What are the impacts of tree shade on the absorption of light by grapevine in alley-cropped vineyards?

Juliette GRIMALDI\textsuperscript{1,2} juliette.grimaldi@inra.fr, Yingjie WANG\textsuperscript{2}, Jean-Philippe GASTELLIU-ETCHEGORRY\textsuperscript{2}, Eric CHAVANON\textsuperscript{2}, Nicolas LAURET\textsuperscript{2}, Jordan GUILLEUX\textsuperscript{2}, Vincent BUSTILLO\textsuperscript{2}, Thomas HOUET\textsuperscript{3}

1. INRA UMR System, Montpellier, France
2. CESBIO, Toulouse, France
3. LETG-Rennes COSTEL - CNRS, Rennes, France

Financial support
Fondation de France and CASDAR Vitiforest
Introduction
Modern forms of agroforestry vineyards
Modern forms of agroforestry vineyards

What are the microclimatic impacts from trees?
Main mechanisms at stakes

**Shading**
- Direct sunlight incoming radiations
- Diffuse incoming radiations
- Insolation, heat

**Sheltering**
- Wind
- Shaded zone

**Water budget modifications**
- Rainfalls
- Canopy interception & evaporation
- Transpiration
- Through-fall
- Stem-flow
- Ground evaporation
- Root uptakes
- Modified water storage capacity
- Hydraulic lift
Main mechanisms at stakes

Shading

- Direct sunlight incoming radiations
- Insolation
- Heat

Canopy interception & evaporation

Transpiration

Ground evaporation

Through-fall

Stem-flow

Root uptakes

Modified water storage capacity

Hydraulic lift

Impacts on grapevine energy and water budgets

Sheltering

Water budget modifications

- Rainfalls
- Canopy interception & evaporation
- Transpiration
- Through-fall
- Stem-flow
- Ground evaporation
- Runoff interception & infiltration
- Modified water storage capacity
- Hydraulic lift

Direct sunlight
- Incoming radiations

Insolation

Heat

Diffuse incoming radiations

Shading

P.A.R

Transpiration

Available water

Wind

T_vine
day/night

RH

T_ave

T_ground

ATMOSPHERE

VEGETATION

GROUND

de la Trois types de mécanismes engendrés par les arbres…

Impacts on grapevine energy and water budgets
Main mechanisms at stakes

Shading

- Direct sunlight incoming radiations
  - Insolation
  - Heat
  - Shading

SHELTERING

- Wind
- Shaded zone
- Sheltered zone

Water budget modifications

- Rainfalls
- Canopy interception & evaporation
- Transpiration
- Through-fall
- Stem-flow
- Root uptakes
- Modified water storage capacity
- Hydraulic lift

Impacts on grapevine energy and water budgets

- P.A.R
- Transpiration
- Available water
- Wind
- T_{air}
- T_{ground}
- RH

Yield

Berry quality for wine making

- Direct sunlight incoming radiations
- Diffuse incoming radiations
- Insolation
- Heat
- Shading

Sheltering zone

- Sheltered zone
- Insolation
- Heat
- Shading

Yield

Berry quality for wine making
Research questions

→ Impacts of trees on grapevine light absorption?

→ Variability according to vegetation structure?

→ Variability according to meteorological context?
Material and methods
<table>
<thead>
<tr>
<th>Model</th>
<th>Vegetation modeling</th>
<th>Light modeling, scattering and light extinction (LE) computation</th>
<th>Model outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light partitioning method from Wallace (1995) (Annex A)</td>
<td>Canopies: 1D medium filled with mixed canopies. It is characterized by the LAI of each canopy component</td>
<td>LE: Beer’s Law</td>
<td>Fraction of light available at the top of each canopy component</td>
</tr>
<tr>
<td>The simple model of light interception by discontinuous canopies of</td>
<td>Trees: cone / ball / parallelepiped canopies</td>
<td>Light: Global incoming radiation</td>
<td>Fraction of the incoming light available at ground level over a given period of time (1D time integrated budget)</td>
</tr>
<tr>
<td>Jackson and Palmer (1979)</td>
<td>Crop: none</td>
<td>LE: Beer’s law</td>
<td></td>
</tr>
<tr>
<td>Gap Light Analyzer GLA (Frazer et al. 1999)</td>
<td>Trees: Hemispherical images of tree canopies</td>
<td>Light: Global radiation including a diffuse fraction</td>
<td>1/ amount of above-and below-canopy (transmitted) direct, diffuse, and total solar radiation incident on a horizontal or arbitrarily inclined surface</td>
</tr>
<tr>
<td></td>
<td>Landscape: Horizontal layers subdivided in 3D cells</td>
<td>LE: Empirical equation of intercepted PAR according to the gap fraction in the canopy images, the global incident radiation and the cloudiness factor</td>
<td>2/ sunfleck-frequency distribution and daily duration</td>
</tr>
<tr>
<td>Light module in WaNuLCAS agroforestry model (Van Noordwijk and Lusiana 1998; Noordwijk et al. 2004)</td>
<td>Canopies: All the cells in a given layer are defined by a AD for each type of canopy components (tree leaves, crop leaves, woody parts)</td>
<td>Light: Direct light only</td>
<td>Absorbed PAR per horizontal layer of vegetation and per vegetation type (tree/crop)</td>
</tr>
<tr>
<td>Hybrid model which was actually used for the first time in ‘gap models’ FORSKA model (Prentice and Leemans 1990)</td>
<td>Landscape: 3D array of cells. Trees: ellipsoid turbid medium</td>
<td>Light: Global radiation from a standard overcast sky model</td>
<td>Absorbed PAR in each 3D cell of tree canopy or crop. (pseudo 3D instantaneous budget)</td>
</tr>
<tr>
<td></td>
<td>Crop: homogeneous understory turbid layer. Discontinuities in the crop canopy (i.e. sparse canopies) are managed considering the individual plant shade area (m²), the individual plant leaf area (m²) and the plant density (plants m⁻²)</td>
<td>Scattering: One order of scattering from the canopy external envelop (albedo)</td>
<td></td>
</tr>
<tr>
<td>RATP model (Radiation, Absorption, Transpiration and Photosynthesis) of Sinoquet et al. (2001), initially developed by Sinoquet and Bonhomme (1992) and modified by Meloni and Sinoquet (1997) to consider three-dimensional heterogeneous canopies</td>
<td>Landscape: 3D array of cells. Canopies: Each cell can contain several canopy components (various types of leaves, woody parts, fruits), and is characterized by the AD of every component in the cell</td>
<td>Light: discrete beams from direct and diffuse sources</td>
<td>Intercepted PAR flux for each plant component type in each voxel (3D instantaneous budget)</td>
</tr>
<tr>
<td>DART (Discrete Anisotropic Radiative Transfer) (Gastellu-Etchegorry et al. 1996, 2012)</td>
<td>Landscape: 3D array of cells including atmosphere layers</td>
<td>Flux tracking: radiosities method</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Canopies: same as RATP and/or ensemble or accurate planar 3D objects with optical properties</td>
<td>LE: Equation of radiative transfer applied in each cell.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Light: discrete beams from direct and diffuse sources</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DART: The Discrete Anisotropic Radiative Transfert model

- Developed at CESBIO since 1996
- Physical based model
  - radiative budget
  - remotely sensed images
- 3D modeling of heterogeneous and complex landscapes
- Free academic licences:
  - http://www.cesbio.ups-tlse.fr/dart/#/
- Graphical interface (GUI) and python scripts
Study site: an agroforestry vineyard in south-western France
Study site: an agroforestry vineyard in south-western France

\[d_{\text{trees}}: 10 \text{ m} \times 20 \text{ m}\]
\[d_{\text{vines}}: 1 \text{ m} \times 2.5 \text{ m}\]
\[d_{\text{w/t}}: 3.25 \text{ m}\]
Orientation : NW/SE

Sorbus domestica

Sorbus domestica

Pyrus pyraster
Building 3D landscape mock-ups including realistic vegetation cover and topography

Lagardère (32)

monocropped zone

zone in agroforestry

Land cover maps
- Grass
- Bare ground
- Grapevine
- Tree row 1
- Tree row 2
- Tree row 3

Terrain model
Five arrangements of vegetation

Lagardère (current)

- Orientation NW/SE

H = 3.9 m
H = 7.7 m
H = 8.2 m
Five arrangements of vegetation

Lagardère future

- Orientation NW/SE
- Orientation N/S

H = 7 m
H = 13.7 m
H = 15.4 m
Five arrangements of vegetation

Lagardère without trees

- Orientation NW/SE (current)
- Orientation N/S
Methodological challenge #1:
Properties of tree and vine canopies
Methodological challenge #1: Properties of tree and vine canopies

Tree morphology

(a) turbid canopy

(b) cloud of triangles

(c) exact 3D objects

RAMI4 database - Wildoski J-L, etal. (2011)
doi: 10.1029/2010JG001511
Methodological challenge #1: Properties of tree and vine canopies

Tree morphology

Grapevine morphology

(a) turbid canopy  (b) cloud of triangles  (c) exact 3D objects

H_{spring} = 0.5 m
H_{summer} = 1 m

RAMI4 database - Wildoski J-L, etal. (2011)
doi: 10.1029/2010JG001511
Methodological challenge #2: Simulation of a realistic time serie of cloud cover
Methodological challenge #2: Simulation of a realistic time serie of cloud cover

\[
SKYL = \frac{E_{BOA}^{\text{diff}}}{E_{BOA}^{\text{tot}}} = \frac{\"\text{sky (atmosphere) irradiance}\"}{\"\text{total (sun + sky) irradiance}\"}
\]
Methodological challenge #2: Simulation of a realistic time series of cloud cover

**Adjustment of aerosols and cloud optical depth using on site measures of total solar irradiance**

\[ \epsilon = \frac{E_{\text{simu}} - E_{\text{mes}}}{E_{\text{mes}}} = 3\% \]

**Period**
from 1-April. 2016 to 15-sept. 2016

**Time step**
every 5 days * every hour of the day

**Spectral bands**

**Adjustment simulations**

**Thematic simulations**
Results
Instantaneous 3D radiative budget in the PAR waveband
Instantaneous energy absorbed by grapevine (2D projection)

Arrangement: BIG TREES orientation W/E

15/08/2016 17h00

Clear sky

$E_{\text{PAR}}^{\text{tot}} = 300 \text{ W/m}^2$

SKYL = 0.4
Instantaneous energy absorbed by grapevine (2D projection)

Arrangement: BIG TREES orientation W/E

15/08/2016 17h00

Clear sky
$E_{\text{PAR tot}} = 300 \text{ W/m}^2$
$\text{SKYL} = 0.4$

18/08/2016 16h00

Overcast sky
$E_{\text{PAR tot}} = 120 \text{ W/m}^2$
$\text{SKYL} = 0.99$
Cumulated energy absorbed by grapevine from budburst to harvest, in 2016 (2D projection)

Variability in space
Cumulated energy absorbed by grapevine from budburst to harvest, in 2016 (2D projection)

Variability in space

Current trees W/E

Futur trees W/E

No tree W/E

Futur trees N/S

No tree N/S

Cumulated energy absorbed by grapevine from budburst to harvest, in 2016 (2D projection)
Cumulated energy absorbed by grapevine from budburst to harvest, in 2016 (2D projection)

Variability in space

Current trees W/E

Futur trees W/E

No tree W/E

Futur trees N/S

No tree N/S

\[ \mu : -10\% \]

\[ \mu : -15\% \]

\[ \sigma \text{ decreases} \]
How important are «details»?

15/04/2016 15h00

$E_{\text{PAR tot}} = 370 \, \text{W/m}^2$

$\text{SKYL} = 33 \%$

$\Rightarrow$ Tree: Turbid trees allowing sunflecks equival object representations

$\Rightarrow$ Vine: the climate of turbid and object representations differ at plant scale
How important are « details »?

15/04/2016 15h00

$E_{\text{PAR}_{\text{tot}}} = 370 \text{ W/m}^2$

$SKYL = 33\%$

$SKYL = 0\%$

→ Tree: Turbid trees allowing sunflecks equiv al object representations

→ Vine: the climate of turbid and object representations differ at plant scale

→ Diffuse PAR and multiple scattering show important contribution to radiative budget
How important are « details »?

15/04/2016 15h00

E_{\text{PAR tot}} = 370 \text{ W/m}^2

SKYL = 33 %

→ Tree: Turbid trees allowing sunflecks equivalent object representations

→ Vine: the climate of turbid and object representations differ at plant scale

SKYL = 0 %

→ Diffuse PAR and multiple scattering show important contribution to radiative budget

→ Modelling 3D architecture of grapevine is essential
Conclusions and perspectives
First references ever obtained

✓ Shading from AF trees show low impact on the available PAR in this context.
✓ Orientation only impacts spatial variability of light absorbance.
✓ Methodological approach:
  ✓ Calibrated meteorological sequence
  ✓ 3D representation of vegetation
→ An infinity of new contexte and arrangements can be modelled
# Limitations and perspectives for improvements

**ATTENTION!**

| Too intense cloudiness in the PAR due to modelling cloud with aerosol phase functions. | New runs of simulations are being processed with a new version of DART allowing more accurate modelling of clouds |
| Tree shade is certainly underestimated under clear-sky conditions or moderate cloudiness | Searching for new tree models |
| Tree foliage density seems low | Spectrometer measures / Simulation of images |

| NOT YET VALIDATED vegetation optical properties |  |
Perspectives for optical parameters correction: simulated image vs. UAV borne image

Captured RGB Image

Simulated image

Agroforestry area

No tree area
Thank you for your attention!

juliette.grimaldi@inra.fr

The DART Team
Jean-Philippe GASTELLU-ETCHEGORRY,
Yingjie WANG, Eric CHAVANON,
Nicolas LAURET, Jordan GUilleux

www.cesbio.ups-tlse.fr/dart/##/