MACSUR Project
The case study of vineyards.

Eco-physiological and biophysical modeling applied to the growth and productivity of vineyards in northwestern Italy

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Adoption of a multidisciplinary approach to study the grapevine agro-ecosystem: analysis of biotic and abiotic factors able to influence yield and quality of wine

Development of instruments and knowledge for vineyard management and wine quality improvement

**Project Phases**

- Field experimental activity
- Numerical modeling

- Agrometeorologists
- Physiologists
- Physicists
- Entomologists
- Phytopathologists
- Chemicals
- Wine producers and companies
The DSS Platform

- Meteorological data
- Phenological data
- Ecophysiological data
- Quality analysis
- Micrometeo data

Data processing and numerical modeling

Historical database: bioclimatic informations and must quality and productivity data

Data spazialization

Real time informations on mobile devices

Vinegrowers and advisors can choose the best practices for the vineyard management
STEPS OF THE INTEGRATED PROJECT

1. Realization of an historical database (climatic and bioclimatic data, ecophysiological informations, grape quality and productivity)

2. Field experimental activities

3. Model evaluation, calibration and application

- Biophysical approach
- Ecophysiological approach
The field experimental activity

Growing seasons 2008-2013
Experimental measurements carried out in several vineyards
Varieties: Nebbiolo and Barbera
Regions: Monferrato and Langhe

Directly measured variables:

CONTINUOUSLY
• Air temperature and humidity
• PAR (Photosynthetically active radiation)
• Wind speed and direction
• Soil temperature and humidity
• Net radiation

BIMONTHLY
• Physiological variables (dry matter)
• Point gaseous exchanges
• LAI

• Grape quality parameters
• Vine productivity parameters
Experimental setup

\[ \frac{R_{\text{int}}}{R_{\text{inc}}} = 1 - e^{-LAIk} \]

Multi PAR probe Tecno-El

Photosintetic Light Temp Smart Sensor Pro RH and Temp Hobo

LAI2000 Li-Cor

ECH2O EC-TM Decagon

Data from:
Agrometeorological network, Regione Piemonte

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Experimental setup
Fast response sensors – Eddy Covariance

Ultrasonic anemometer

Corrections for:
- Too high temperatures
- Tilted positioning with respect to the active surface

Solent R2 Gill Ins.
KH2O Campbell
2008–2010

cv Barbera
Cultivar considered

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>No. of vineyards</th>
<th>No. of meteorological stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arneis</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Nebbiolo</td>
<td>30</td>
<td>12</td>
</tr>
<tr>
<td>Barbera</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Cabernet sauvignon</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Chardonnay</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Dolcetto</td>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td>Favorita</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Freisa</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Merlot</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Moscato</td>
<td>46</td>
<td>19</td>
</tr>
<tr>
<td>Pelaverga</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Pinot nero</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Sauvignon</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

For climatological analysis data were provided by 28 electronic stations, belonging to the Regional agrometeorological network (RAM) located within 5 km from the vineyards, in Alessandria, Asti and Cuneo Provinces.

Area investigated and localization of meteorological stations
## Historical dataset

### Grape Quality Indices

<table>
<thead>
<tr>
<th>MOSCATO GRAPE</th>
<th>N E B B I O L O e B A R B E R A G R A P E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of 100 raisins (g)</td>
<td>pH</td>
</tr>
<tr>
<td>Average raisins weight (g)</td>
<td>pH</td>
</tr>
</tbody>
</table>

A1 = potential anthocyanins; A3.2 = potential extractable anthocyanins; A280 = total polyphenols index
EA% = indice di maturità cellulare; Mp% = tannins contribution

## Bioclimatic Indices:

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>ESCURS o SET</th>
<th>THERMAL EXCURSION SUM (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMng</td>
<td>MINIMUM DAILY TEMPERATURE (°C)</td>
<td>TOTAL SOLAR RADIATION [MJ/m²];</td>
</tr>
</tbody>
</table>
| NTMn | DAYS WITH MINIMUM TEMP. < 0 AND = 15 °C | PHOTOSINTETIC ACTIVE RADIATION [MJ/m²]
| TMxg | MAXIMUM DAILY TEMPERATURE (°C) | NHH_giorn | NORMALI HEAT HOURS (NHH) |
| NTMx | DAYS WITH MAXIMUM TEMP. > 0 AND = 35 °C | TMMinAx | LOWEST DAILY TEMPERATURE (°C) |
| TMmg | MEDIUM DAILY TEMPERATURE (°C) | TmaxAx | HIGHEST MAXIMUM TEMPERATURE (°C) |
| PGg o SPU | TOTAL PRECIPITATIONS (mm) | Ggelo | DAYS WITH TMIN < 0° |
| P>1 o NGP | NUMBER OF RAINY DAYS | Gdisgelo | DAYS WITH Tmax < 0° |
| STI o STA | THERMAL SUM (°C) | ETO | EVAPOTRANSPIRATION ETO (mm) |
| HUGLIN | HUGLIN INDEX (°C) | | | | | | | |
ECOPHYSIOLOGICAL APPROACH

1. CO₂ Assimilation, respiration models

2. RUE – Radiation Use Efficiency

\[ B = \text{RUE} \times R_g \times 0.5 \times [1 - e^{(-k_e \times LAI)}] \]

3. TUE – Traspiration Use Efficiency

\[ B = K_{BT} \times \frac{T_p}{VPD} \]

4. RUE - TUE Models

\[ B = \min (B\text{-RUE}, B\text{-TUE}) \]

NET PRIMARY PRODUCTIVITY
Introduzione della pianta: ecofisiologia

Analizzatore di scambi gassosi
LCpro+

Barra solarimetrica Multi-Par Probe

Intercettazione luminosa della chioma (LtInt)

\[ LtInt = \sum_{i=1}^{10} \frac{(d_i - RIL)}{10 \times RIL} \]

LAI-2000 Plant Canopy Analyzer

Leaf Area Index (LAI)
...some results...

Trend comparison of maximum Assimilation Rate (Amax) of four repetitions of Barbera vine in Grugliasco (TO), 2012

Trend comparison of Assimilation in four repetitions of Barbera vine in Grugliasco (TO) with PAR range from 0 to 1500 μmolm-2s-1, 2012

Trend comparison of Leaf Area Index in four repetitions of Barbera vine in Grugliasco (TO), 2012
Assimilation (A), stomatal conductance (gs), stem water potential (SWP) and water use efficiency (WUE) trend during the summer seasons 2011 in three different vineyards.
Barbera 2011-2012: comparison between TSS (a) and TA (b) observed and estimated data curves, between veraison and grape harvest, using multiple regression models. Error calculation of the simulation model.
Total Soluble Solids (°Brix) trend in Barbera grape, 2012. Grugliasco (To)

Titratable acidity (g/l ac.tartaric) trend in Barbera grape, 2012. Grugliasco (To)

Comparison between TSS observed and estimated data curves in Barbera grape, 2012. Grugliasco (To)

Comparison between TA observed and estimated data curves in Barbera grape, 2012. Grugliasco (To)
BIOPHYSICAL APPROACH
The “complication” of hilly vineyards

Normally turbulent sensible (and latent) heat flux from sonic anemometer data are evaluated with the implied hypothesis of homogeneous, uniform and horizontal plane.

The condition \( \bar{w} = 0 \) is imposed and the turbulent heat fluxes are evaluated in the horizontal plane.

Hilly vineyards are not horizontal (and not uniform and not homogeneous) \( \rightarrow \) need to evaluate the fluxes with respect to the streamline plane.

Execution of a planar fit (mean values over a “long” period in order to avoid short term variations: 30 min).

Fluxes are evaluated every 30 minutes:
- \( z \) axis is fixed (perpendicular to the plane)
- \( x-y \) vary in the time: \( u \) wind speed is aligned along the mean wind speed (\( // \) to the plane).
The UTOPIA model

University of TOrino model of land Process Interaction with Atmosphere
1-D diagnostic model

Vegetation – 1 layer ("BIG LEAF")

Vegetation classes characterized by:

- Minimum stomatal resistance
- Leaf diameter
- Root depth
- Albedo
- Emissivity
- Height
- Cover
- Leaf Area Index (LAI)
Radiative balance

\[ R_n = H + \lambda_v E + Q_g + P_h \]

\( R_n \) net radiation - available energy flux for:

- evaporation or condensation (air, soil and vegetation)
  \( \lambda_v E \)  LATENT HEAT FLUX
- air or surface warming or cooling
  \( H \)  SENSIBLE HEAT FLUX
- soil warming or cooling
  \( Q_g \)  SOIL HEAT FLUX
- photosynthesis \( P_h \)
Meteorological data 2008-2009

Cumulated precipitation (mm)

Air temperature (°C)

Relative humidity (%)
Other data in 2009

Pressure (hPa)

Wind speed (m/s)

Silty Clay Loam

Soil temperature (°C) 5 cm

Daily precipitation (mm) and soil moisture

April 2, 2014

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Vegetation parameters 2008 - 2009

Vegetation height

LAI

Vegetation cover

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UTOPIA simulations: energy balance 2008 - 2009

Net radiation
Latent HF
Sensible HF
Soil HF

2008
2009

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Heat flux physics in UTOPIA

Turbulent fluxes, flux-gradient law by analogy with Ohm's Law

\[
H = \rho c_p w \theta
\]

\[
H = -k \frac{dT}{dz}
\]

\[
H = H_f + H_g
\]

\[
H_f = \rho_a c_p s_b \left( T_f - T_{af} \right) \sigma_f
\]

\[
H_g = \rho_a c_p s_d \left( T_1 - T_{af} \right) \left( 1 - \sigma_f \right)
\]

Sensible heat flux for a vegetated surface

Latent heat flux for a vegetated surface
Why UTOPIA?

Continuation of a study previously carried out on stomatal conductance of Nebbiolo* wine
Preliminary results:

- First experimental section over vine (gas exchange analyzer)
- Study of the link between physiological and meteorological factors through the stomatal conductance
- UTOPIA: New parameterization of transpiration in function of temperature and air humidity, radiation and CO₂
- Decrease of the conductance at CO₂ concentration higher than environmental values (climatic perspective)

* Prino S., Spanna F., Cassardo C. 2009
UTOPIA simulations: vegetation parameters 2008 - 2009

Vegetation height

Value of the vegetation class vineyards

Measured value

LAI

Vegetation cover

April 2, 2014

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UTOPIA: comparison with different initializations
transpiration 2008 - 2009

Model using a specific vegetation class
Model using measured data for some variables
Comparison between UTOPIA and measurements – 2009

Sensible HF

Net radiation

April 2, 2014
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NELLA VITE LE CONDIZIONI CLIMATICHE GENERALI E IL REGIME TERMICO, IN PARTICOLARE:

✓ rappresentano fattori che maggiormente influenzano il ritmo di crescita e sviluppo (range termico compreso tra i 10 ed i 20 °C Tm annua)

✓ influiscono nel determinare le epoche di comparsa delle principali fasi fenologiche e la composizione chimica dell'uva al momento della raccolta

**IMPORTANTE:**
Individuare strumenti di facile applicazione che esprimano relazioni tra condizioni meteo e produzione enologica per fornire agli operatori strumenti di analisi e interpretazione per la gestione e pianificazione della loro attività
Per esprimere numericamente le esigenze climatiche della vite, sono stati elaborati **INDICI BIOCLIMATICI UTILI A**:

- **INDIVIDUARE LE AREE IDONEE ALLA COLTIVAZIONE DELLA VITE**

- **DIFFERENZIARE E DELIMITARE LE DIVERSE ZONE VITICOLE IN BASE ALL'OBIETTIVO PRODUTTIVO CHE SI PERSEGUIE**

Gli indici agroclimatici servono quindi a:

- definire quantitativamente le risorse del territorio in funzione delle esigenze della coltura

- valutare le caratteristiche di una particolare annata in funzione della coltivazione e non della qualità’

... MA NON CI DANNO INFORMAZIONI SULLE RISPOSTE DELLA PIANTA...
ECOFISIOLOGIA VEGETALE

studia le risposte fisiologiche degli organismi vegetali all’ambiente circostante e alla variabili meteorologiche.

Ciò che consente la vita delle piante in uno specifico ambiente è l’adattamento, che può riguardare la specie e il singolo individuo.

QUANTIFICARE LE POTENZIALITÀ PRODUTTIVE DELLA PIANTA E STIMARE L’ENTITÀ DEGLI EFFETTI DI STRESS CONTRIBUISCE A PROGRAMMARE GLI INTERVENTI NECESSARI PER OTTIMIZZARE LA PRODUTTIVITÀ VEGETALE

✔ Simulare affidabilmente un agroecosistema consente di considerare fenomeni complessi (es: infestanti, avversità biotiche e abiotiche)
MODELLO MECCANICISTICO

LIVELLO PRODUTTIVO
Dai vegetali al modello matematico

POTENZIALE

LIMITATO PER TEMPERATURA

LIMITATO PER L’ACQUA

LIMITATO PER I NUTRIENTI
(AVVERSITA’ BIOTICHE E ABIOTICHE)

PRODUZIONE FINALE
(ripartita tra gli organi)

GASS - Assimilaz. Lorda [g CH₂O]

PAR (Lambert Beer)

APAR (Rg*0.5)

Rg [MJ m⁻²]

respirazione, conversione e traslocazione

PNA - Assimilazione Potenziale [g CH₂O]

Limitaz termica

T aria, ...

PNA_TL - Assimilaz. Pot.,le limitata per T [g CH₂O]

Limitaz idrica

T aria, RH Rglob, vento,....

PNA_TL WL - Assimilaz. Pot.,le limitata per T e W[g CH₂O]

Limitaz nutrienti

Fattori chimici e biologici

Tt, acqua

NPP - Produzione Primaria Netta [g CH₂O]

Ripartizione assimilati

Fase fenologica

T aria, RH Rglob, vento,....

ACCUMULO

Foglie
frutti
fusto
radici
New approaches

NDVI - with Drone, 01-08-2013
Conclusions, perspectives, future work

- The work is still *in progress*, and the study involves 2-3 complementary projects
- Interesting results considering an integrated approach with agrometeorological, ecophysiological, physical and vinegrowing aspects
- With MACSUR we have the opportunity to involve in the working group other European countries, other modelers, and other dataset of other vinegrowing areas.
- In particular we are going to share data and methods with other groups working in Spain, France and Germany.
- We have the possibility to validate and calibrate models for tree or shrubs species also considering the product quality
- If we understand the “vineyard system” we can also make simulations for future scenarios under climate change conditions
Conclusions, perspectives, future work

- The work is still *in progress*, thus results are quite preliminary and refer to only Cocconato station and Barbera vineyard
- 2008 and 2009 seasons are climatically different
  - Good opportunity to examine several climate ranges
- Broad consistence between the meteorological factors and the components of energy and radiation balances, soil variables
  - To better quantify these considerations, it is necessary to examine also the data of the other two stations (work in progress) and the data of the 2010 (in measurement)
- The application of UTOPIA model at local scale can provide a wide range of variables difficult to measure extensively
  - It can be possible to assess the climatology of these parameters in the wine regions
  - These parameters can be linked with wine quality
- Need to check UTOPIA to be confident on these values – critical points are:
  - Influence of tilting on solar radiation (done)
  - Initial and boundary conditions of vegetation parameters (LAI, cover, height, …)
  - Accurate description of soil texture