Phenotyping the Response of an Apple Tree Hybrid Population to Soil Water Constraint under Field Conditions: New Insights Brought by High Resolution Imaging

VIRLET N.\(^1a\), LEBOURGEOIS V.\(^2a\), MARTINEZ S.\(^1b\), LABBÉ S.\(^2b\), COSTES E.\(^1b\), REGNARD J.L.\(^1a,\)$

\(^1a\) Montpellier SupAgro, UMR AGAP 1334, TA-A-108/03, Av. Agropolis, 34398 Montpellier Cedex 5, France
\(^1b\) INRA, UMR AGAP 1334, TA-A-108/03, Av. Agropolis, 34398 Montpellier Cedex 5, France
\(^2a\) CIRAD, UMR TETIS, Station Ligne-Paradis, 7 chemin de l’IRAT, 97410 Saint-Pierre, France
\(^2b\) IRSTEA, UMR TETIS, Remote Sensing Center, 500 rue J.F. Breton, 34093 Montpellier Cedex 5, France

$: presenting author (regnard@supagro.inra.fr)
Context

- Global changes → new traits for fruit breeding
- Transpiration behavior of apple → genetic variability of response to a water constraint
- High-throughput genetic/genomic data → high-throughput phenotyping methodology

Estimation of leaf transpiration by thermal infrared:

- Usually used for irrigation scheduling via water stress indices: Crop Water Stress Index (CWSI) (Idso et al., 1981; Jackson et al., 1981)
  - based on difference between leaf surface and air T° (T_s - T_a) and its variation
  - continuous cover
  - semi-arid and arid conditions

- CWSI also used as indicator of plant water status in annual crops
  - \( g_s \) estimation through \( I_g \) index: \( I_g = (T_{dry} - T_{leaf}) / (T_{leaf} - T_{wet}) \) (Jones et al., 1999, 2009)
  - mapping \( \Psi_{leaf} \) from CWSI (Alchantis et al., 2010)

Moran et al. (1994): Water Deficit Index (WDI), through adaptation of CWSI
- based on relation between (T_s - T_a) and the NDVI vegetation index
  - applicable to discontinuous cover
  - empirical estimation: \( WDI_e = (T_s - T_{min}) / (T_{max} - T_{min}) = 1 - E_{act} / E_{max} \) (Clarke, 1997)
Objectives - Hypotheses

Use of multispectral imaging for phenotyping an apple hybrid population (mature trees) under water constraint applied in field conditions

Study based on:
- Airborne high-resolution image acquisition in RGB, NIR and TIR (Lebourgeois et al., 2008; Avion Jaune®)
- Estimation of tree transpiration rate through foliage temperature
- Vegetation index: adapted T° (TIR image) at the nature of transpiring surface
- Applying WDI at tree scale, sensitivity of this index to genotypic differences

Hypotheses:

→ Relevant and sensible method for characterizing the stomatal response of hybrids to water stress

→ Ability to reveal apple genetic variability for this trait (disentangling isohydric vs anisohydric behaviors)
  
  (e.g. grapevine: Schulze, 2003; Soar et al., 2006)
Experimental approach: field set-up

1. Location
INRA-Diaphen Melgueil expr farm
(43°36’ N, 3°58’ E)

2. Field set-up
- 488 apple trees
- 122 hybrids (Starkrimson * Granny Smith progeny) / M9 rootstock
- 2 parents
- 10 rows
- 2 seasonal water treatments: S, NS (Stressed, Non Stressed)
- 2 tree replicates per genotype & treatment

3. Orchard management
Micro-meteorology
• Global radiation, direct & diffuse PPFD,
• Soil & air T°, air RH
• Wind speed
• Rainfall

Soil
• Soil water content (Sentek™ capacitive sensors)
• Soil water potential (Watermark™ probes)
Experimental approach

1. 2010 campaign image acquisition

Acquisition system:
- Visible (RGB)
- Near Infrared (NIR)
- Thermal Infrared (TIR)

Soil device:
- 9 geolocation targets (image superposition)
- 1 « hot » target
- 1 « cold » target

Atmospheric correction

Aluminium targets (for TIR images geolocation)

3 ULA flights
- July 16: low water constraint
- August 3: moderate water constraint
- August 17: severe water constraint

Airborne image acquisition between 350 and 480m altitude

11h30-12h00
10h-11h
Experimental approach: water stress scheduling
Experimental approach: Image processing

1. Acquisition of 5 channels

Visible: - blue: ~450 nm
   - green: ~550 nm
   - red (R): ~670 nm
Near Infrared (NIR): ~745nm
Thermal Infrared (TIR): 8-14μm
Experimental approach: Image processing

1. Acquisition of 5 channels

Visible: - blue: ~450 nm
- green: ~550 nm
- red (R): ~670 nm
Near Infrared (NIR): ~745nm
Thermal Infrared (TIR): 8-14µm
2. Water Deficit Index Computation

- \( \text{NDVI} = \frac{(\text{NIR} - \text{R})}{(\text{NIR} + \text{R})} \)
- \( (T_s - T_a) \): difference between surface and air temperature
- pixels plotted according to NDVI and \( T_s - T_a \)

- Scatterplot delimited by quantile regression

- Equations of the 2 oblique lines permit computation of WDI

\[
\text{WDI} = \frac{(T_s - T_a) - (T_s - T_{a\text{min}})}{(T_s - T_{a\text{max}} - (T_s - T_{a\text{min}})} = 1 - \frac{\text{ET}_{\text{act}}}{\text{ET}_{\text{max}}} = \frac{\text{AC}}{\text{AB}}
\]

WDI index varies from 0 (well-watered tree) to 1 (severely stressed)
3. Water Deficit Index Computation:

Each tree delimited by a 60 cm radius buffer zone

- 3*3 to 5*5 cm resolution for NDVI image
- 30*30 cm resolution for TIR image

Performed on Erdas Imagine® software

- NDVI and $T_s - T_a$ values of each individual pixel $\rightarrow$ WDI values
- avg. NDVI & $T_s - T_a$ values per tree in buffer zone $\rightarrow$ avg. tree WDI value
Results

1. NDVI, Ts – Ta and WDI, 3 dates

<table>
<thead>
<tr>
<th>Effect</th>
<th>NDVI</th>
<th>Ts-Ta</th>
<th>WDI</th>
<th>NDVI</th>
<th>Ts-Ta</th>
<th>WDI</th>
<th>NDVI</th>
<th>Ts-Ta</th>
<th>WDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genotype</td>
<td>3.6</td>
<td>&lt;10^{-15}</td>
<td>2</td>
<td>1.8</td>
<td>&lt;10^{-4}</td>
<td>1.1</td>
<td>n.s.</td>
<td>1.9</td>
<td>&lt;10^{-4}</td>
</tr>
<tr>
<td>Drought</td>
<td>0.6</td>
<td>n.s.</td>
<td>307</td>
<td>15</td>
<td>&lt;10^{-3}</td>
<td>902</td>
<td>&lt;10^{-15}</td>
<td>775</td>
<td>&lt;10^{-15}</td>
</tr>
<tr>
<td>G * D</td>
<td>0.9</td>
<td>n.s.</td>
<td>0.5</td>
<td>0.9</td>
<td>n.s.</td>
<td>0.5</td>
<td>n.s.</td>
<td>0.5</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

- Genotypic effect on WDI although less effect on Ts - Ta
- Strong drought effect on most stress indices
- Additive effects of Genotype and Drought
- Relationships between soil moisture, tree water status and WDI (not shown)
Discussion

1 - Pixel resolution of TIR images
1 pixel in thermal domain # 36 to 100 pixels in visible domain
Resolution to be increased to distinguish well exposed & shadow leaves, soil & branches

Use of Unmanned Aerial Vehicle (UAV) to increase resolution of TIR image (6 to 10 cm)

2 - Delineating most appropriate foliage zone for each tree
60 cm buffer method: more soil “top-viewed” for smaller trees
→ Taking a larger interest zone
→ NDVI value thresholding to disentangle soil vs vegetation and delimitate tree foliage

3 - Genetic analysis to be performed :
• Apple tree behavior,
• Genetic determinants of transpiration
Conclusions and prospects

On-going Nicolas Virlet’s PhD work (2010-13)

2011 campaign: currently analyzed; image pipeline analysis undertaken

2012: image and field acquisition just running ... with an UAV Oktokopter®

Apple tree behavior under water constraint

- Genotypic differences mostly revealed at the beginning of water stress application
- UAV regular flights → dynamic response of each tree to increasing stress
- Analysis of time series: disentangling isohydric vs anisohydric behaviors
Acknowledgements

N. Virlet PhD scholarship: SupAgro & Telerieg

Program financial support: SupAgro, INRA & Telerieg

Partners

AGAP-PAM Team
D. Fabre

L’Avion Jaune Team
M. Assenbaum
M. Houlès
B. Roux

Remote Sensing Center
A. Bégué
A. Jolivot

Diascope expl Unit & DiaPhen platform
M. Delalande
S. Féral
F. Meunier