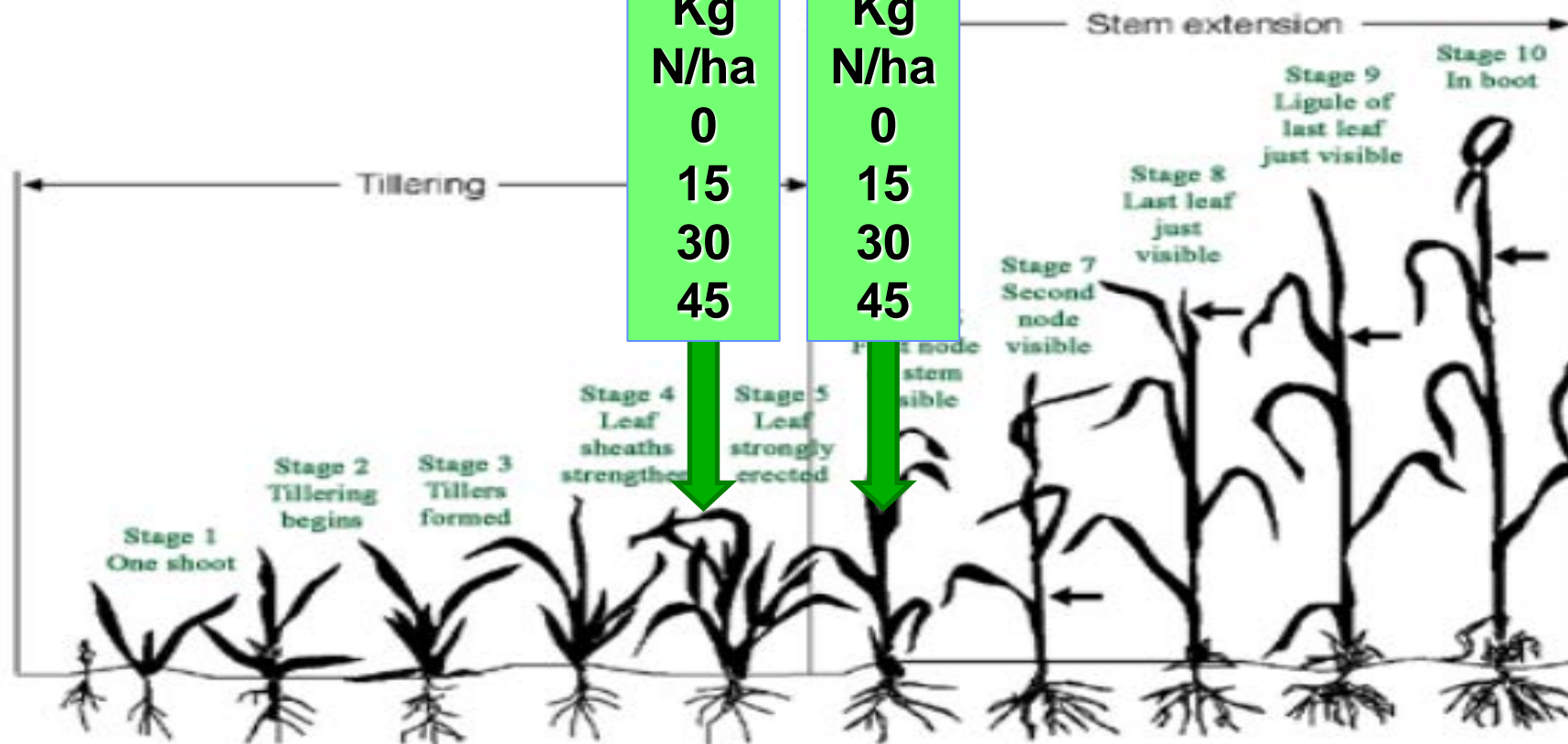
ASD FieldSpec® HH portable
Vis-NIR spectroradiometer
(3 nm FWHM at around 700 nm)
FOW of 25°, 1.5 m above the canopy

Three SPAD readings from the
uppermost fully expanded leaf of two
plants within the ASD footprint.



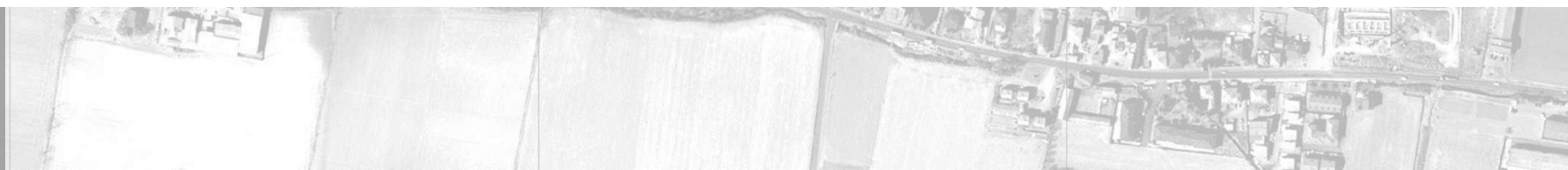
**Kg
N/ha**
0
15
30
45

**Kg
N/ha**
0
15
30
45





Index	Formula	S2 bands
<i>Broad-band (VIS-NIR)</i>		
NDVI	$(\rho_{NIR} - \rho_{red}) / (\rho_{NIR} + \rho_{red})$	B4 B8
OSAVI	$(\rho_{NIR} - \rho_{red}) / (\rho_{NIR} + \rho_{red} + 0.16)$	B4 B8
Green NDVI	$(\rho_{NIR} - \rho_{green}) / (\rho_{NIR} + \rho_{green})$	B3 B8
Green SR (or CI)	$\rho_{NIR} / \rho_{green}$	B3 B8
CVI	$(\rho_{NIR} / \rho_{green}) \cdot (\rho_{red} / \rho_{green})$	B3 B4 B8
MTVI	$1.2 \cdot 1.2 \cdot (\rho_{NIR} - \rho_{red}) - 2.5 \cdot (\rho_{red} - \rho_{green}) $	B3 B4 B8
<i>Narrow-band (VIS-red edge-NIR)</i>		
TCI/OSAVI	$[1.2 \cdot (\rho_{700} - \rho_{550}) - 1.5 \cdot (\rho_{670} - \rho_{550}) \cdot \sqrt{\rho_{700} / \rho_{670}}] / OSAVI_{B4, B7}$	B3 B4 B5
MCARI/OSAVI	$[(\rho_{700} - \rho_{670}) - 0.2 \cdot (\rho_{700} - \rho_{550})] \cdot (\rho_{700} / \rho_{670}) / OSAVI_{B4, B7}$	B3 B4 B5 B7
TCARI/OSAVI	$3 \cdot [(\rho_{700} - \rho_{670}) - 0.2 \cdot (\rho_{700} - \rho_{550}) \cdot (\rho_{700} / \rho_{670})] / OSAVI_{B4, B7}$	B3 B4 B5 B7
MTCI	$(\rho_{750} - \rho_{710}) / (\rho_{710} - \rho_{680})$	B4 B5 B6
REIP _{S2}	$705 + 35 \cdot \{ [0.5 \cdot (\rho_{783} + \rho_{665}) - \rho_{705}] / (\rho_{740} - \rho_{705}) \}$	B4 B5 B6 B7
NAOC	$1 - \int_{643}^{795} \rho_{d\lambda} / 152 \cdot \rho_{795}$	B4 B5 B6 B7





The Chlorophyll Vegetation Index

We proposed the chlorophyll vegetation index (CVI) as a broad-band leaf chlorophyll estimator at the canopy scale:

$$CVI = \frac{\rho_{NIR}}{\rho_{GREEN}} \cdot \frac{\rho_{RED}}{\rho_{GREEN}}$$

The CVI is obtained from the Green SR by introducing the red/green ratio **as a normalization factor** to minimize the **LAI** sensitivity of the index.

(the index relies on the assumption that, before canopy closure, the red/green ratio is representative of the relative abundance of vegetation and soil)

CVI development from a field spectrometric experiment



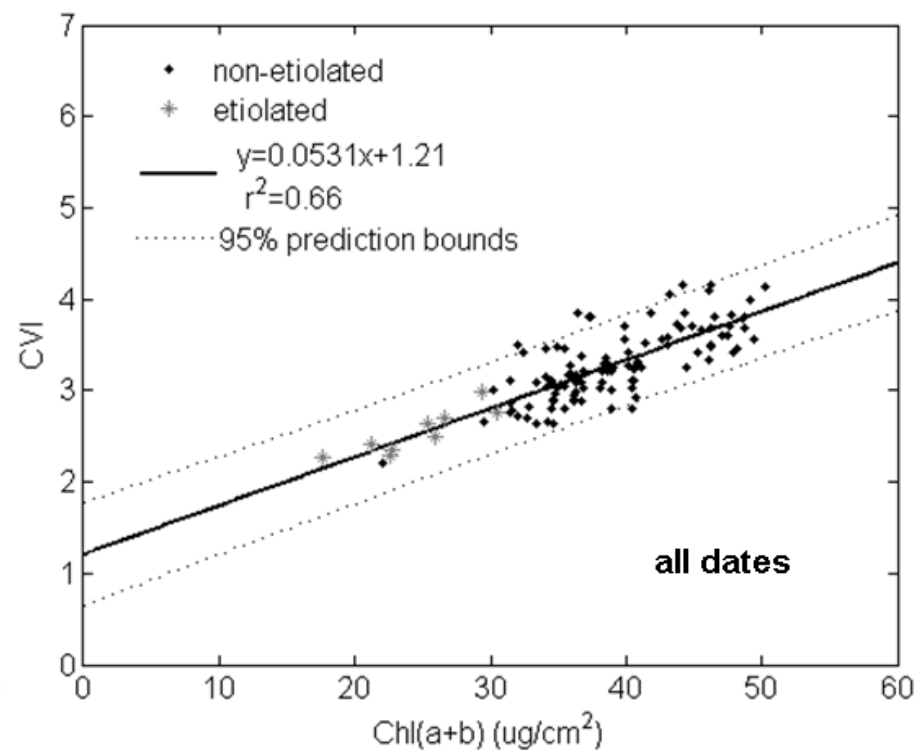
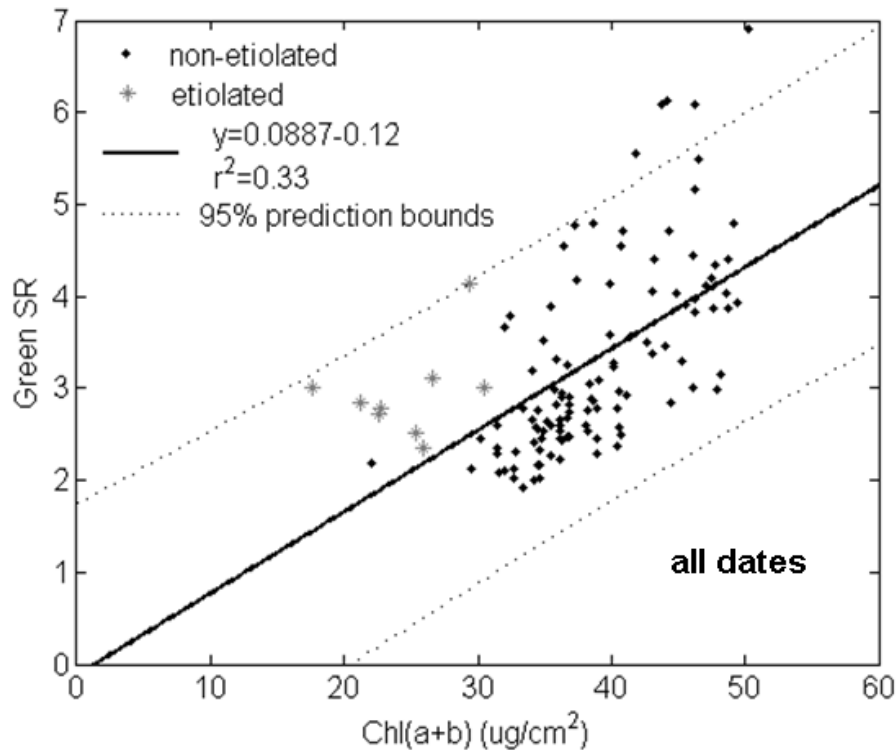
- 2 seeding dates ($\Delta 10$ days)
- 4 N fertilization levels (0-90-180-270 kg/ha)
- etiolating treatments



CVI sensitivity to leaf Chl. at the canopy scale

all dates, some etiolated canopies

LAI 0.1-2.3 - leaf [Chl] 18-50 $\mu\text{g cm}^{-2}$

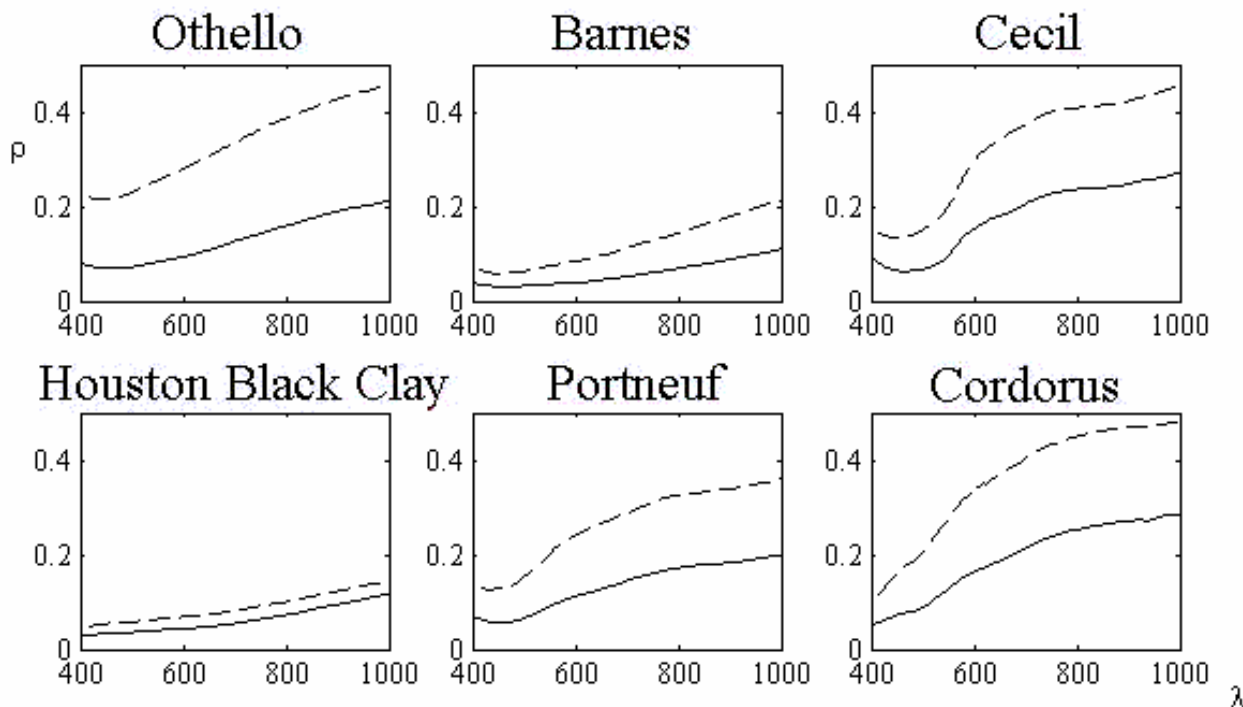


An effective normalization of the different LAI values is obtained by the introduction of the red/green ratio

A large synthetic dataset

the CVI sensitivity at the canopy scale to leaf [Chl] was assessed for a wide range of soils and crops conditions and for different θ_s by the analysis of a large synthetic dataset (280,800 spectra) obtained by using in the direct mode the coupled PROSPECT+SAILH models:

- 6 soils
- 12 soil water contents from wet to dry
- 3 average leaf angle (ALA 30°, 50° e 70°) planophile-erectophile
- 13 [Chl.a+b] from 20 (chlorosis) to 50 $\mu\text{g cm}^{-2}$
- 20 LAI values from 0.2 to 4.0
- five solar zenith angles (30, 37.5, 45, 52.5 and 60 d.d.)





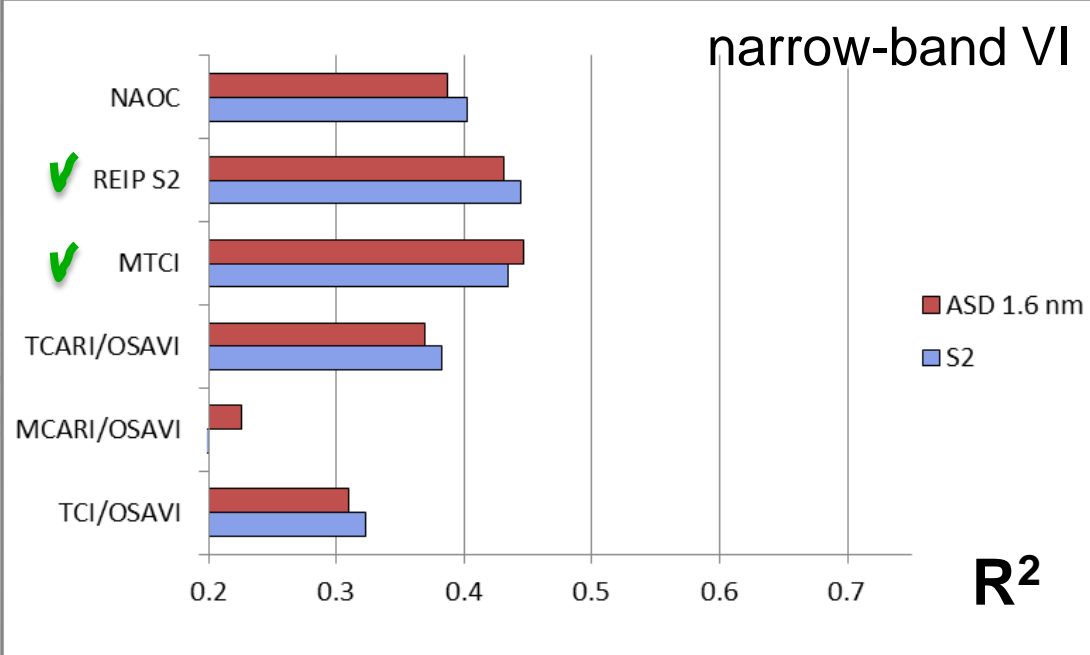
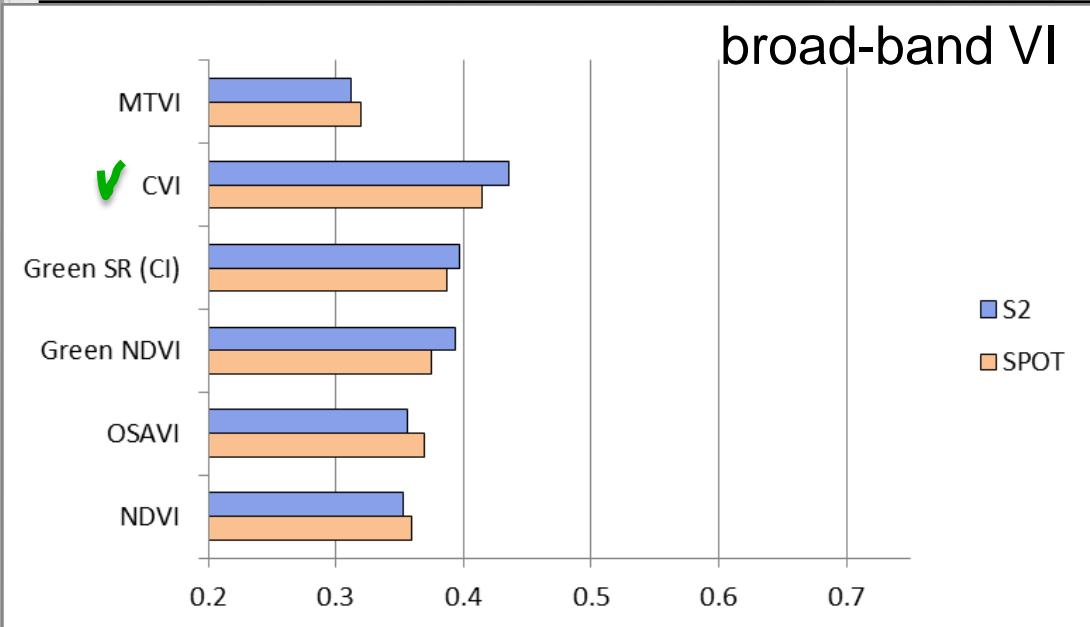
REIP_{S2} – linear interpolation of Sentinel 2 bands

The linear interpolation, (Guyot and Baret 1988, Clevers 1994) is a simple method that needs few red/red-edge/NIR bands for the calculation of the red-edge inflection spectral position.

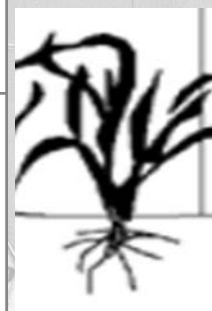
Using the linear interpolation method with Sentinel 2 B4-B5-B6-B7 center wavelengths:

$$\lambda_{REIPS2} = 705 + 35 \cdot \left(\frac{\frac{1}{2}(\rho_{783} + \rho_{665}) - \rho_{705}}{\rho_{740} - \rho_{705}} \right)$$

Results: Feekes 5 (n=127)



regressions' R² values vs. SPAD measures: VI obtained from average reflectance in **Sentinel 2** and **SPOT HRG** spectral bands



**before
 ΔN
 effect**

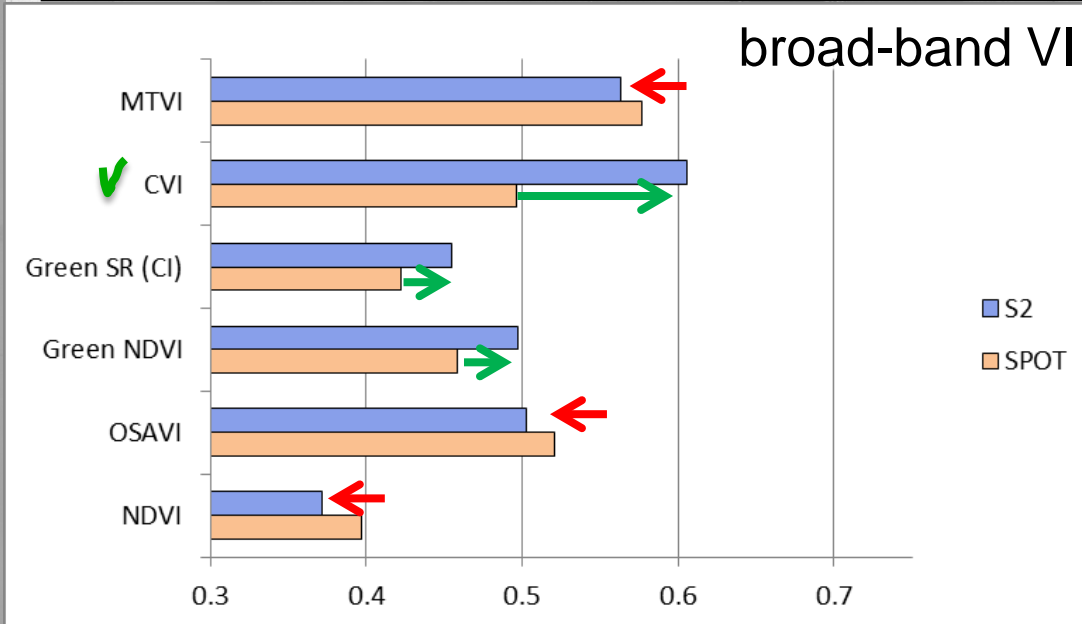
regressions' R² values vs. SPAD measures: VI obtained from **ASD** (1.6 nm) **VI original λ** and average reflectance in **Sentinel 2** spectral bands

R²

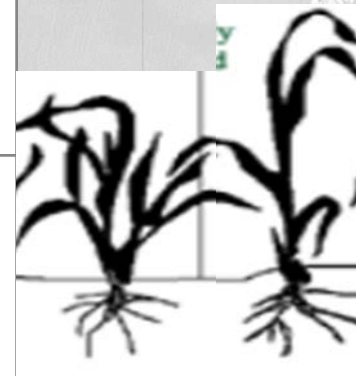
Results: Feekes 5-6 (n=255)



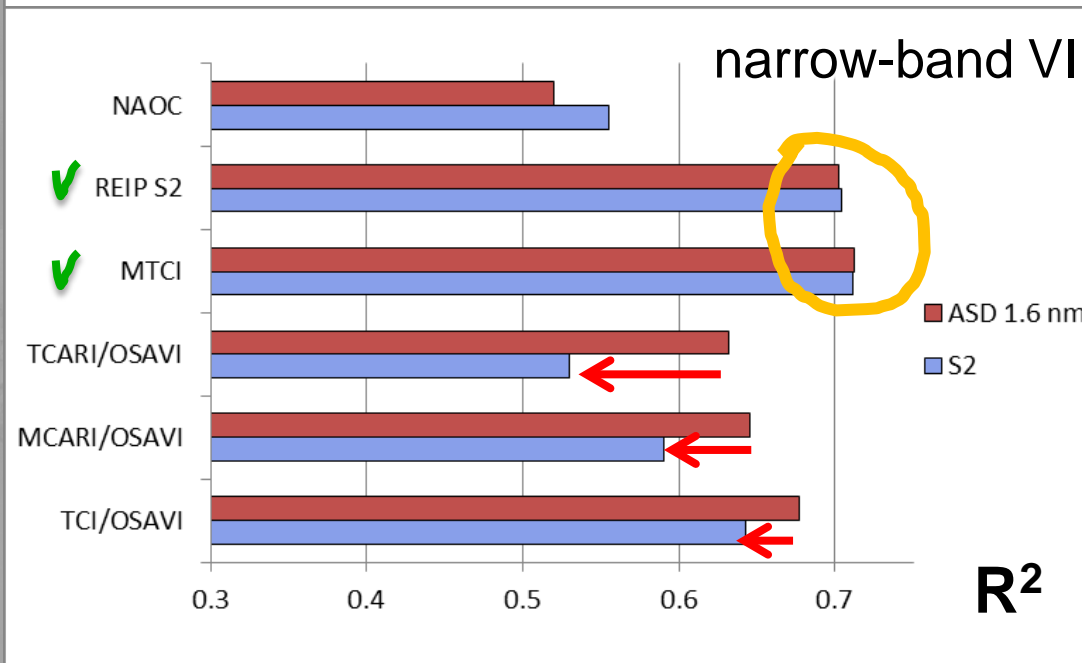
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April 23 - 27 2012



regressions' R^2 values vs. SPAD measures: VI obtained from average reflectance in **Sentinel 2** and **SPOT HRG** spectral bands



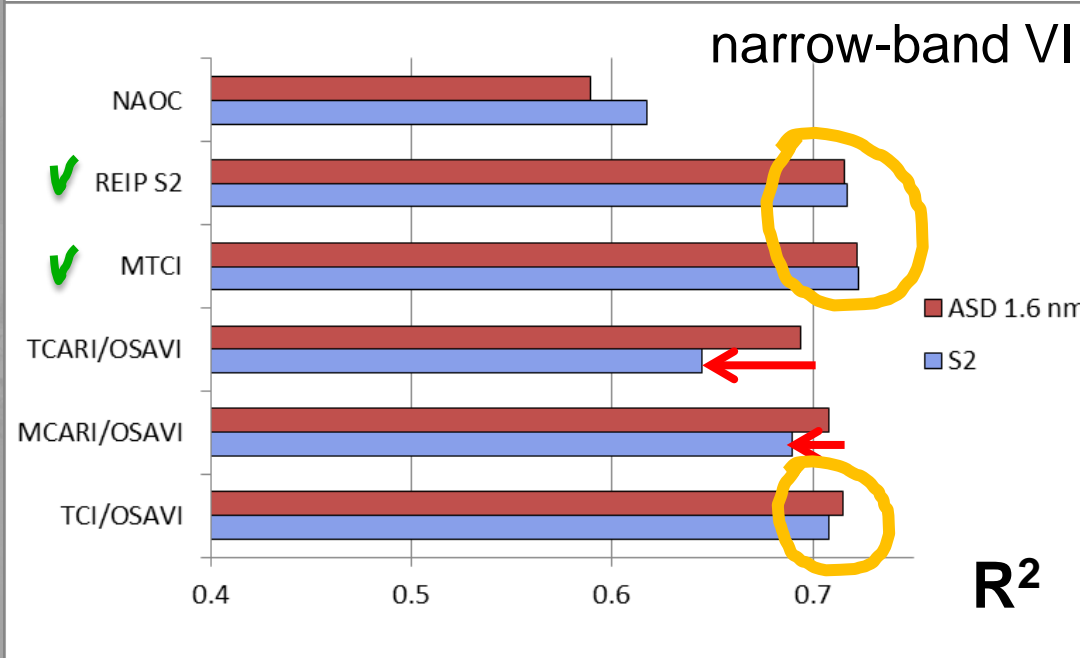
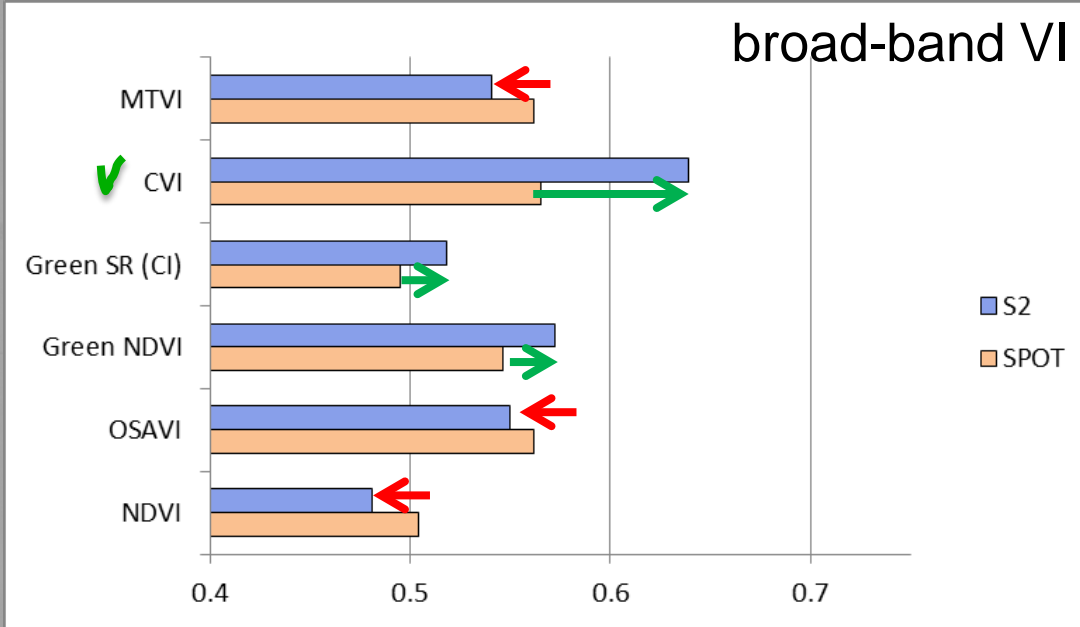
1 ΔN
app.
effect



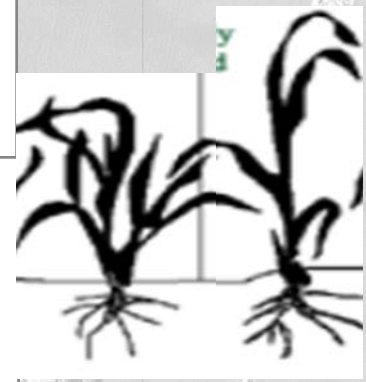
regressions' R^2 values vs. SPAD measures: VI obtained from **ASD (1.6 nm)** **VI original λ** and average reflectance in **Sentinel 2** spectral bands

R^2

Results: Feekes 5-6-9 (n=351)



regressions' R^2 values vs. SPAD measures: VI obtained from average reflectance in **Sentinel 2** and **SPOT HRG** spectral bands



2 ΔN app. effect



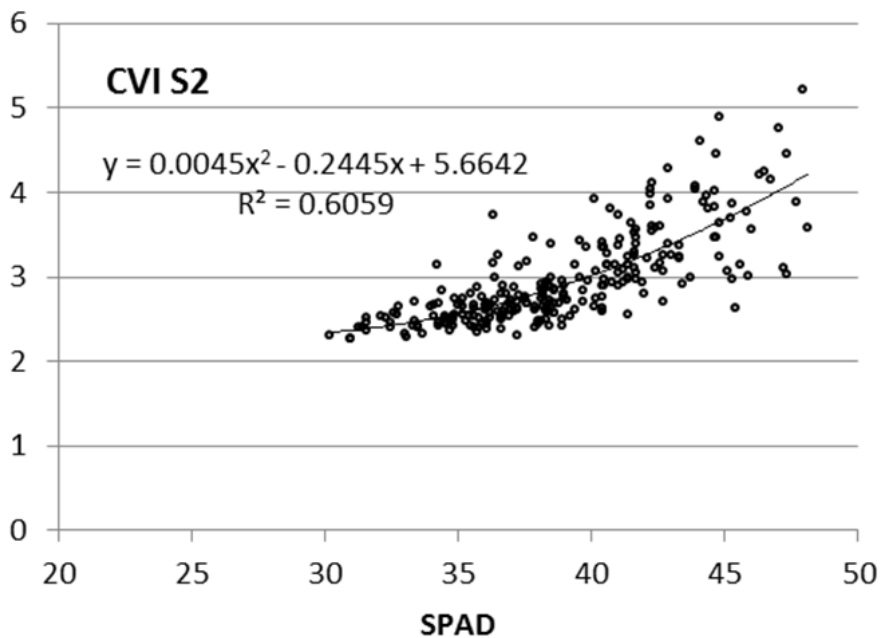
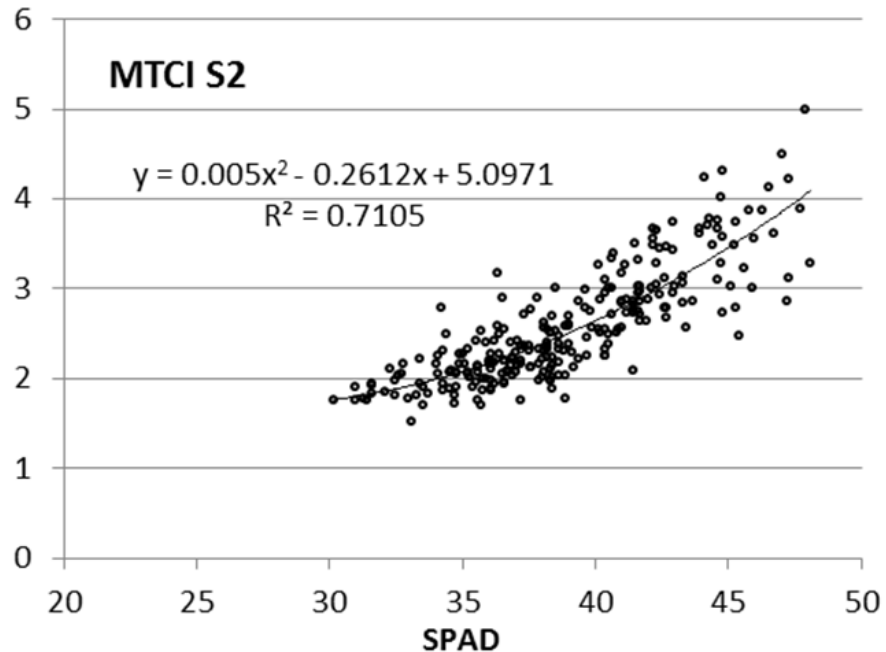
regressions' R^2 values vs. SPAD measures: VI obtained from **ASD** (1.6 nm) **VI original λ** and average reflectance in **Sentinel 2** spectral bands

R²

Conclusions



S2 red-edge bands can be effectively used for leaf Chla+b empirical estimation in winter wheat at Feekes 5-6 – with 20m spatial resolution



S2 VIS-NIR bands can be almost as effectively used for the same objective – with 10m spatial resolution

A close-up photograph of several vibrant green leaves on a branch. The leaves are oval-shaped with prominent veins and slightly wavy edges. The background is a soft-focus mix of more green leaves and a bright blue sky. The word "Grazie" is printed in a bold, yellow, sans-serif font in the center of the image.

Grazie