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$_{a+b}$]
Introduction: objectives

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.
**methods: VIs**

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<td><strong>Broad-band (VIS-NIR)</strong></td>
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<tr>
<td>NDVI</td>
<td>(\frac{(\rho_{\text{NIR}} - \rho_{\text{red}})}{(\rho_{\text{NIR}} + \rho_{\text{red}})})</td>
<td>B4 B8</td>
</tr>
<tr>
<td>OSAVI</td>
<td>(\frac{(\rho_{\text{NIR}} - \rho_{\text{red}})}{(\rho_{\text{NIR}} + \rho_{\text{red}} + 0.16)})</td>
<td>B4 B8</td>
</tr>
<tr>
<td>Green NDVI</td>
<td>(\frac{(\rho_{\text{NIR}} - \rho_{\text{green}})}{(\rho_{\text{NIR}} + \rho_{\text{green}})})</td>
<td>B3 B8</td>
</tr>
<tr>
<td>Green SR (or CI)</td>
<td>(\frac{\rho_{\text{NIR}}}{\rho_{\text{green}}})</td>
<td>B3 B8</td>
</tr>
<tr>
<td>CVI</td>
<td>(\frac{\rho_{\text{NIR}}}{\rho_{\text{green}}} \cdot \frac{\rho_{\text{red}}}{\rho_{\text{green}}})</td>
<td>B3 B4 B8</td>
</tr>
<tr>
<td>MTVI</td>
<td>(1.2 \cdot \left[1.2 \cdot (\rho_{\text{NIR}} - \rho_{\text{red}}) - 2.5 \cdot (\rho_{\text{red}} - \rho_{\text{green}})\right])</td>
<td>B3 B4 B8</td>
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<tr>
<td><strong>Narrow-band (VIS-red edge-NIR)</strong></td>
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<tr>
<td>TCI/OSAVI</td>
<td>(\frac{1.2 \cdot (\rho_{700} - \rho_{550}) - 1.5 \cdot (\rho_{670} - \rho_{550}) \cdot \sqrt{\rho_{700}/\rho_{670}}}{\text{OSAVI}_{B4,B7}})</td>
<td>B3 B4 B5</td>
</tr>
<tr>
<td>MCARI/OSAVI</td>
<td>(\frac{(\rho_{700} - \rho_{670}) - 0.2 \cdot (\rho_{700} - \rho_{550}) \cdot (\rho_{700}/\rho_{670})}{\text{OSAVI}_{B4,B7}})</td>
<td>B3 B4 B5 B7</td>
</tr>
<tr>
<td>TCARI/OSAVI</td>
<td>(3 \cdot \frac{(\rho_{700} - \rho_{670}) - 0.2 \cdot (\rho_{700} - \rho_{550}) \cdot (\rho_{700}/\rho_{670})}{\text{OSAVI}_{B4,B7}})</td>
<td>B3 B4 B5 B7</td>
</tr>
<tr>
<td>MTCI</td>
<td>(\frac{(\rho_{750} - \rho_{710})}{(\rho_{710} - \rho_{680})})</td>
<td>B4 B5 B6</td>
</tr>
<tr>
<td>REIP(_S2)</td>
<td>(705 + 35 \cdot \left{0.5 \cdot (\rho_{783} + \rho_{665}) - \rho_{705} \sqrt{(\rho_{740} - \rho_{705})}\right})</td>
<td>B4 B5 B6 B7</td>
</tr>
<tr>
<td>NAOC</td>
<td>(1 - \int_{645}^{795} \rho_{\lambda} d\lambda / 152 \cdot \rho_{795})</td>
<td>B4 B5 B6 B7</td>
</tr>
</tbody>
</table>
The Chlorophyll Vegetation Index

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

\[
CVI = \frac{\rho_{\text{NIR}}}{\rho_{\text{GREEN}}} \cdot \frac{\rho_{\text{RED}}}{\rho_{\text{GREEN}}}
\]

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 (Δ10 days)
- 4 N fertilization levels (0-90-180-270 kg/ha)
- etiolating treatments
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 $\theta_s$ 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°, 70°) planophile-erectophile
- 13 [Chl.a+b] from 20 (chlorosis) to 50$\mu$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:

\[
\lambda_{REIPS2} = 705 + 35 \cdot \frac{1}{2} \left( \rho_{783} + \rho_{665} \right) - \rho_{705} \left( \rho_{740} - \rho_{705} \right)
\]
Results: Feekes 5 (n=127)

**broad-band VI**
- MTVI
- CVI
- Green SR (CI)
- Green NDVI
- OSAVI
- NDVI

**narrow-band VI**
- NAOC
- REIP S2
- MTCI
- TCARI/OSAVI
- MCARI/OSAVI
- TCI/OSAVI

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

**before ∆N effect**

**R²**
Results: Feekes 5-6 (n=255)

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

- 1 $\Delta N$ app. effect

- VI original $\lambda$ and average reflectance in Sentinel 2 spectral bands
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 $\Delta N$ app. effect

regressions’ $R^2$ values vs. SPAD measures: VI obtained from ASD (1.6 nm) VI original $\lambda$ and average reflectance in Sentinel 2 spectral bands
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

$S2 \text{ VIS-NIR bands can be almost as effectively used for the same objective – with 10m spatial resolution}$
Grazie