Concepts and theory: Spectral reflectance, canopy temperature and chlorophyll content

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Water status projected to 2025 at Mediterranean area basin (adapted from IWMI, 2000).
Bring durable **improvement in agricultural water management and economic development** of six Mediterranean areas in the context of adaptation to climate change, increasing water scarcity, and desertification risk.

Adapted from IWMI, 2000.
ACLIMAS – How?

WP1 – STARTUP
Offices/ Stations; Demonstration fields
Varieties * Management; Equipment

WP2 – DEMONSTRATION
Genotypes; Irrigation;
Conservation tillage; Nitrogen

WP3 – IMPLEMENTATION
Best performing genotypes; water
and management practices

WP4 – SUSTAINABILITY
Economical; Social;
Environmental

WP5 – TRAINING AND DISSEMINATION
Courses; Field days; Brochures;
Guidelines; Videos, Website

http://www.aclimas.eu/
ACLIMAS – http://www.aclimas.eu/

هو مشروع تطبيقي تمويله من قبل الاتحاد الأوروبي (ACCLIMAS)، ويدعى (ACCLIMAS) للإطار المتواصل المستدام لمناخ الموفرة الأمور. يركز المشروع على التغير المناخي، من خلال تجريب ستة بلدان من حوض البحر الأبيض المتوسط سبع مناطق مستندات احترافية في تطبيق التحديات المستدامة. أطراف المشروع تشمل الموارد المائية والنظم البيئية والاقتصادية، والتحديات الاجتماعية في المنطقة، والتحديات الاجتماعية في المنطقة. يتيح المشروع تحسينات في نظام البحر الأبيض المتوسط، وزيادة تنوع الحياة البحرية، ويدعم مبادرات التحول إلى النظم المستدامة في سياق التكيف مع تغير المناخ، وزيادة شعور المياه البحرية. نهجاً كليباً للمشروع يعتمد على التخصصات (ACLIMAS)، ومخاطر التصحر. ينتج وعاء المحدود، الذي يجمع مجموعة من الفئات المحلية للتكيف مع العوامل المائية، مع بعض المعلومات عن "الكليماس". 

بعض المعلومات عن "الكليماس"
Canopy sensors

**Greenseeker® 505 Handheld**
(NTech Industries, Inc.)

**SPAD-502Plus** (Konica Minolta)
Chlorophyll content

**Infrared Thermometer INF151** (UEI)
Canopy temperature

**NDVI**

**Visual Senescence Scoring**
Stay-green

*Senescence scoring*

0 1 2 3 4 5 6 7 8 9 10
• Help to interpret the results:
  – Explain yield variation (across sites and seasons),
  – Quantify the impact of drought on yield (pre-/ post-anthesis water use).

• Help to optimise inputs to the expected yield:
  – Optimize water use;
  – Fine tune N application.

• Link physiology to a predicted Ideotype.

• Better demonstrate to the farmers.
Radiation

Canopy Spectral Reflectance

Greenseeker HandHeld

- Incident radiation
- Absorbed
- Transmitted
- Reflected
Influenced by the canopy optical properties

**Leaf level:**
- Pigments,
- Proteins,
- Cell Walls,
- Leaf cuticles,
- Lignin,
- Cellulose,
- Sugars,
- Starch,
- Water, etc.

**Canopy level:**
- Leaf Area Index (LAI),
- Leaf angles,
- Plant height.

**Physical & Environment:**
- Soil (not dense foliage),
- Latitude & Longitude,
- Season & time,
- Clouds,
- Wind.

<table>
<thead>
<tr>
<th>Index</th>
<th>Name</th>
<th>Physiological process</th>
<th>Type</th>
<th>Calculation</th>
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</thead>
<tbody>
<tr>
<td>NDVI</td>
<td>Normalized difference vegetation index</td>
<td>Green area, photosynthetic capacity, N status</td>
<td>VI</td>
<td>([R_{900} - R_{680}] / [R_{900} + R_{680}])</td>
</tr>
<tr>
<td>R-NDVI</td>
<td>Red normalized difference vegetation index</td>
<td>Green area, photosynthetic capacity, N status</td>
<td>VI</td>
<td>([R_{780} - R_{670}] / [R_{780} + R_{670}])</td>
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<tr>
<td>G-NDVI</td>
<td>Green normalized difference vegetation index</td>
<td>Green area, photosynthetic capacity, N status</td>
<td>VI</td>
<td>([R_{780} - R_{550}] / [R_{780} + R_{550}])</td>
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<tr>
<td>SRa</td>
<td>Simple Ratio</td>
<td>Green biomass</td>
<td>VI</td>
<td>([R_{800} / R_{680}] ) and ([R_{900} / R_{680}])</td>
</tr>
<tr>
<td>RARS_a</td>
<td>Ratio analysis of reflectance spectra chlorophyll a</td>
<td>Chlorophyll a content</td>
<td>PI</td>
<td>([R_{675} / R_{700}])</td>
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<tr>
<td>RARS_b</td>
<td>Ratio analysis of reflectance spectra chlorophyll b</td>
<td>Chlorophyll b content</td>
<td>PI</td>
<td>([R_{675} / (R_{650} \times R_{700})])</td>
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<tr>
<td>RARS_c</td>
<td>Ratio analysis of reflectance spectra carotenoid</td>
<td>Carotenoid content</td>
<td>PI</td>
<td>([R_{700} / R_{500}])</td>
</tr>
<tr>
<td>NPI</td>
<td>Normalized pheophytinization index</td>
<td>Normal chlorophyll degradation; can be used to estimate phenology, pests and diseases</td>
<td>PI</td>
<td>([R_{415} - R_{435}] / [R_{415} + R_{435}])</td>
</tr>
<tr>
<td>SIPI S</td>
<td>Structural independent pigment index</td>
<td>Senescence related to stress</td>
<td>PI</td>
<td>([R_{800} - R_{435}] / [R_{415} + R_{435}])</td>
</tr>
<tr>
<td>PRI</td>
<td>Photochemical reflectance index WI Water index</td>
<td>Dissipation of excess radiation</td>
<td>PI</td>
<td>([R_{531} - R_{570}] / [R_{531} + R_{570}])</td>
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<tr>
<td>WI</td>
<td>Water index</td>
<td>Plant water status</td>
<td>WI</td>
<td>([R_{970} / R_{900}])</td>
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<td>NWI-1</td>
<td>Normalized water index 1</td>
<td>Plant water status</td>
<td>WI</td>
<td>([R_{970} - R_{900}] / [R_{970} + R_{900}])</td>
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<td>NWI-2</td>
<td>Normalized water index 2</td>
<td>Plant water status</td>
<td>WI</td>
<td>([R_{970} - R_{850}] / [R_{970} + R_{850}])</td>
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<td>Normalized water index 3</td>
<td>Plant water status</td>
<td>WI</td>
<td>([R_{970} - R_{880}] / [R_{970} + R_{880}])</td>
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<td>NWI-4</td>
<td>Normalized water index 4</td>
<td>Plant water status</td>
<td>WI</td>
<td>([R_{970} - R_{920}] / [R_{970} + R_{920}])</td>
</tr>
</tbody>
</table>

Normalized Difference Vegetation Index (NDVI)

\[
NDVI = \frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}} = \frac{R_{900} - R_{680}}{R_{900} + R_{680}}
\]

- Green area
- Photosynthetic capacity
- N status

Canopy size/ Vegetative greenness:
- Ground cover
- Pre-anthesis biomass
- Nitrogen content
- Senescence/ Stay-green
- Yield

Advantages
- Active NDVI
  ("independent of light conditions")
- Integrative
- Non-destructive
- Quick

Disadvantages
- Training needed
- Saturation of NDVI
  (may begin at LAI = 1, insensitive to changes > 2)
Glasshouse pot experiment:
- 4 Durum wheat genotypes;
- 3 Water treatments (well watered, intermediate and severe water stress);
- Low and high N;
- NDVI at stem extension and anthesis.

**ANOVA**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Above Ground DW</th>
<th>Total Green Area</th>
<th>Above Ground N</th>
<th>NDVI&lt;sub&gt;Anthesis&lt;/sub&gt;</th>
<th>NDVI&lt;sub&gt;StemExtension&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Regime (WR)</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
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<tr>
<td>Nitrogen Supply (NS)</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Genotype (G)</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>WR x NS</td>
<td>***</td>
<td>ns</td>
<td>***</td>
<td>***</td>
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</tr>
<tr>
<td>WR x G</td>
<td>***</td>
<td>ns</td>
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<td>NS x G</td>
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<td>ns</td>
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</tr>
<tr>
<td>WR x NS x G</td>
<td>ns</td>
<td>ns</td>
<td>**</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

**Biomass**

- $AGDW = 85.5$ NDVI - 2.5
  - $R^2 = 0.87^{***}$

**Green Area**

- $TGA = 2.5$ NDVI - 0.06
  - $R^2 = 0.79^{***}$

**N**

- $AGN = 2.92$ NDVI - 0.18
  - $R^2 = 0.85^{***}$

Estimation of GAI Biomass of Wheat and Barley up to Anthesis (Western Australia - 1992)

Durum wheat grown on Low and High N levels (Southern Italy - 2006)

**GY vs NDVI**

\[ GY = 1.76e^{1.59 \times NDVI} \]
\[ R^2 = 0.70^{**} \]

NDVI measurements 2 weeks after anthesis, 5 samples = 100 readings plot\(^{-1}\).

Effects of crop management techniques on Growth and Senescence (Central Mexico - 2006)


6 Muted Wheat lines screened for fast and slow canopy senescence under low and high N (Glasshouse)

Chlorophyll Content

Chlorophyll extracted with acetone

Wikipedia (http://www.wikipedia.org/)

Adapted from: Plants in Action (http://plantsinaction.science.uq.au/)
SPAD Measuring Principle

**Illuminating System**

**Sample**

**Receptors**

**Amplifier**

**A/D converter**

**Microprocessor**

**Display**

**Keys**

SPAD-502Plus (Konica Minolta)
Advantages

• **Active** (“independent of light conditions”)
• **“Cheap”**
• **Quick/ Easy**

Disadvantages

• **Point measurement only:**

Chlorophyll content of green tissues:

• Photosynthetic potential
• Effects of drought
• Nutrient deficiency
• Senescence/ Stay-green

SPAD

Chlorophyll content of green tissues:
Chlorophyll content and SPAD (Sweden - 1999)
- 2 Wheat genotypes;
- leaves at different development stages (including premature, fully mature and senescent leaves)

**Dragon:** \( \text{Chl} = 0.467 \ e^{0.0416 \ \text{SPAD}}, \ R^2 = 0.81 \)

**Lantvete:** \( \text{Chl} = 0.435 \ e^{0.0455 \ \text{SPAD}}, \ R^2 = 0.85 \)

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**SPAD and Photosynthesis (Anthesis)** (Glasshouse 2007)
- Barley cv. Rum
- Irrigated and drought
- 3 N levels: 0, 50 & 100 Kg N ha\(^{-1}\)
Durum wheat grown on Low and High N levels
(Southern Italy - 2006)

GY vs SPAD

Flag leave SPAD measurements 2 weeks after anthesis, 3 readings per plot.

Wheat grown on seven N levels (South East, UK – 8 seasons from 1993-2001)

6 Muted Wheat lines screened for fast and slow canopy senescence under low and high N (Glasshouse)

Mutant lines with a range of flowering and physiological maturity dates.

Surface temperature of the canopy is related to transpiration – Evaporative cooling

Infrared Thermometer

- Measure the energy (E) emitted by a surface.
- \( E = \varepsilon \sigma T^4 \) (Stefan’s Law), where:
  \( \sigma = 5.68 \times 10^{-8} \) Joules m\(^{-2}\) s\(^{-1}\) (Stefan-Boltzmann constant) and
  \( \varepsilon = \) “emittance efficiency factor” (plants 0.95 – 0.98).
Canopy Temperature

IRT

Canopy Temperature/ Temperature Depression

\[ CTD \ (°C) = T_{air} - T_{canopy} \]

- Stomatal conductance
- Plant water status
- Rooting
- Yield

Advantages

- Integrative
- Non-destructive
- Quick/ Easy
- “Cheap”

Disadvantages

- Very susceptible to environmental conditions:
  Needs cloudless sunny conditions and interacts with time of the day.
Canopy temperature – Yield

Wheat Genotypes NW Mexico 2011

Canopy temperature – Drought Susceptibility

Drought Susceptibility Index

\[ S_{\text{yield}} = \frac{(1 - \text{Yield}_{\text{drought}}/\text{Yield}_{\text{irrigation}})/(1 - \text{X}_{\text{drought}}/\text{X}_{\text{irrigation}})}{X_{\text{yield}} \text{ for all genotypes}} \]

\[ S_{\text{biomass}} = \frac{(1 - \text{Biomass}_{\text{drought}}/\text{Biomass}_{\text{irrigation}})/(1 - \text{Z}_{\text{drought}}/\text{Z}_{\text{irrigation}})}{Z_{\text{biomass}} \text{ for all genotypes}} \]

Evaluation of 15 Wheat landraces and 2 improved cultivars
(Israel in 1986/87 – 1987/88)

- Rainout shelter
- Drought and Full irrigation
- Canopy temperature measured weekly, better correlations when the stress was higher.

Evaluation of Wheat genotypes to drought (NW Mexico 2006 and 2007)

- Drought and Irrigated treatments
- 8 genotypes

Canopy Temperature Depression

$$\text{CTD (°C)} = T_{\text{air}} - T_{\text{canopy}}$$

Evaluation of 8 wheat Cultivars (NW Mexico)
- Hot, Irrigated conditions
- Grain Yield 1990 – 1995
- Stomatal Conductance 1993 – 1995
- CTD 1993 – 1995

Evaluation of 16 wheat Cultivars
(Mexico, Egypt, India, Sudan and Brazil in 1990/91 – 1991/92)
• Yield on the 5 sites
• CTD measured in Mexico
(before and after irrigation when canopy cover was before and in 1992/93)
• Average photosynthetic rate of flag leaves measured in Mexico
(flag leaves at booting, anthesis and grain filling in 1991/92)

Fitting the senescence data

\[ \text{score} = p_0 + p_1 \times (1 - \exp((-p_2 \times \text{STA}/ p_1)) + (10 - p_1 - p_0/ (1 + \exp(-4 \times p_3 \times (\text{STA} - p_4)/ (10 - p_1 - p_0))) \]

**Score**: visual senescence score  
**STA**: thermal time after anthesis (°C days)  
**p0**: score at anthesis  
**p1**: score at the end of the slow phase  
**p2**: maximum rate of the slow phase  
**p3**: maximum rate at rapid phase ($\text{Sen}_{Rate}$)  
**p4**: date at which **p3** is reached.  
**Sen\text{Onset}**: onset of senescing phase date.  
**Stay-green** associated with **Sen\text{Onset}** and **Sen_{Rate}**
Visual Senescence Scoring

Photosynthetic Area
- Light interception
- Photosynthetic performance
- Transpiration surface
- Crop biomass and yields

Advantages
- Non-destructive
- “Cheap”
- Quick/Easy
- “Precise”

Disadvantages
- Subjective to user errors
- Time consuming
Wheat (Cap Horn) High N
(Glasshouse - 2006)

Green Leaf vs SPAD

% Green Leaf vs SPAD

% Green Leaf = -0.77 + 3.4 x SPAD - 0.029 x SPAD²
R² = 0.97
Onset of post-anthesis Senescence (2006/7 and 2007/8)

- 16 Wheat cultivars;
- 4 sites:
  Sutton Bonington and Norwich, UK; Estrées-Mons and Clermont-Ferrand, France.

Fig. 7. Linear regression amongst 16 cultivars in low N treatment of onset of post-anthesis senescence (SEN$_{ONSET}$) in thermal time (base temp. 0°C) after anthesis (GS61) on (a) N-utilization efficiency (kg grain DM per kg above-ground N (AGN) at harvest); (♦) Clermont-Ferrand $R^2 = 0.09$; (×) Estrées Mons $y = 0.08x + 13.06$; $R^2 = 0.32$; $P < 0.05$; (□) Norwich $y = 0.08 + 24.27$; $R^2 = 0.50$, $P < 0.001$; (△) Sutton Bonington $y = 0.05x + 31.14$, $R^2 = 0.70$, $P < 0.01$ and (b) grain yield (0% moisture content); (♦) Clermont-Ferrand $y = 0.002x + 4.01$; $R^2 = 0.25$, $P = 0.05$; (×) Estrées-Mons $y = 0.01x + 1.56$, $R^2 = 0.55$; $P < 0.01$; (□) Norwich $R^2 = 0.11$; (△) Sutton Bonington $y = 0.01x + 4.58$, $R^2 = 0.38$, $P < 0.05$. Values represent means in 2007–8.