Proximal Vegetation Sensors

Vegetation indexes

Area **2** – **Technologies**

Lesson **4** – **Proximal Sensing**

Sequence ID – **14**

UPM

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DISCLAIMER

A2.L4.T2 Proximal vegetation sensors

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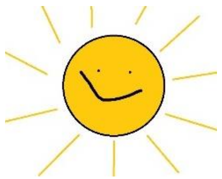
Type of Plant Sensors

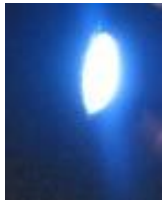
- Optical
  - Transmittance (SPAD)
  - Fluorescence
  - Reflectance (NDVI)
- Thermography
  - WSI

Optical Sensors: Some Facts

- Measure optical properties of plants (transmittance, reflectance, fluorescence)
- The measurements of the optical sensors are closely related to the actual amount of N in the crop, so they can provide a reliable estimate of the state of N
- Measures in contact with the leaf or a few centimeters (<2 m) from the plant at regular time intervals or at critical times

Optical interactions





Light source

Fluorescence

Reflectance

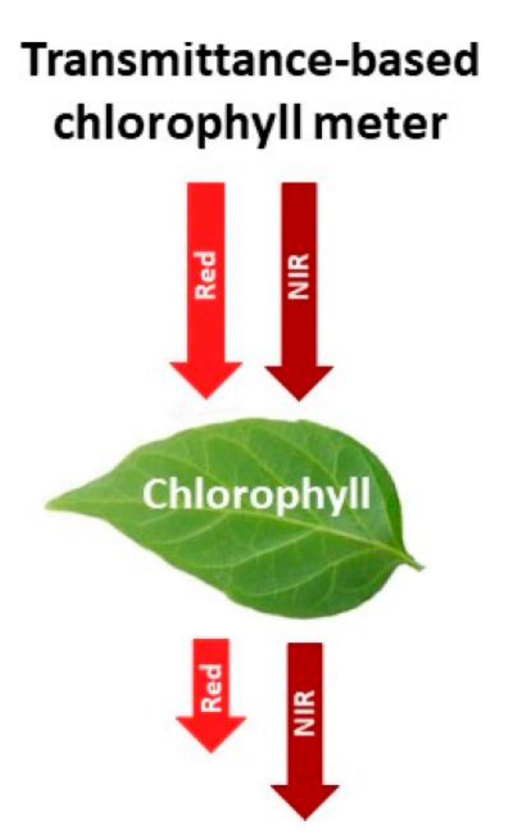
Transmittance

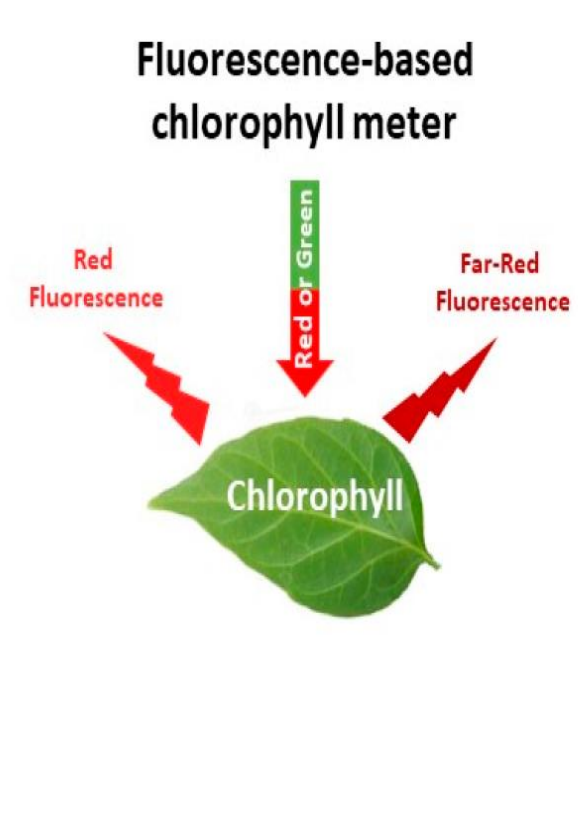
Chlorophyll meters

N = f (Chlorophyll)

Chlorophyll absorbs red radiation

Chlorophyll transmits near infra-red (NIR) radiation





Ratio red to far-red chlorophyll fluorescence depends on the chlorophyll content

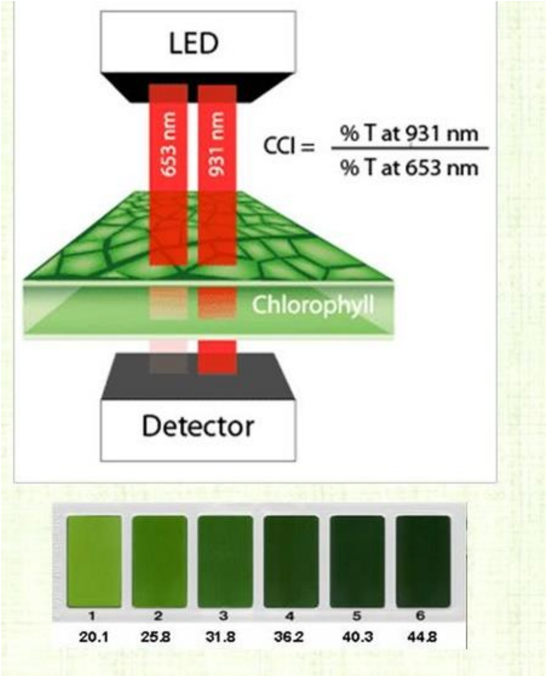
Source: Padilla et al., 2018

Transmittance-based chlorophyll meter

✓ SPAD-502

$$SPAD = k \log_{10} \frac{I_{0(650)} I_{(940)}}{I_{(650)} I_{0(940)}}$$

✓ Hydro N-Tester



✓ atLEAF +

Fluorescence-based chlorophyll meter

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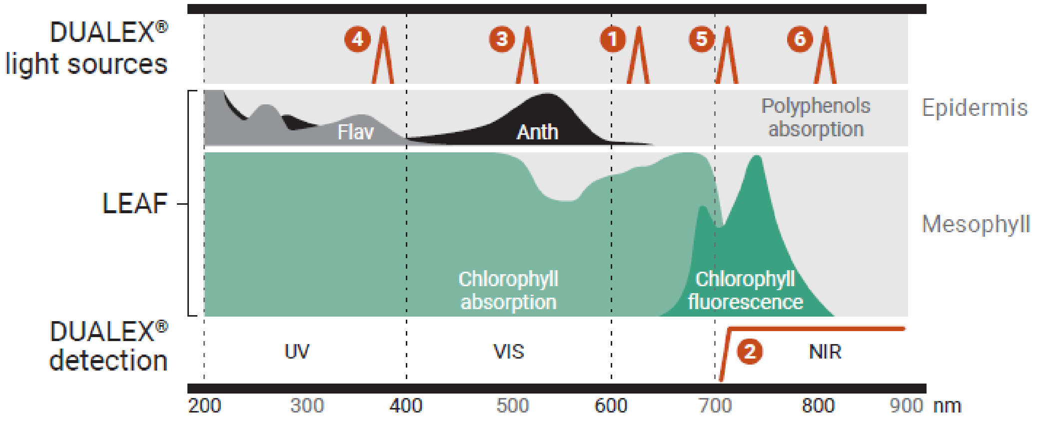
Accurate measurement of chlorophyll

DUALEX® measures the chlorophyll content of leaf thanks to a transmittance ratio at two different wavelengths. One in the far-red 5 absorbed by chlorophyll and one in the near-infrared 6 as reference.



The only leafclip sensor to measure flavonols and anthocyanins contents

DUALEX® measures flavonols and anthocyanins content of the leaves epidermis thanks to a differential ratio of chlorophyll fluorescence.

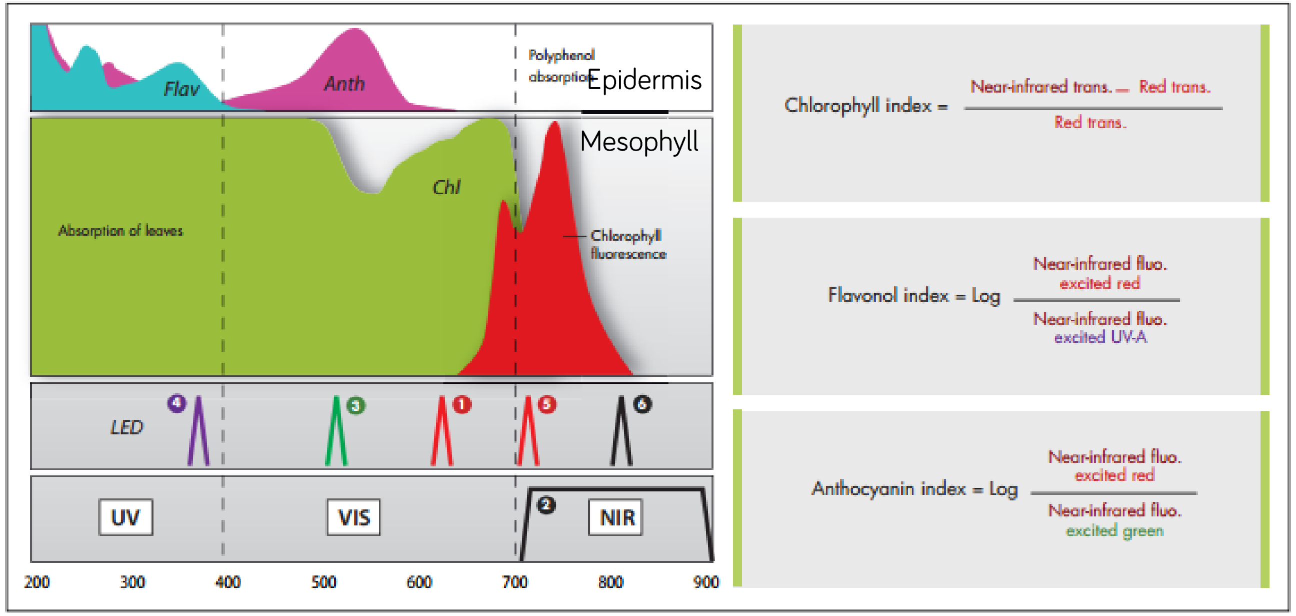
Near-infrared chlorophyll fluorescence is measured under a first reference excitation light not absorbed by polyphenols 1. It is compared to a second sampling specific light absorbed by polyphenols (e.g. green 3 for anthocyanins or UV 4 for flavonols).

Only a fraction of this light reaches the chlorophyll in the mesophyll and can generate near-infrared chlorophyll fluorescence 2. This principle of measurement is called the screening effect of polyphenols on chlorophyll fluorescence.

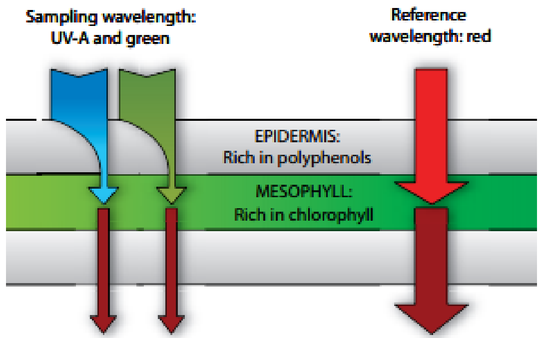
✓ Dualex Force A

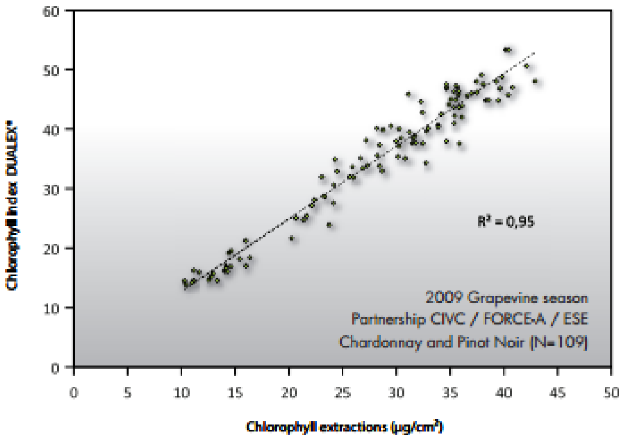
Source: https://www.force-a.com/products/dualex

Fluorescence-based chlorophyll meter



The difference in chlorophyll fluorescence measured in the near-infrared is thus directly proportional to the amount of polyphenols present in the epidermis of the leaf.



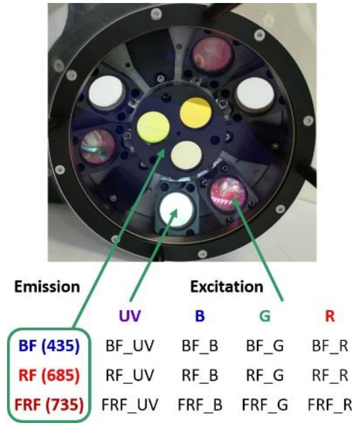


POLYPHENOL measurement

Near-infrared chlorophyll fluorescence ❷ is measured under a first reference excitation light ❶ not absorbed by polyphenols. It is compared to a second sampling light specific to a particular type of polyphenols (e.g. green ❸ for anthocyanins or UV-A ❹ for flavonols). Only a fraction of this light reaches the chlorophyll in the mesophyll and can generate near-infrared fluorescence.

CHLOROPHYLL measurement

The SFR (Simple Fluorescence Ratio) is directly related to the chlorophyll content of the sample. It is the ratio of chlorophyll fluorescence measured in the near-infrared ❷ to the chlorophyll fluorescence measured in the red ❺, whatever the excitation in the visible. Because of the overlapping of the absorption and the emission spectrum of chlorophyll, re-absorption occurs at shorter wavelengths (red) but not at longer (near-infrared) wavelengths.



✓ Multiplex Force A

Source: https://www.force-a.com/products/multiplex

NBI: Nitrogen Balance Index

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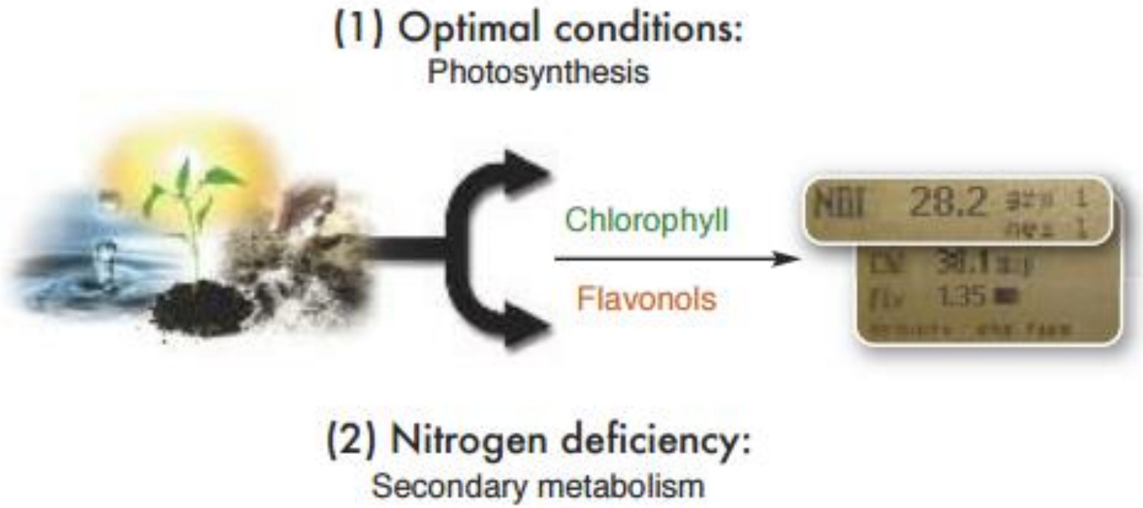
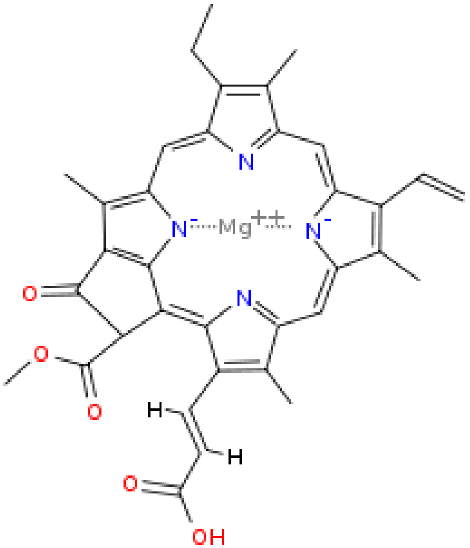
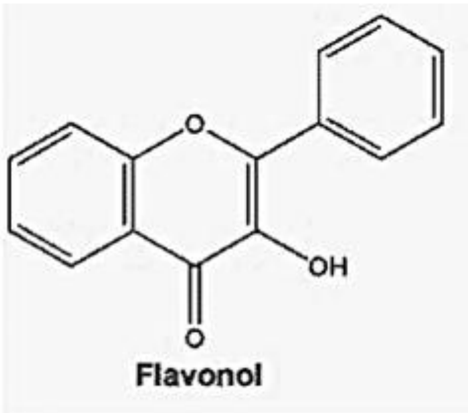
Polyphenols, specifically flavonols, are indicators of nitrogen status. When a plant is under optimal conditions, it favors its primary metabolism and synthesizes proteins (N-containing molecules) containing chlorophyll, and few flavonols (carbon-based secondary compounds). In case of nitrogen deficiency, the plant directs its metabolism towards an increased production of flavonols







NBI= Chlorophyll / Flavonols

Reflectance: Agronomics Status, Bases of Optical Spectrum

VISIBLE RANGE (RGB)

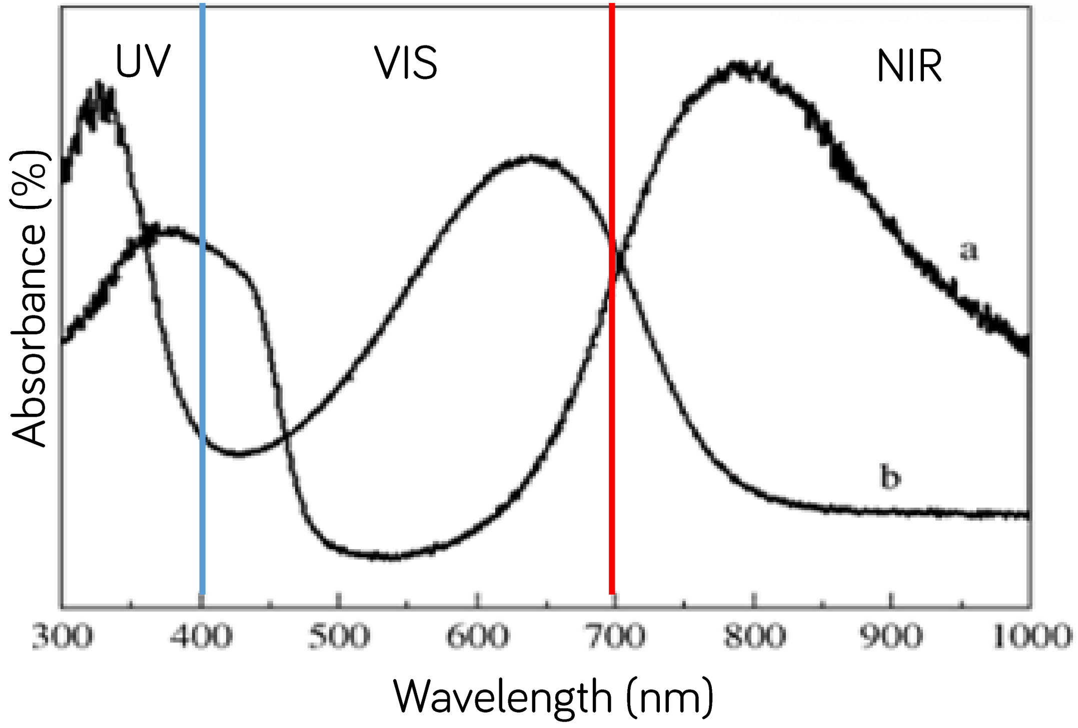
Pigments absorb radiation:

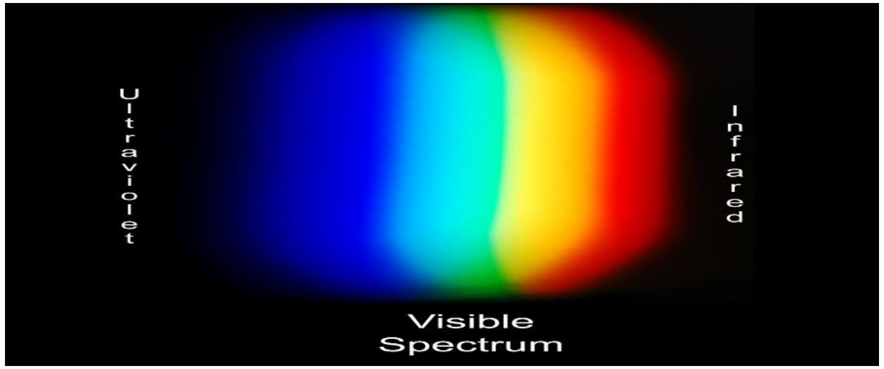
- Chlorophyll
- Carotenoids
- Polyphenols

INFRARED (not visible)

Density and structure of cells and tissues; water content

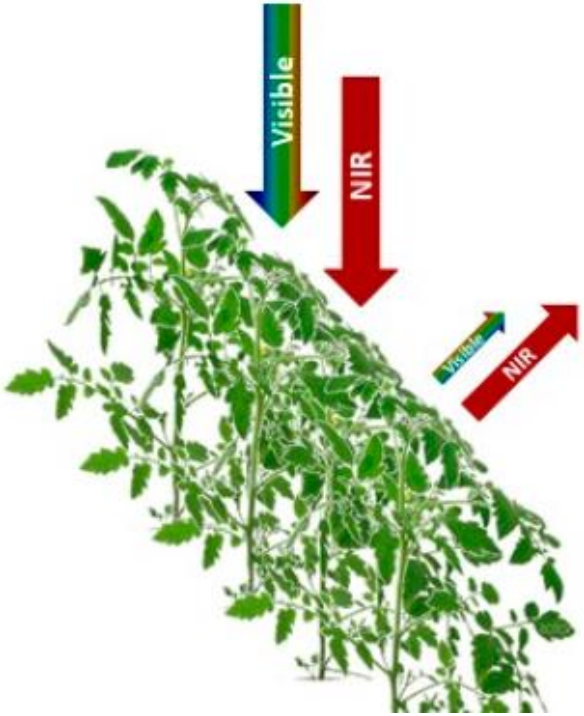
- Biomass
- Leaf Area Index
- Health





Reflectance patterns of crops

- ✓ Plant tissue normally absorbs approximately 90% of the visible radiation (390 to 750 nm) and reflects approximately 50% of the NIR (750 to 1300 nm).
- ✓ The degree of absorbance and reflectance in the visible and NIR portions of the spectrum varies with crop N content, thus, providing information on the crop N status
- ✓ N-deficient crops, generally reflect more visible and reflect less NIR than N-sufficient crops



Source: Padilla et al., 2018

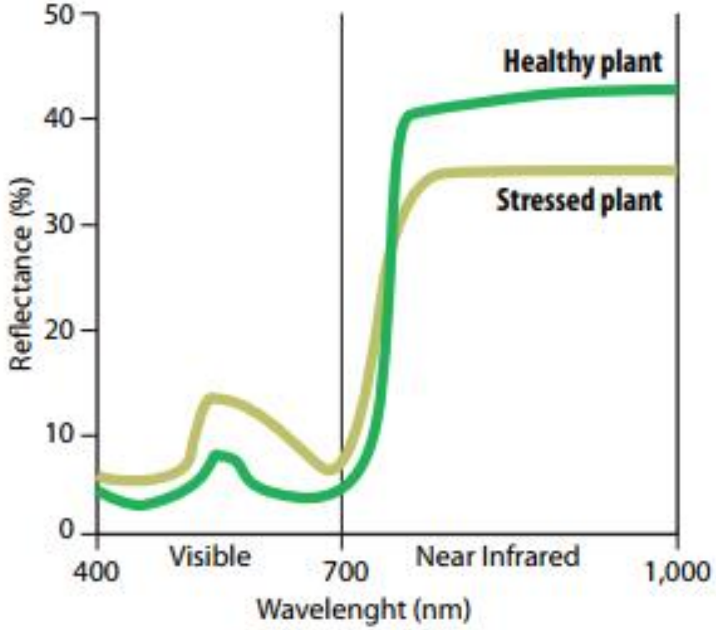
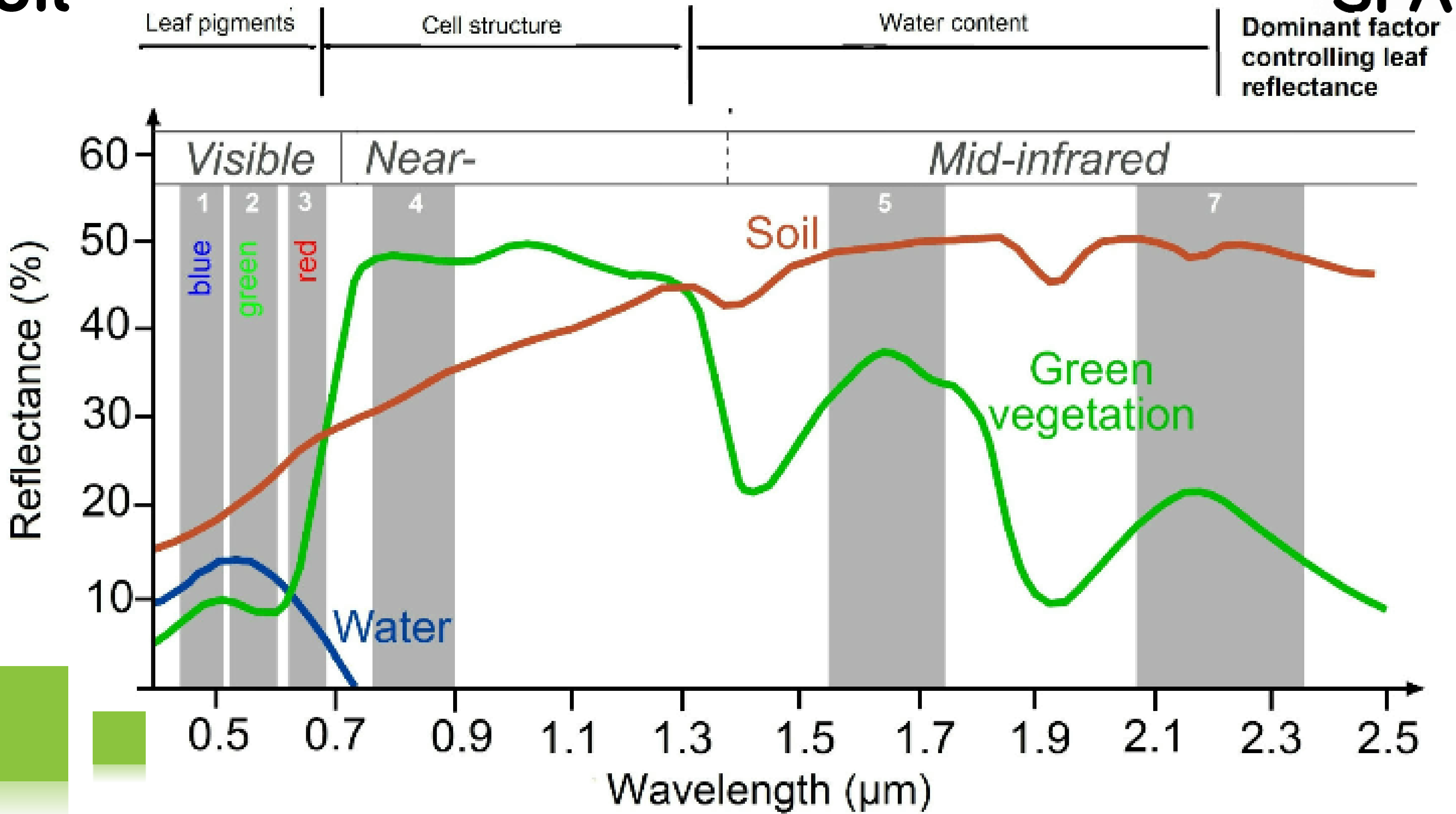


Figure 1. Typical reflectance spectrum of a healthy and a stressed plant.

Reflectance patterns of crops, water and soil



Optical Index: NDVI
Normalized Difference Vegetation Index

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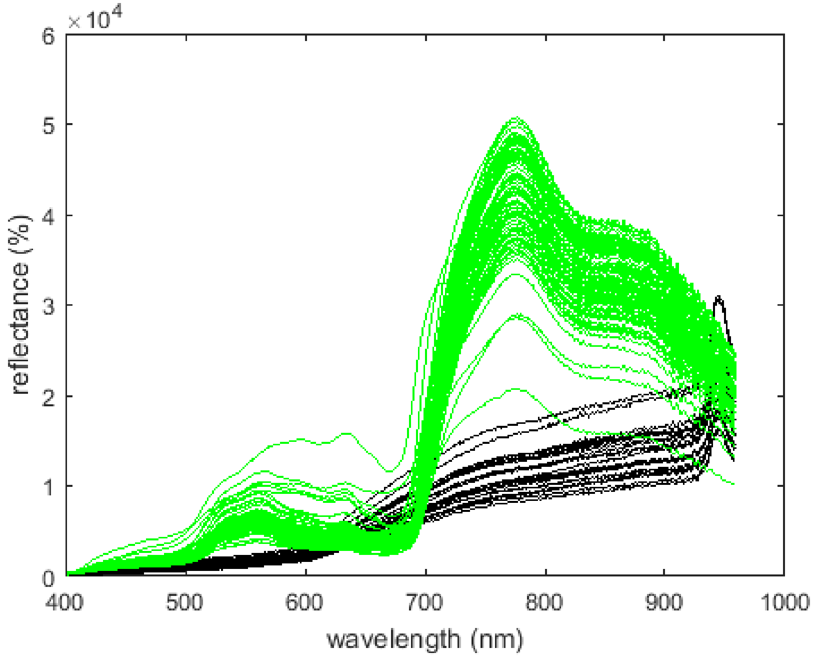

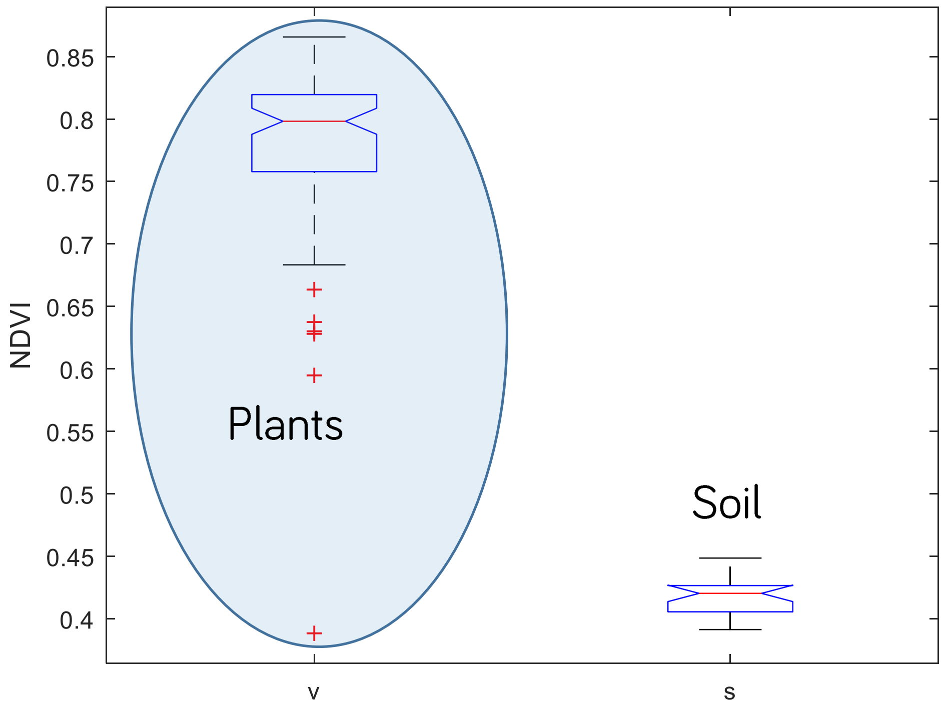

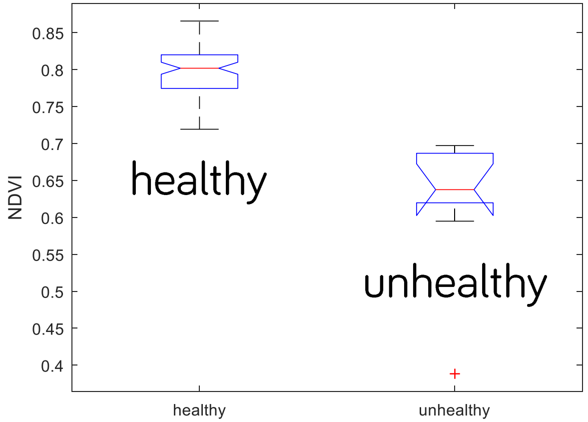

$$NDVI = \frac{IR - R}{IR + R}$$

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Optical Indices

Most commonly used vegetation indices for monitoring crop N status

Source: Padilla et al., 2018

Index	Acronym	Equation	Author
Normalized Difference Vegetation Index	NDVI	$\frac{NIR-Red}{NIR+Red}$	Sellers [88]
Green Normalized Difference Vegetation Index	GNDVI	$\frac{NIR-Green}{NIR+Green}$	Ma et al. [90]
Red Ratio of Vegetation Index	RVI	$\frac{NIR}{Red}$	Birth and McVey [91]
Green Ratio of Vegetation Index	GVI	$\frac{NIR}{Green}$	Birth and McVey [91]
Chlorophyll Index	CI	$\frac{NIR}{Red}-1$	Gitelson et al. [92]
Chlorophyll Vegetation Index	CVI	$\frac{NIR}{Green}*\frac{Red}{Green}$	Vincini et al. [93]
Soil Adjusted Vegetation Index	SAVI	$\frac{NIR-Red}{NIR+Red+L}*(1+L)$	Huete [89]
Optimized Soil Adjusted Vegetation Index	OSAVI	$\frac{NIR-Red}{NIR+Red+0.16}$	Rondeaux et al. [94]
Red Edge Normalized Difference Vegetation Index	RENDVI	$\frac{NIR-Red\ Edge}{NIR+Red\ Edge}$	Gitelson and Merzlyak [95]
Canopy Chlorophyll Content Index	CCCI	$\frac{RENDVI-RENDVI_{min}}{RENDVI_{max}-RENDVI_{min}}$	Barnes et al. [96]
Red Edge Index	REI	$\frac{NIR}{Red\ Edge}$	Vogelmann et al. [97]
Ratio RENDVI/NDVI	RENDVI/NDVI	$\frac{RENDVI}{NDVI}$	Varco et al. [98]
MERIS Terrestrial Chlorophyll Index	MTCI	$\frac{NIR-Red\ Edge}{Red\ Edge-Red}$	Dash and Curran [99]

Commercial Sensors
NDVI

Commercial devices

Source: Padilla et al., 2018

Table 1. Characteristics of some proximal optical sensors with potential for use for nitrogen (N) management of vegetable crops.

Sensor Type	Device †	Manufacturer	Measuring Principle	Wavelengths Used (nm)	Scale
Chlorophyll meter	SPAD-502	Konica Minolta (Tokyo, Japan)	Transmittance	650, 940	Leaf
	N-tester	Yara International (Oslo, Norway)	Transmittance	650, 960	Leaf
	atLEAF+	FT Green LLC (Wilmington, DE, USA)	Transmittance	660, 940	Leaf
	MC-100 Chlorophyll Concentration Meter	Apogee Instruments Inc. (Logan, UT, USA)	Transmittance	653, 931	Leaf
	CCM-200 Chlorophyll Content Meter Plus	Opti-Sciences Inc. (Hudson, NH, USA)	Transmittance	653, 931	Leaf
	DUALEX	Force-A (Orsay, France)	Transmittance	710, 850	Leaf
	MULTIPLEX	Force-A (Orsay, France)	Fluorescence	516, 685, 735	Leaf
Reflectance sensor	MSR5/87/16R	CropScan Inc. (Rochester, MN, USA)	Reflectance (passive ‡)	460, 510, 560, 610, 660, 710, 760, 810	Canopy
	CropSpec	Topcon Positioning Systems, Inc. (Livermore, CA, USA)	Reflectance (passive)	730-740, 800-810	Canopy
	Spectral Reflectance Sensor	METER Group, Inc. (Pullman, WA, USA)	Reflectance (passive)	532, 570, 650, 810	Canopy
	OptRx Crop Sensor	Ag Leader Technology (Ames, IA, USA)	Reflectance (active ‡)	670, 728, 775	Canopy
	N-sensor ALS	Yara International (Oslo, Norway)	Reflectance (active)	670, 730, 760	Canopy
	Crop Circle ACS 430	Holland Scientific (Lincoln, NE, USA)	Reflectance (active)	670, 730, 780	Canopy
	Crop Circle ACS 470	Holland Scientific (Lincoln, NE, USA)	Reflectance (active)	450, 550, 650, 670, 730, 760	Canopy
	RapidScan CS-45	Holland Scientific (Lincoln, NE, USA)	Reflectance (active)	670, 730, 780	Canopy
	GreenSeeker	Trimble Inc. (Sunnyvale, CA, USA)	Reflectance (active)	650, 770	Canopy
	GreenSeeker Handheld	Trimble Inc. (Sunnyvale, CA, USA)	Reflectance (active)	660, 780	Canopy
Flavonols meter	DUALEX	Force-A (Orsay, France)	Fluorescence	375, 650	Leaf
	MULTIPLEX	Force-A (Orsay, France)	Fluorescence	590, 735, 985	Leaf

† Trade or manufacturers' names mentioned are for information only and do not constitute endorsement, recommendation, or exclusion. ‡ Active or passive refers to whether the sensor is fitted or not with an own light source, respectively.

Commercial sensors: on-the-go (variable rate application)

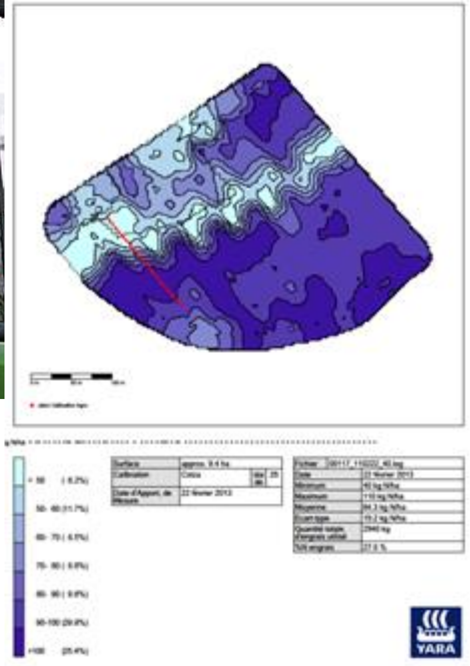
AUTOMATIC SPOT SPRAY SYSTEM

The system senses if a weed is present and signals a spray nozzle to deliver a precise amount of chemical — spraying only the weed and not the bare ground

AUTOMATIC SPOT SPRAY SYSTEM

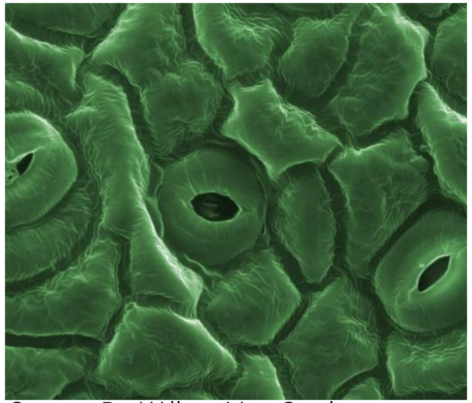
The system uses optical sensors to measure and quantify crop health—or vigor, and address field variability by applying the right amount of fertilizer, in the right place, at the right time.

Commercial sensors: on-the-go (variable rate application)



Water Stress Index (WSI): Canopy Thermography

$$CWSI = \frac{Tleaf - Twet}{Tdry - Twet}$$



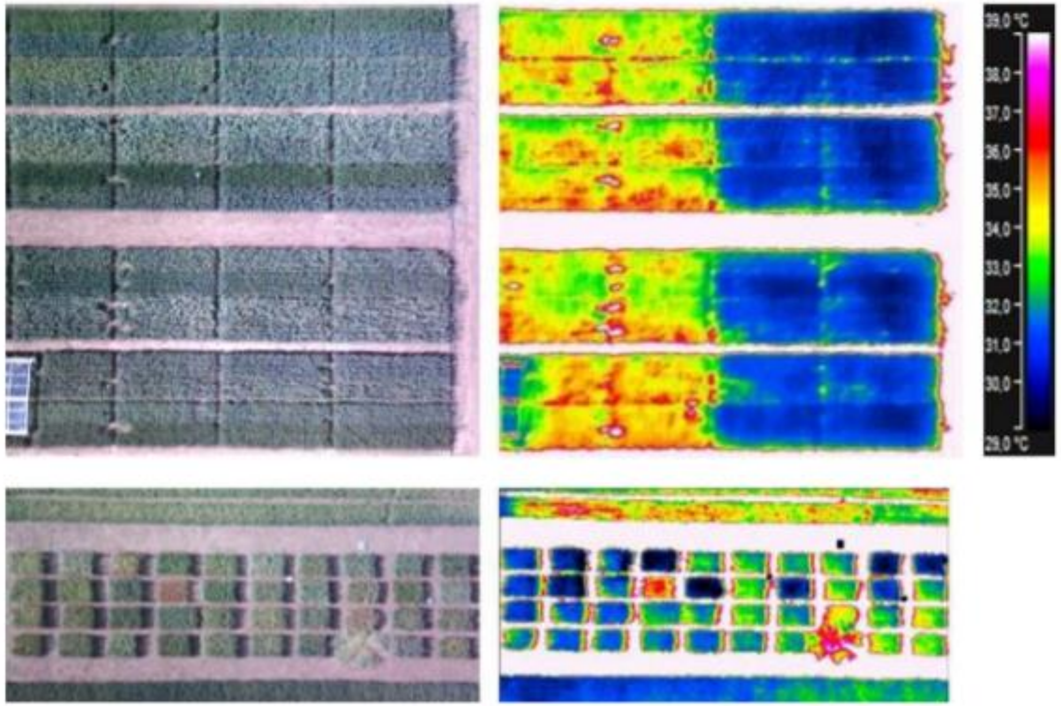
Source: Dr. Willem Van Cotthem, Ghent University (Belgium)

WORKSWELL

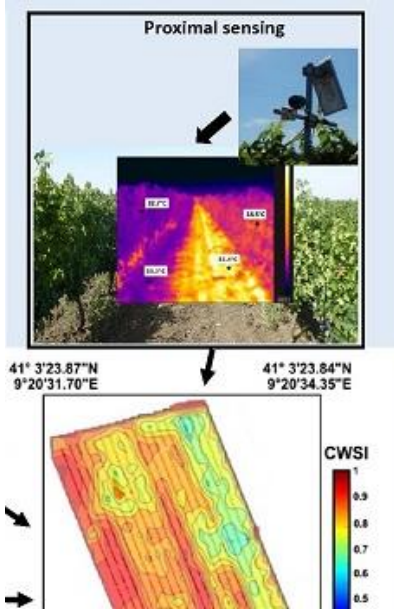
Remote sensing

Water stress (stomata closed)

Optimum water content (stomata open)



Proximal sensing



References

- Carter, G. A., and Knapp, A. K. (2001). Leaf optical properties in higher plants: Linking spectral characteristics to stress and chlorophyll concentration. *American Journal of Botany* **88**, 677-684.
- Guilioni, L., Jones, H. G., Leinonen, I., and Lhomme, J. P. (2008). On the relationships between stomatal resistance and leaf temperatures in thermography. *Agricultural and Forest Meteorology* **148**, 1908-1912.
- Matese, A., Baraldi, R., Berton, A., Cesaraccio, C., Di Gennaro, S. F., Duce, P., Facini, O., Mameli, M. G., Piga, A., and Zaldei, A. (2018). Estimation of Water Stress in Grapevines Using Proximal and Remote Sensing Methods. *Remote Sensing* **10**, 114.
- Oerke, E.-C., Mahlein, A.-K., and Steiner, U. (2014). Proximal Sensing of Plant Diseases. *In* "Detection and Diagnostics of Plant Pathogens" (M. L. Gullino and P. J. M. Bonants, eds.), pp. 55-68. Springer Netherlands, Dordrecht.
- Padilla, F. M., Gallardo, M., Peña-Fleitas, M. T., De Souza, R., and Thompson, R. B. (2018). Proximal Optical Sensors for Nitrogen Management of Vegetable Crops: A Review. *Sensors* **18**, 2083.