Clim4Vitis

Modelling strategies for estimating vine development and growth under different environmental conditions

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DAGRI
DIPARTIMENTO DI SCIENZE E TECNOLOGIE AGRARIE, ALIMENTARI, AMBIENTALI E FORESTALI

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Contents

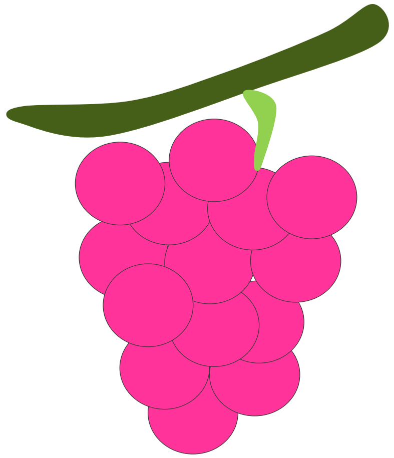
Contents

The most renowned regions for high quality wine production are located in **climatic niches** in which the combination of **climate-soil-cultivar-human** factors defines their specific *Terroir* (Van Leeuwen & Seguin 2006, Seguin 1986)

1. Introduction

Viticulture and Climate change

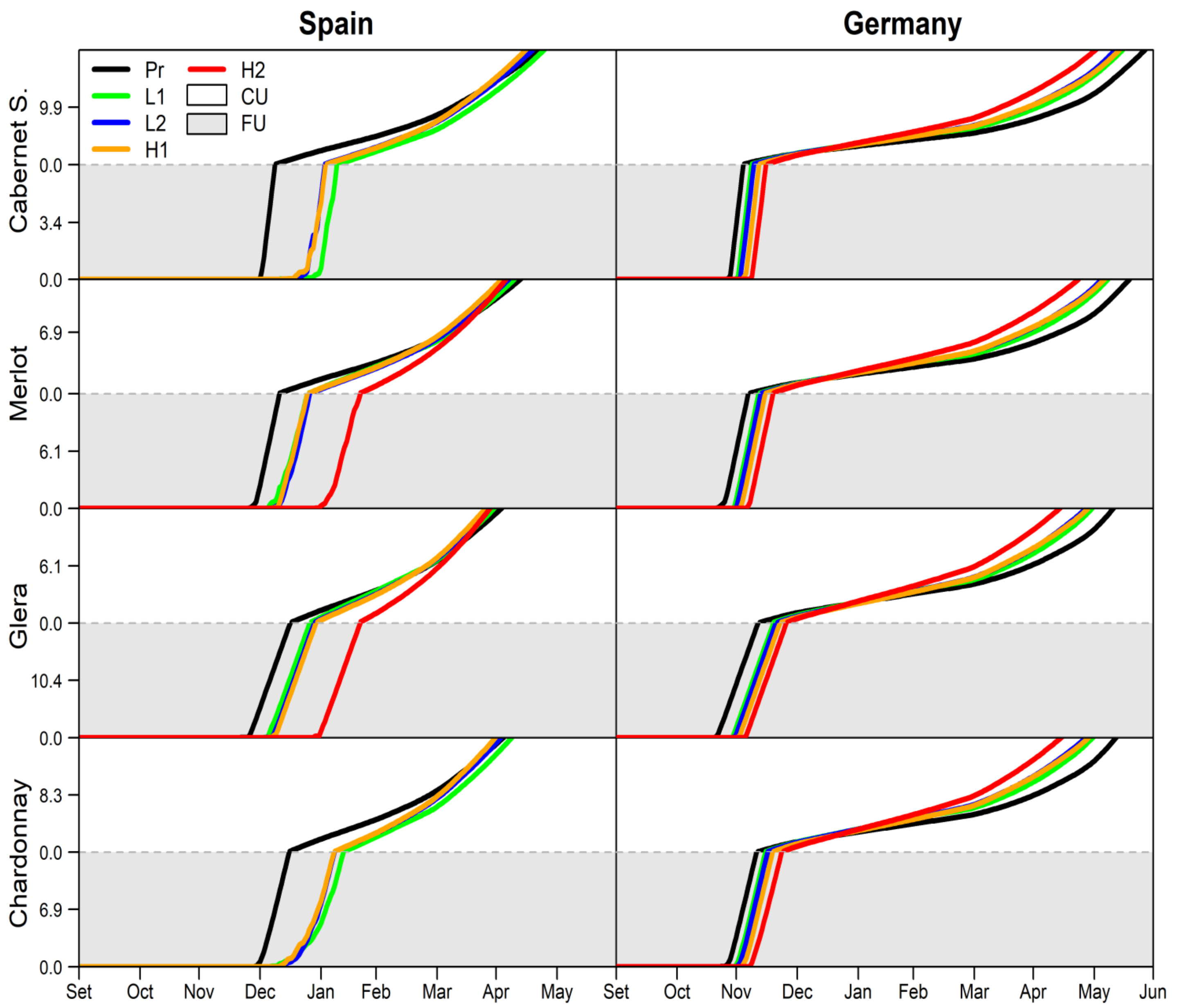
In Europe, the suitability of the most famous wine regions is influenced by climate change and extreme events. The scientific community has already showed the impacts of climate change on grapevine growth but **more detrimental consequences are expected for the future** (Leolini et al. 2018, Fraga et al. 2016)



1. Introduction

Viticulture and Climate change

The **shift of the current suitable areas towards new ones** represents one of the main future changes for European viticulture (Moriondo et al. 2013)



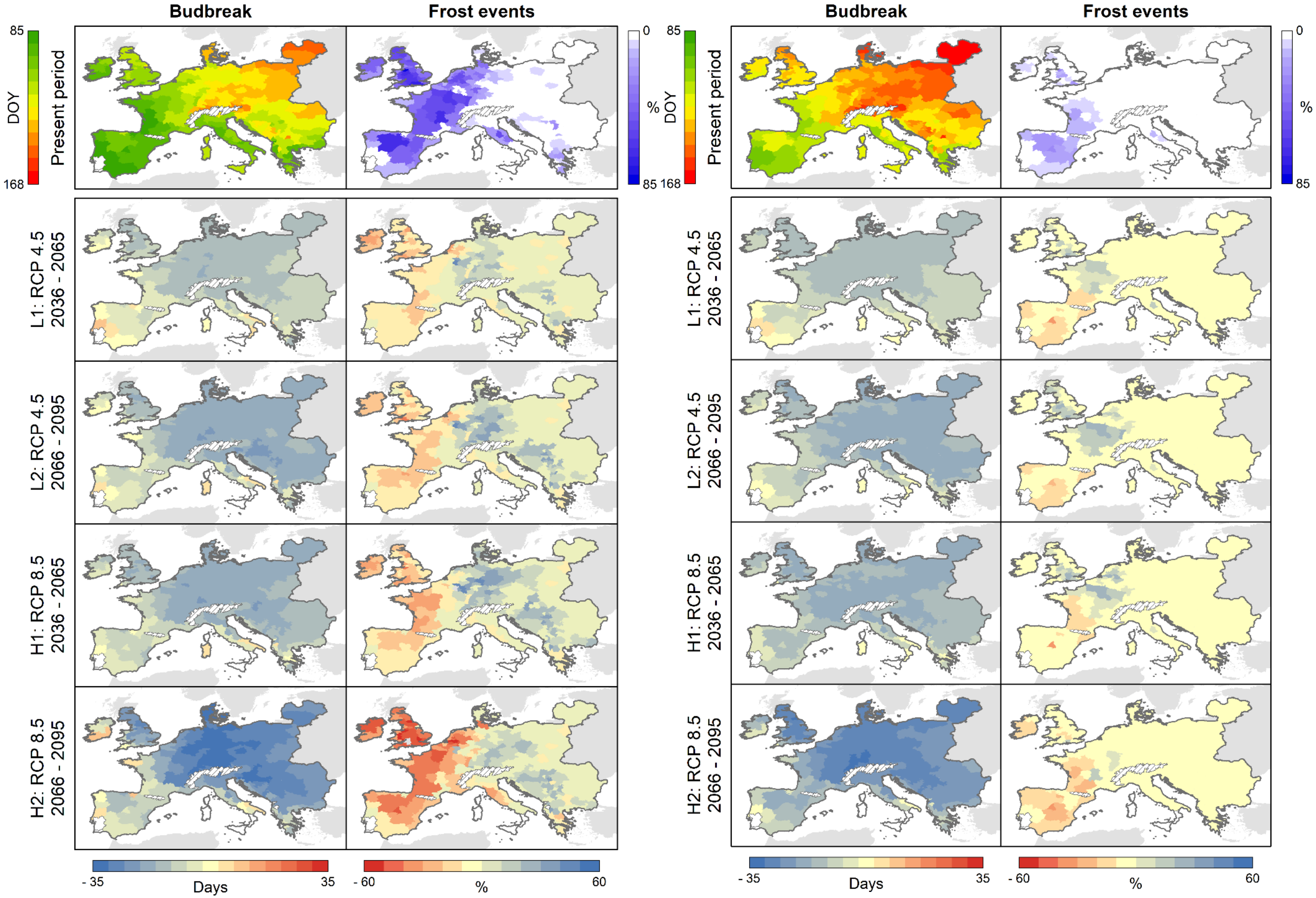
Leolini et al. 2018a

1. Introduction

Viticulture and Climate change

GLERA

CABERNET S.



Leolini et al. 2018a

The models able to simulate grapevine growth and production can be:

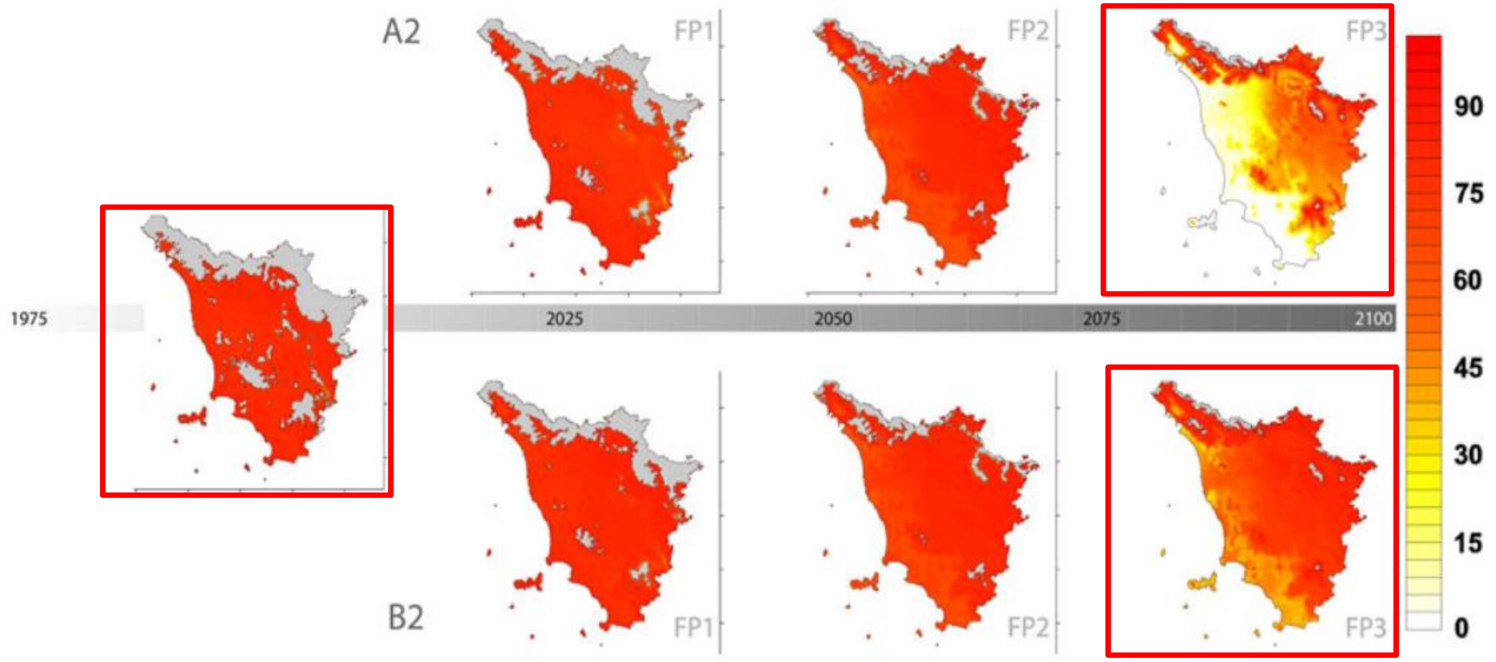
Empiricals *Moriondo et al. 2015*

The response variable (e.g. yield) is explained by some driving variables (e.g. weather variables)

$$VQ = -845.75+104.5(ST)-2.89(ST)^2-0.104(R)$$

Moriondo et al. 2011

VQ = vintage quality
ST = average of T_{min} and T_{max} over the March-October period
R = rainfall



The models able to simulate grapevine growth and production can be:

Empiricals

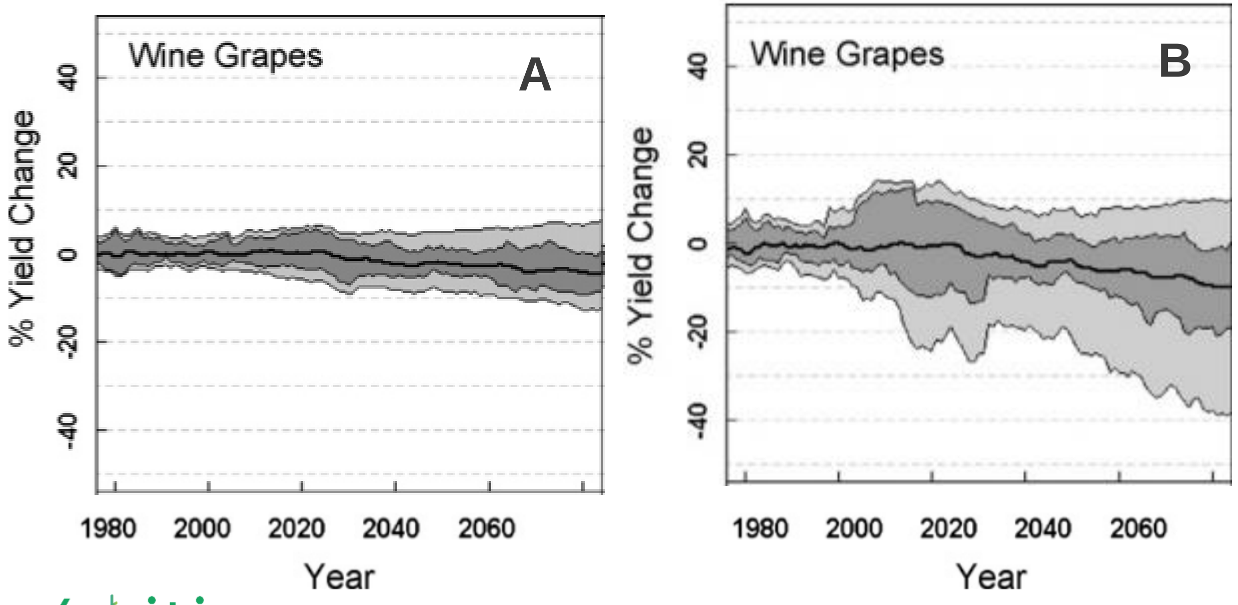
Moriondo et al. 2015

The response variable (e.g. yield) is explained by some driving variables (e.g. weather variables)

$$Y = 2.65T_{n,4} - 0.17T^2_{n,4} + 4.78P_6 - 4.93P^2_6 - 2.24P_{-9} + 1.54P^2_{-9} - 10.50$$

Lobell et al. 2006

Y = yield anomaly (ton acre^{-1})
T_n = minimum temperature (°C)
P = precipitation (mm)



1. Introduction
Grapevine simulation models

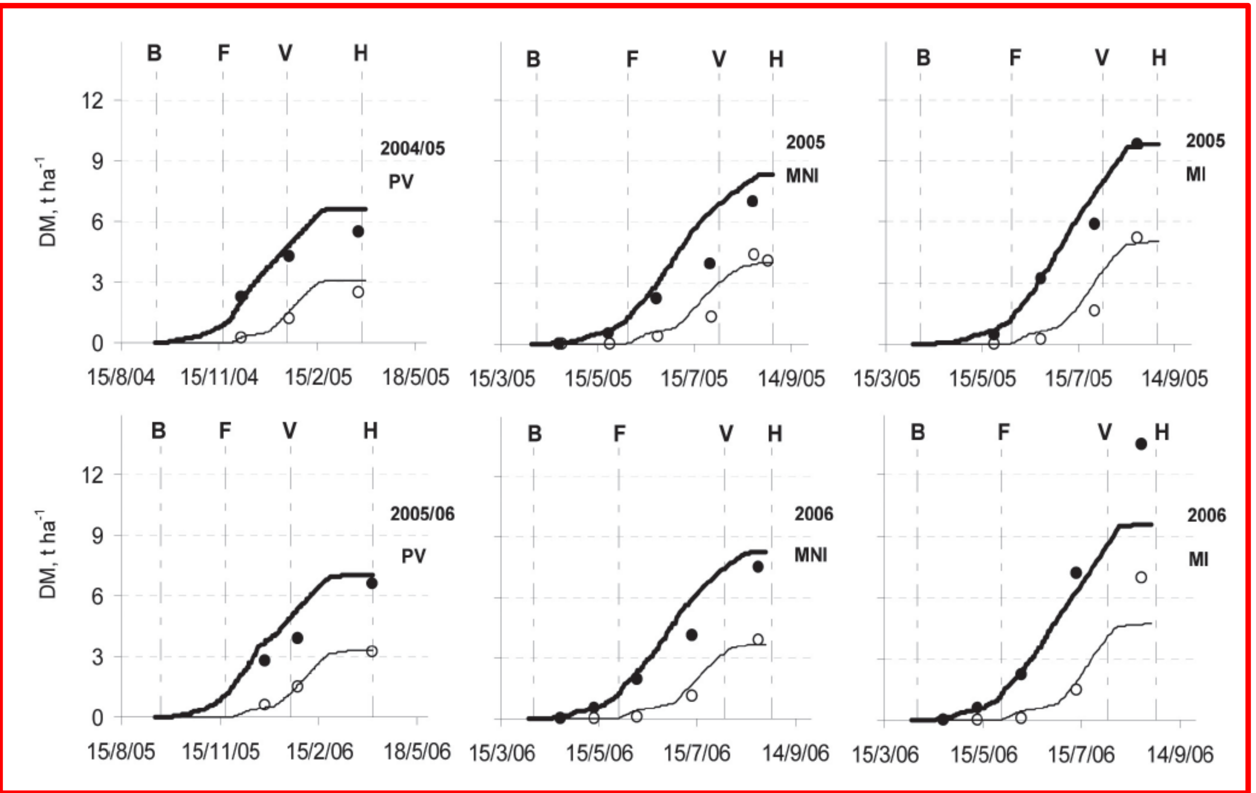
The models able to simulate grapevine growth and production can be:

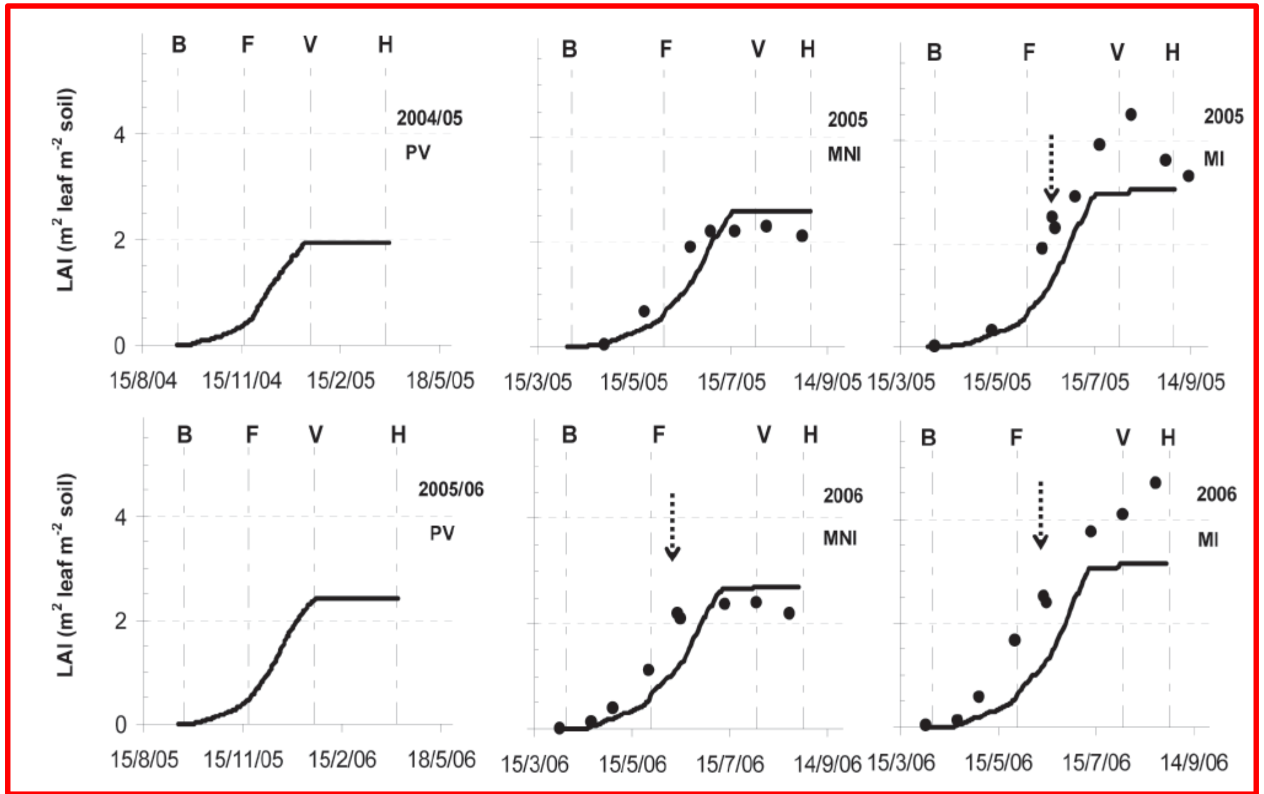
Process-based models

Moriondo et al. 2015

These models simulate the entire grapevine cycle at high detailed level by using mathematical equations that explain the main physiological processes of the plant

Valdés-Gómez et al. 2009





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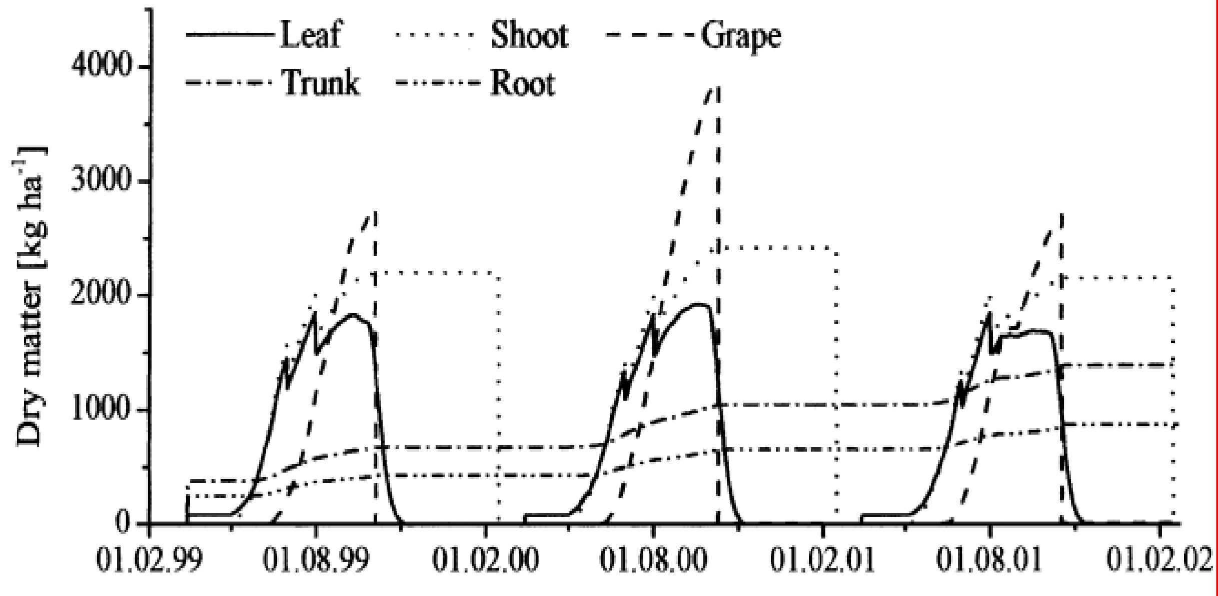
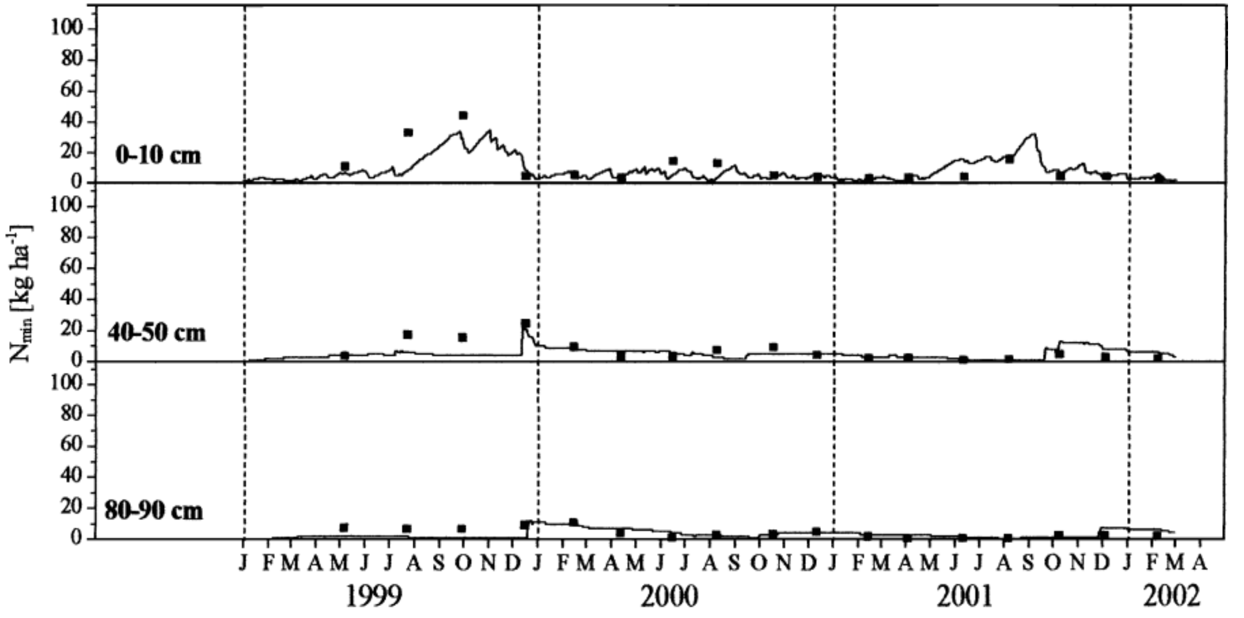
Nendel and Kersebaum 2004





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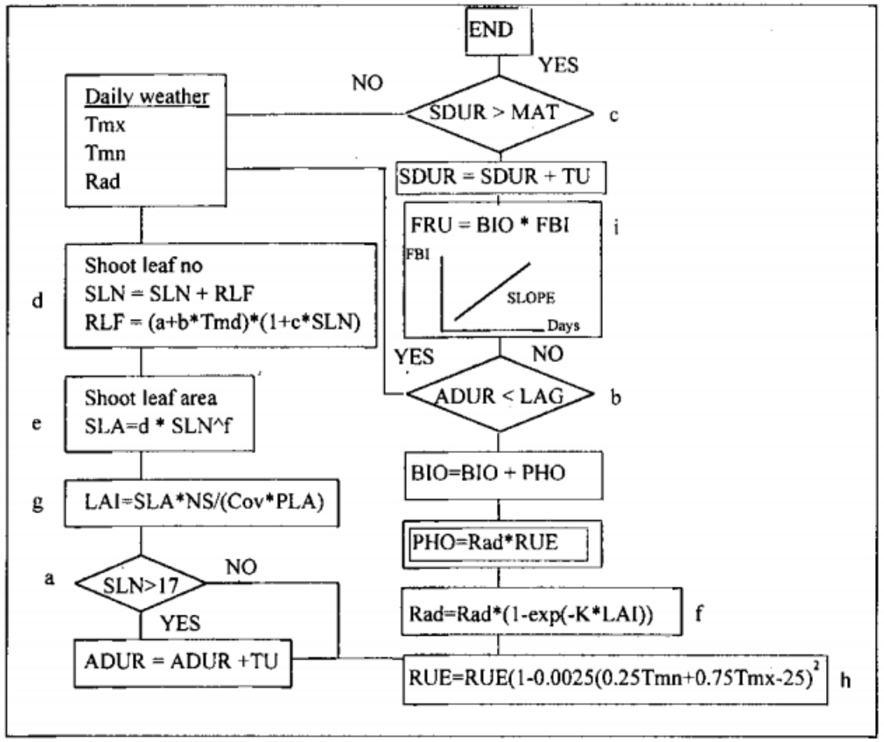
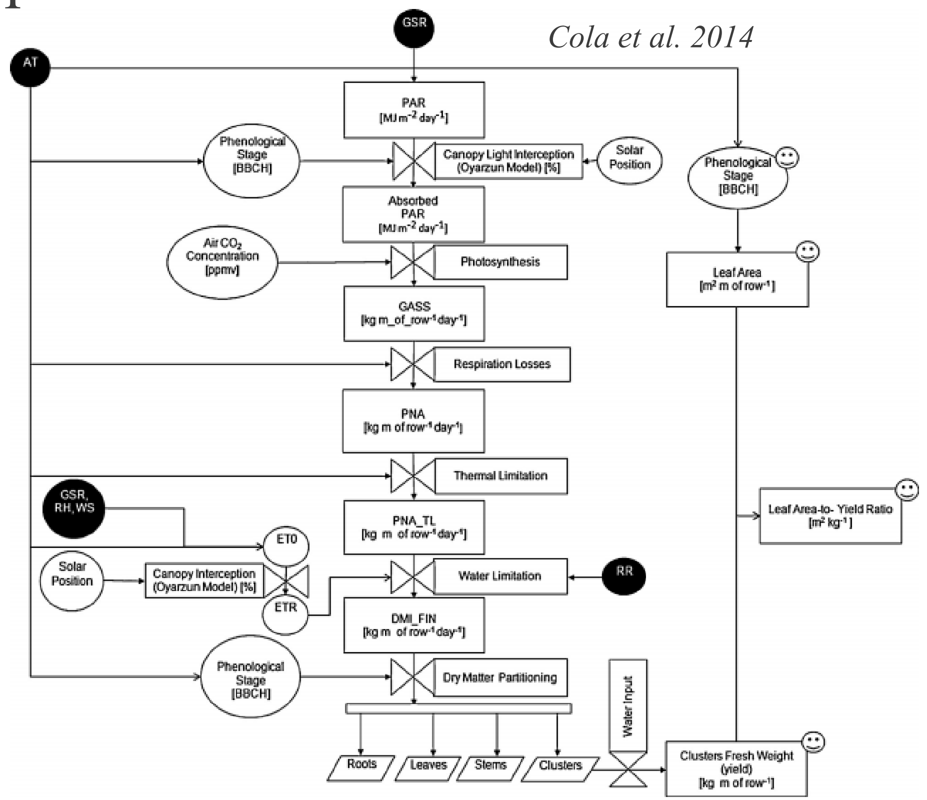
Bindi et al. 1997



Cola et al. 2014



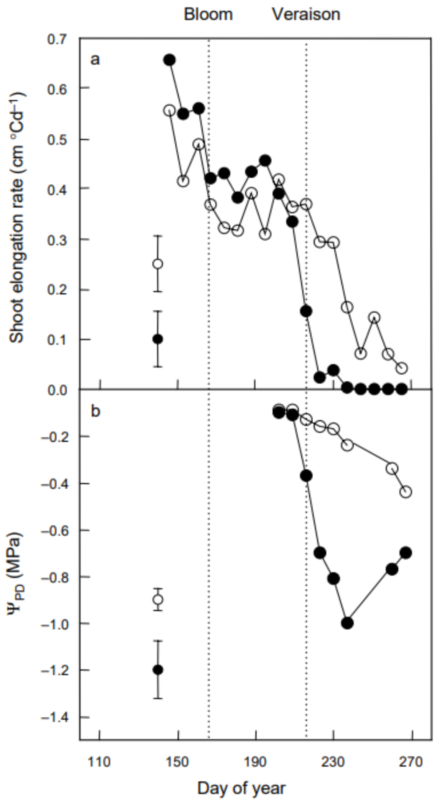
The models able to simulate grapevine growth and production can be:

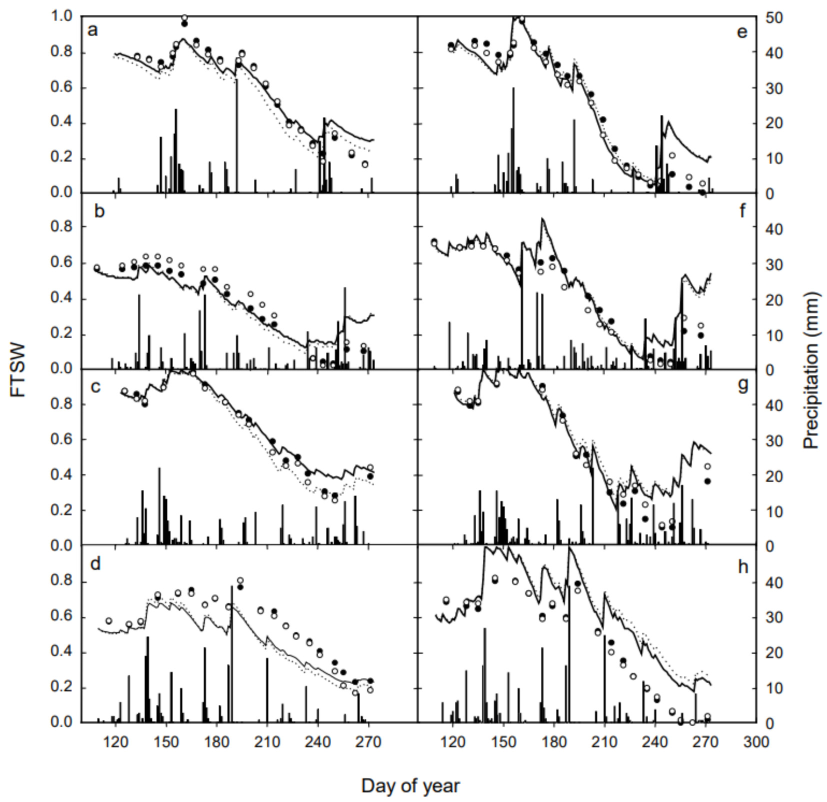
Functional models

Moriondo et al. 2015

These models represent a sub-class of process-based model focused on the description of a specific plant process

Lebon et al. 2003





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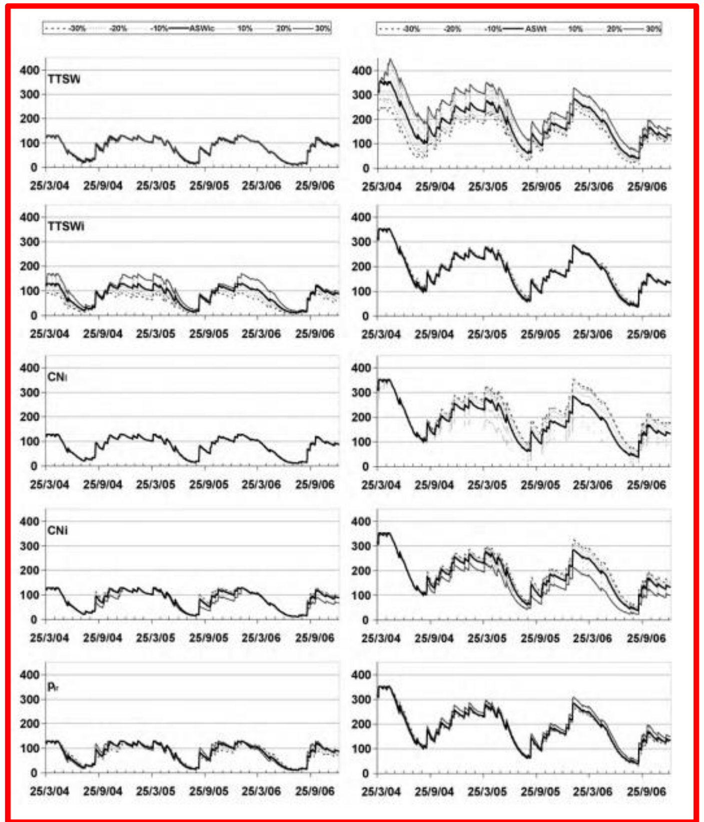
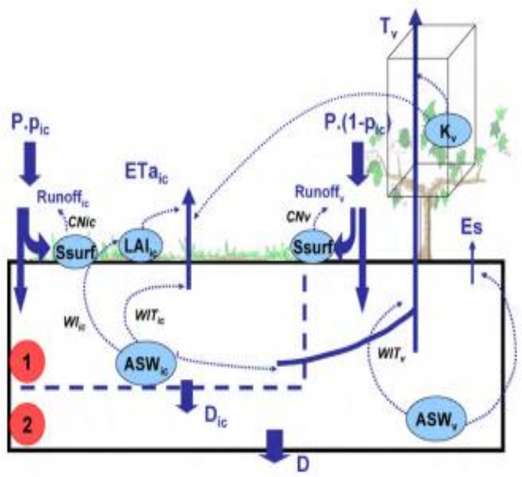


Cellette et al. 2010



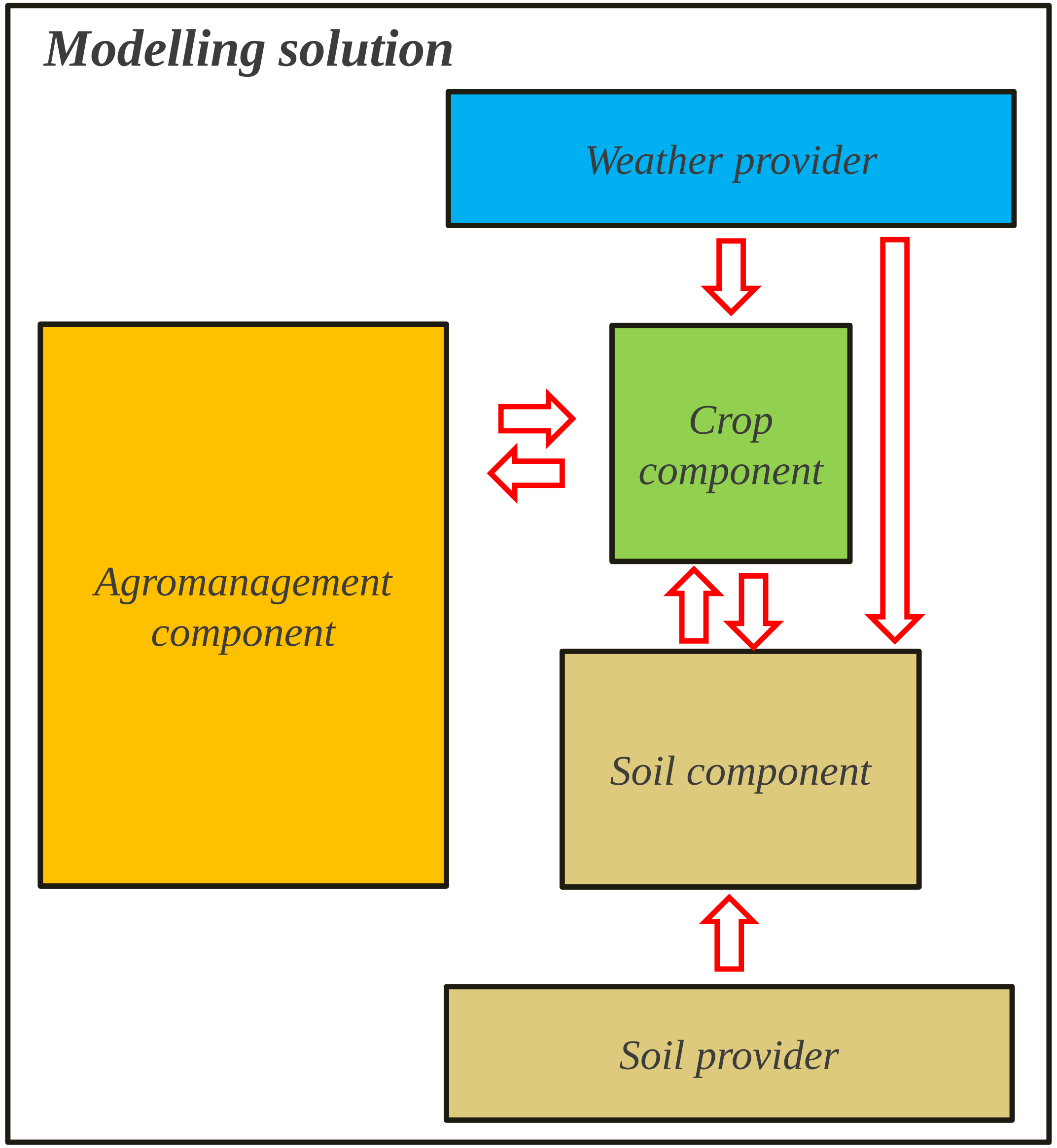
2. UNIFI.GrapeML Description

BioMA implementation of UNIFI.GrapeML

- UNIFI.GrapeML is a model library used **for simulating vine development and growth**, it is jointly developed by UNIFI and CREA-AA

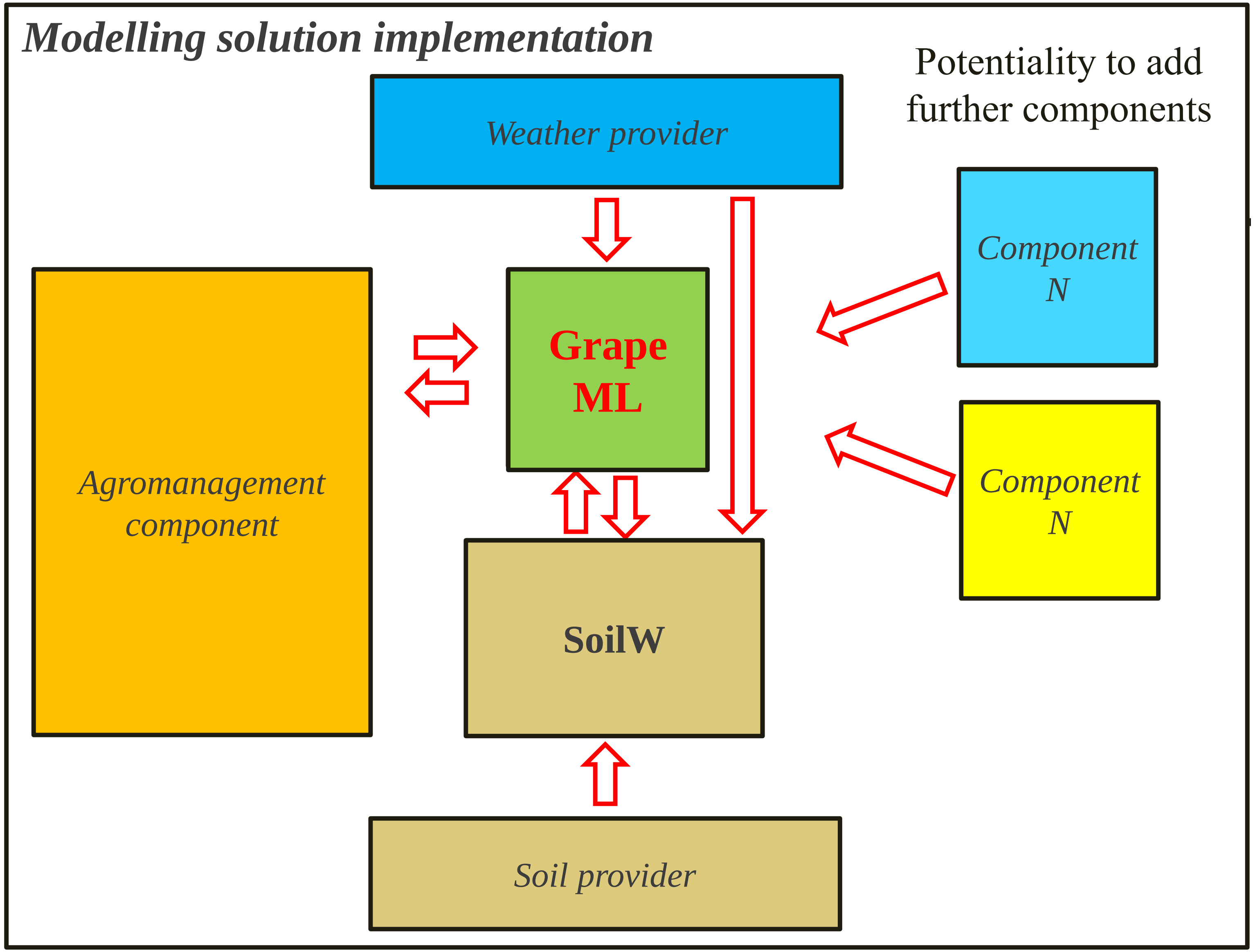
- UNIFI.GrapeML is built in BioMA software environment
- BioMA (Biophysical Model Applications) is a modelling platform which provides tools for implementing, running and testing modular modelling solutions (www.biomamodelling.org)

BioMA implementation of UNIFI.GrapeML



2. UNIFI.GrapeML Description

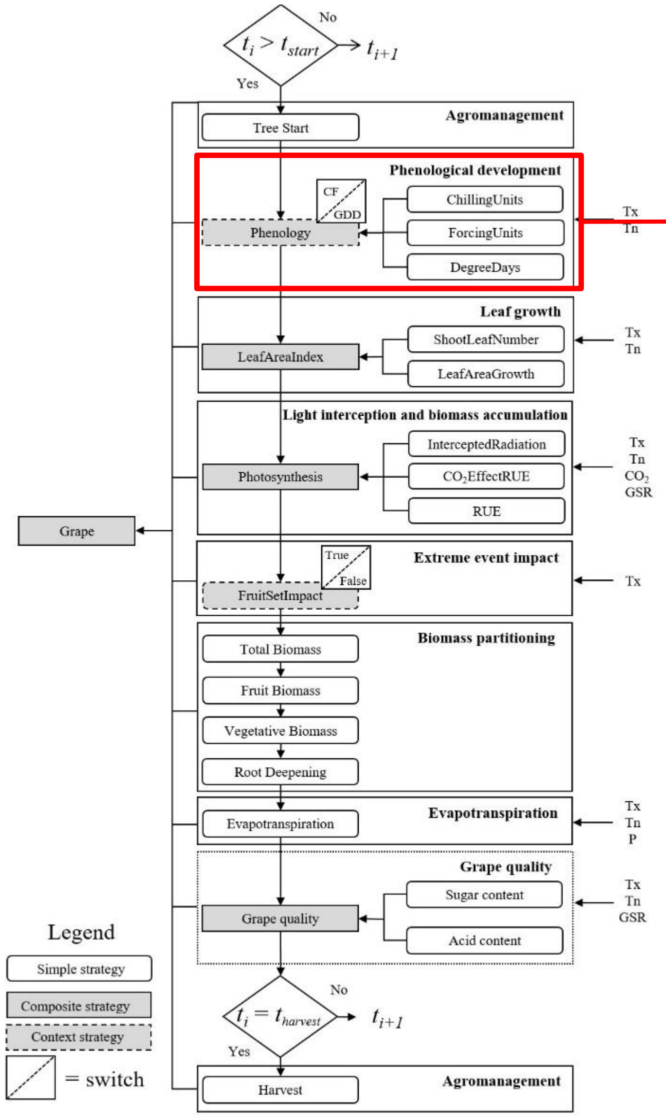
BioMA implementation of UNIFI.GrapeML



UNIFI.GrapeML simulates different physiological processes of grapevine

2. UNIFI.GrapeML Description

UNIFI.GrapeML workflow

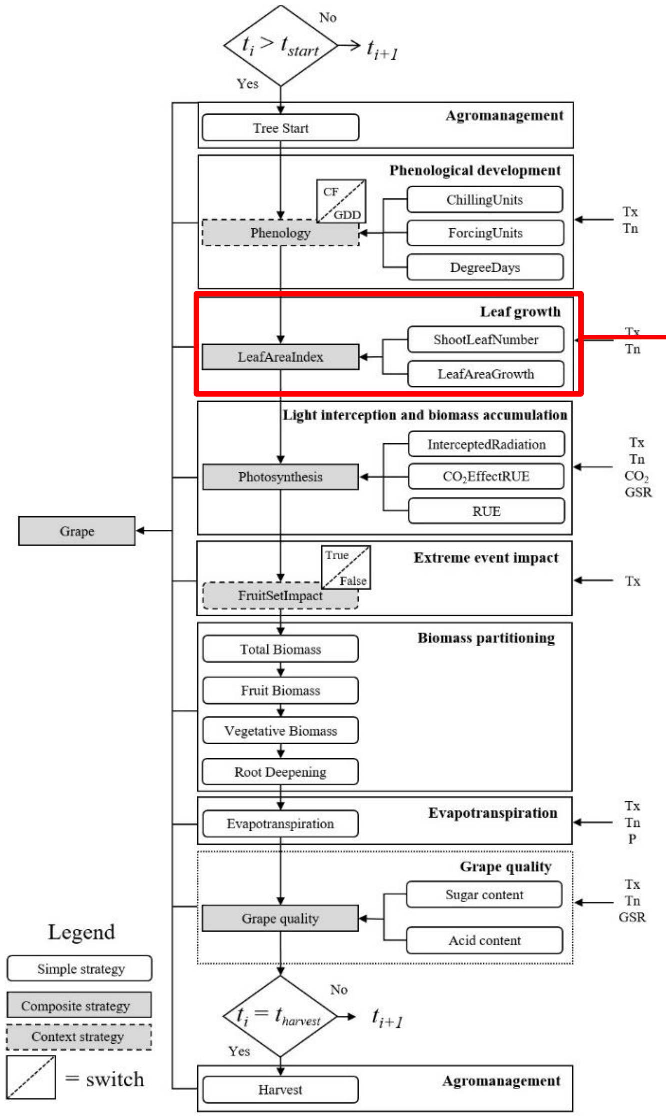


Phenological development

Model user can choose between two options: Chilling-forcing approach and Growing Degree Days approach

2. UNIFI.GrapeML Description

UNIFI.GrapeML workflow

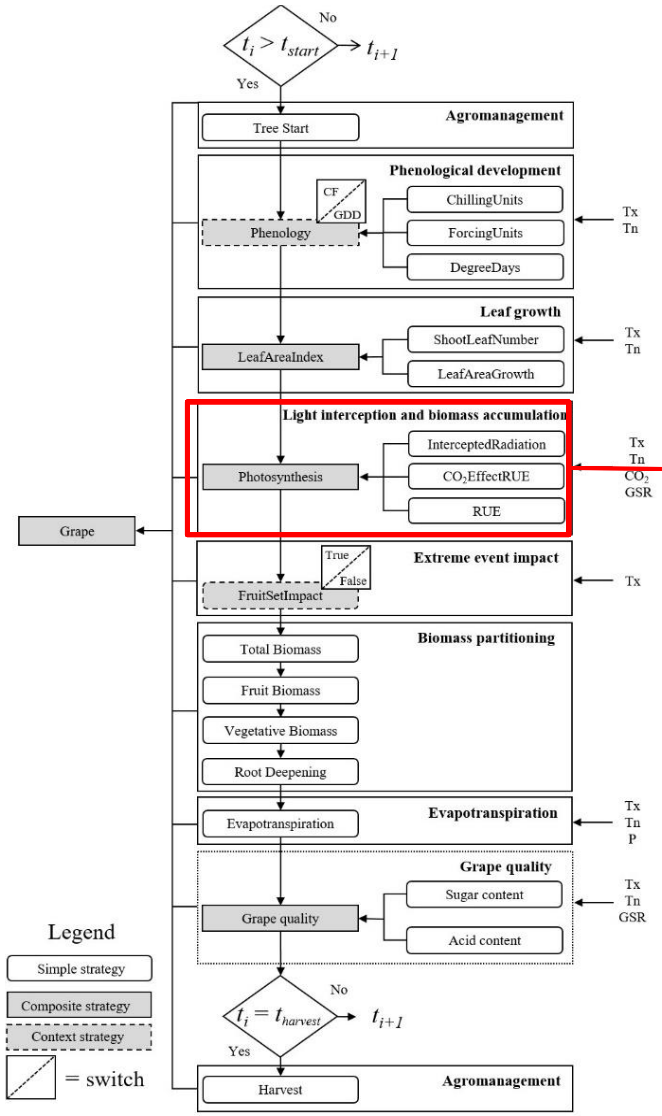


Leaf area growth

Reproduce the plant leaf area and the leaf area index

2. UNIFI.GrapeML Description

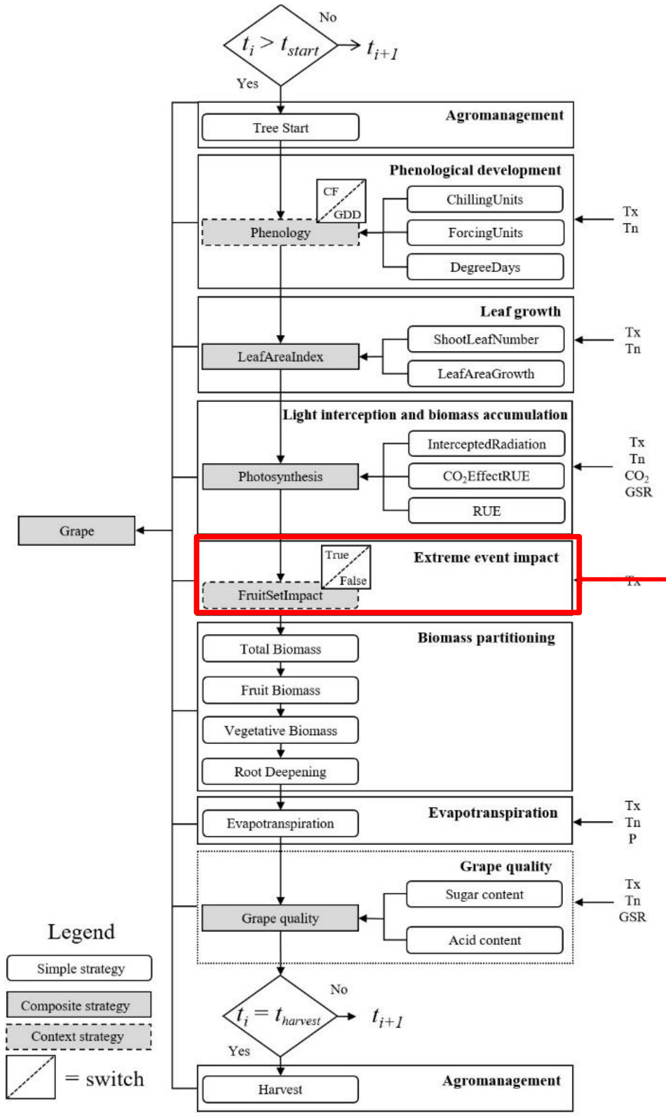
UNIFI.GrapeML workflow



Light interception and biomass accumulation
Radiation intercepted by the canopy and Radiation Use Efficiency are used for simulating photosynthesis process

2. UNIFI.GrapeML Description

UNIFI.GrapeML workflow

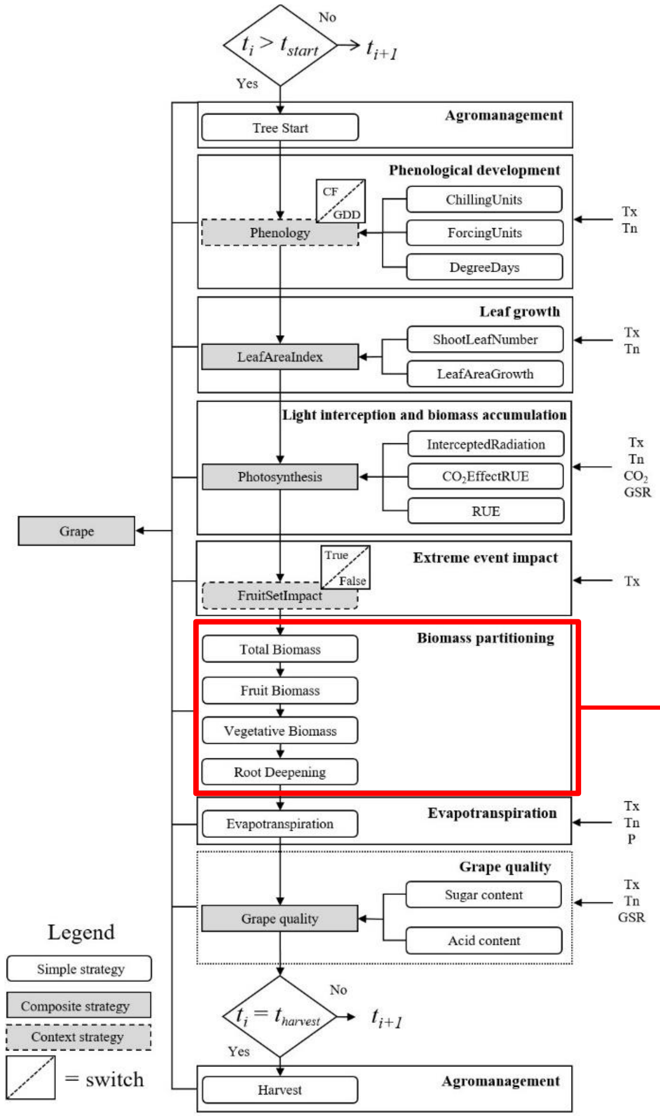


Extreme event impact

A fruit biomass reduction is expected if suboptimal temperatures occur around flowering

2. UNIFI.GrapeML Description

UNIFI.GrapeML workflow

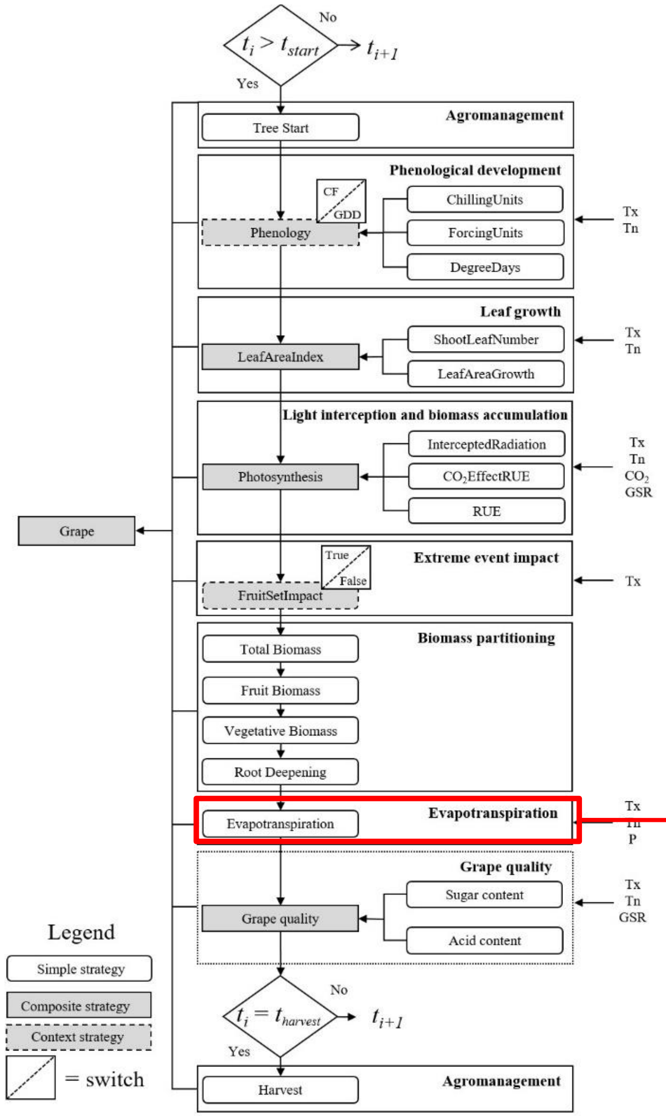


Biomass partitioning

Biomass is partitioned in vegetative, fruit and total biomass. Root growth rate is affected by water stress conditions

2. UNIFI.GrapeML Description

UNIFI.GrapeML workflow

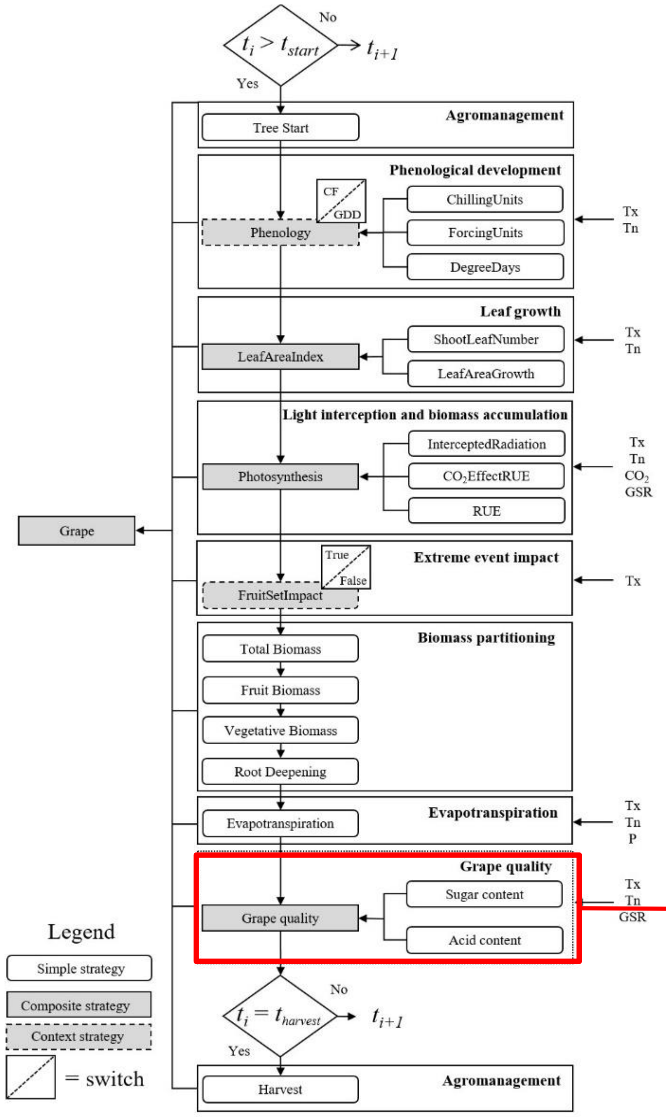


Evapotranspiration

Evapotranspiration implements the interaction between soil and plant component

2. UNIFI.GrapeML Description

UNIFI.GrapeML workflow

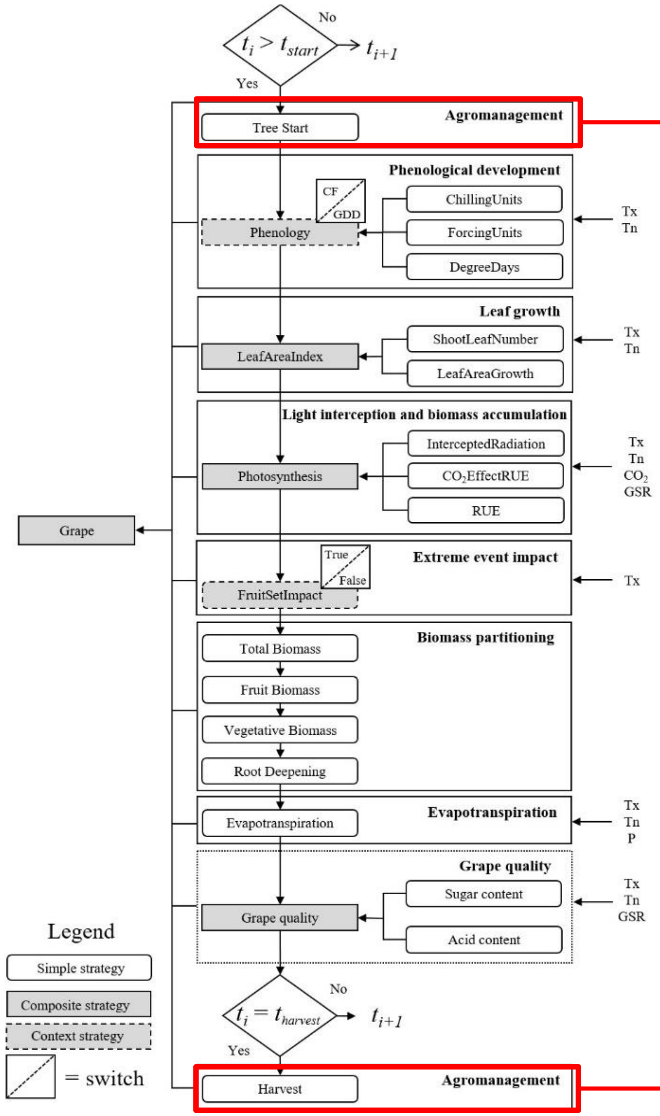


Grape quality

Grape quality is the new implementation for estimating sugar and acid content

2. UNIFI.GrapeML Description

UNIFI.GrapeML workflow

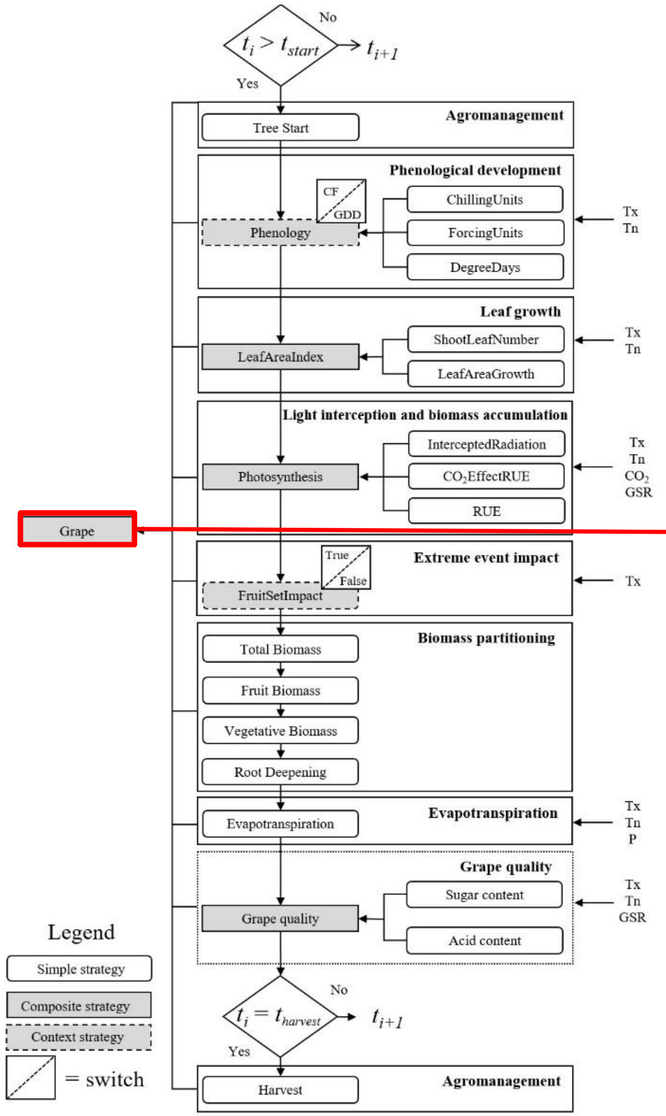


Agromanagement determines the beginning of grapevine cycle

Agromanagement determines the end of grapevine cycle

2. UNIFI.GrapeML Description

UNIFI.GrapeML workflow



Grape calls for all the strategies of the model

2. UNIFI.GrapeML Description

UNIFI.GrapeML inputs, outputs and parameters

INPUTS

For simulation and calibration

Weather | *Plant* | *Soil*

Weather variables

- -Maximum Air Temperature (°C)
- -Minimum Air Temperature (°C)
- -Precipitation (mm)
- -Global Solar Radiation (MJ m^{-2})
- -Maximum Relative Humidity (%)
- -Minimum Relative Humidity (%)
- -Wind (m/s)

2. UNIFI.GrapeML Description

UNIFI.GrapeML inputs, outputs and parameters

INPUTS

For simulation and calibration

Weather *Plant* *Soil*

Plant information

Some examples

- Phenology data (budbreak, flowering, veraison and maturity)
- Shoot number (n°)
- Plant density (m^2)
- Root depth (m)
- Fruit and vegative biomass (g m^{-2})

2. UNIFI.GrapeML Description

UNIFI.GrapeML inputs, outputs and parameters

INPUTS

For simulation and calibration

Weather *Plant* *Soil*

Soil information

Some examples

-Soil depth (m)

- Horizont thickness (m)
- Soil layers (number)
- Field capacity (m^3 m^{-3})
- Wilting point (m^3 m^{-3})
- Saturated Hydraulic Conductivity (mm h^{-1})
- Volumetric Water Content At Saturation (m^3 m^{-3})
- Soil texture (Sand, Silt, Clay, Skeleton; %)
- Bulk density (t m^{-3})
- Organic carbon (%)

2. UNIFI.GrapeML Description

UNIFI.GrapeML inputs, outputs and parameters

OUTPUTS

For simulation and calibration

Plant

Soil

Plant

Some examples

- Phenology (budbreak, flowering, veraison, maturity) (DOY)
- Leaf Area Index (m^2 m^{-2})
- Total, vegetative, fruit biomass (g m^{-2})
- Grape quality (Sugar in °Brix and Acid in g/l)

2. UNIFI.GrapeML Description

UNIFI.GrapeML inputs, outputs and parameters

OUTPUTS

For simulation and calibration

Plant

Soil

Soil

Some examples

- Soil water content at different depths (m)

2. UNIFI.GrapeML Description

UNIFI.GrapeML inputs, outputs and parameters

PARAMETERS

UNIFI.GrapeML parameters are related to different physiological processes

```
</Parameter><Parameter name="ShootNumber">
  <Value>8</Value>
</Parameter><Parameter name="ShootLeafAreaSlope">
  <Value>5.39</Value>
</Parameter><Parameter name="ShootLeafAreaExpansion">
  <Value>1.76</Value>
</Parameter><Parameter name="SLN1">
  <Value>25.9</Value>
</Parameter><Parameter name="SLN2">
  <Value>17.3</Value>
</Parameter><Parameter name="ShootLeafNumberIntercept">
  <Value>-0.28</Value>
</Parameter><Parameter name="LeafAppearanceRate1">
  <Value>0.04</Value>
</Parameter><Parameter name="LeafAppearanceRate2">
  <Value>-0.015</Value>
```

```
</Parameter><Parameter name="PHO1">
  <Value>12.9</Value>
</Parameter><Parameter name="PHO2">
  <Value>14.1</Value>
</Parameter><Parameter name="InitialRUE">
  <Value>1.001</Value>
</Parameter><Parameter name="mRUE550">
  <Value>0.001050605</Value>
</Parameter><Parameter name="qRUE550">
  <Value>0.63328825</Value>
</Parameter><Parameter name="mRUE700">
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```
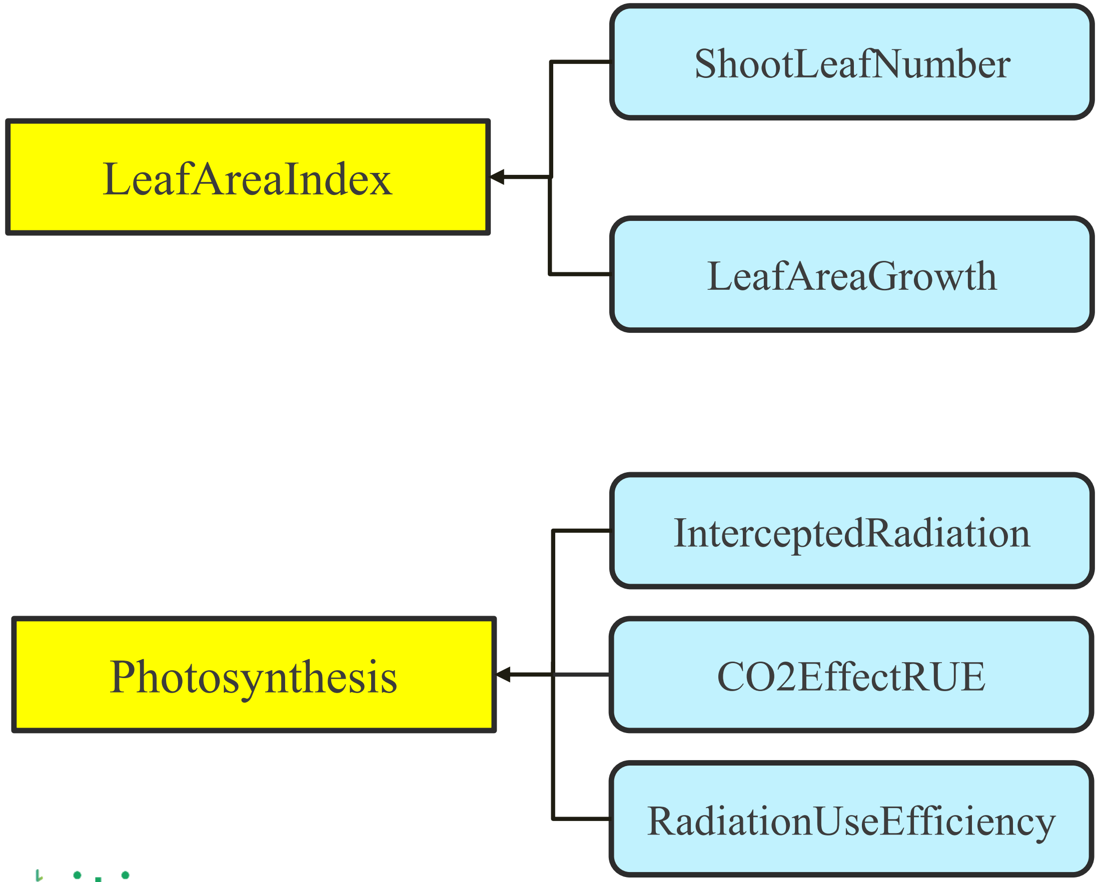
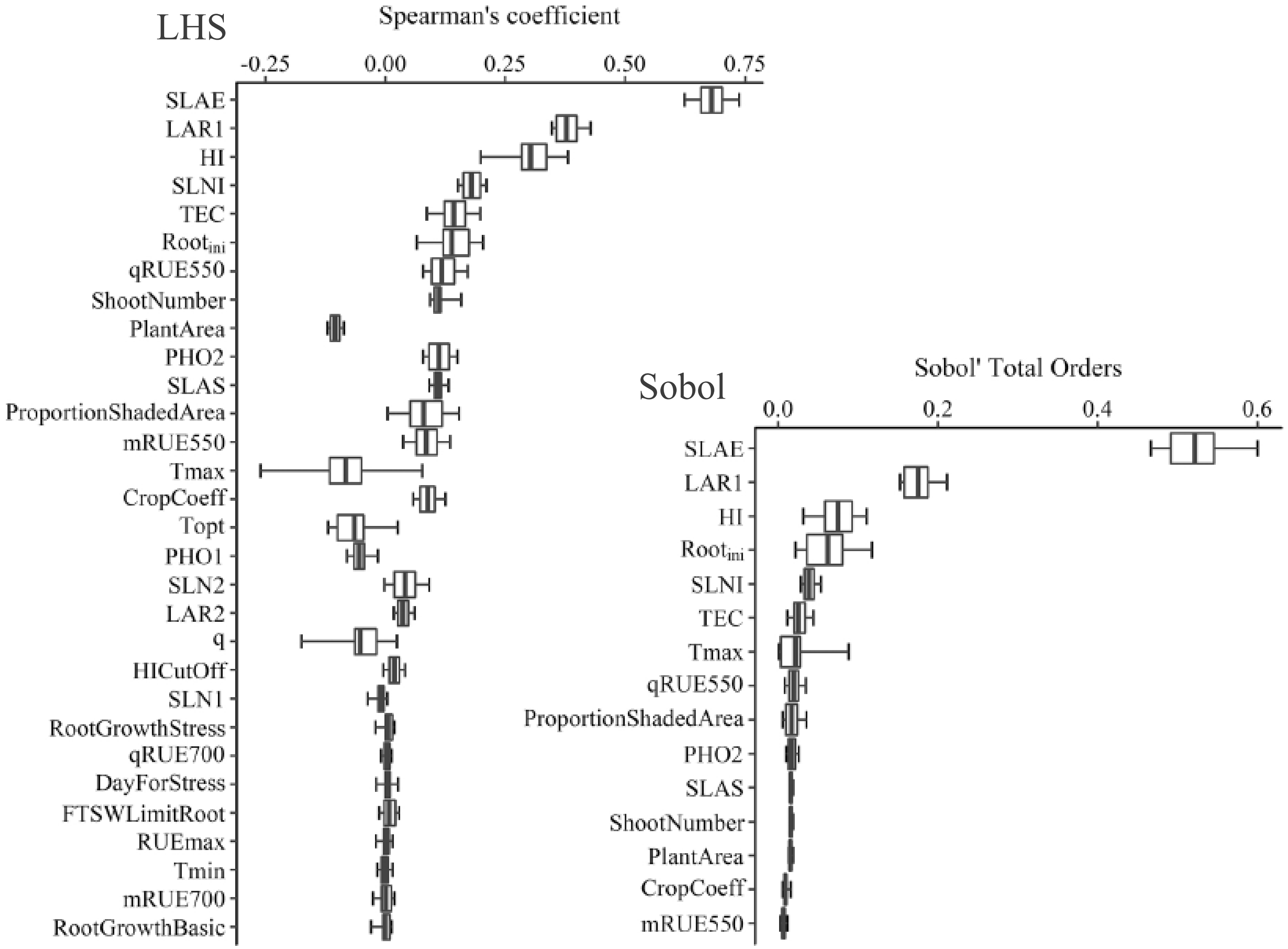



3. UNIFI.GrapeML Results

A Spanish case study

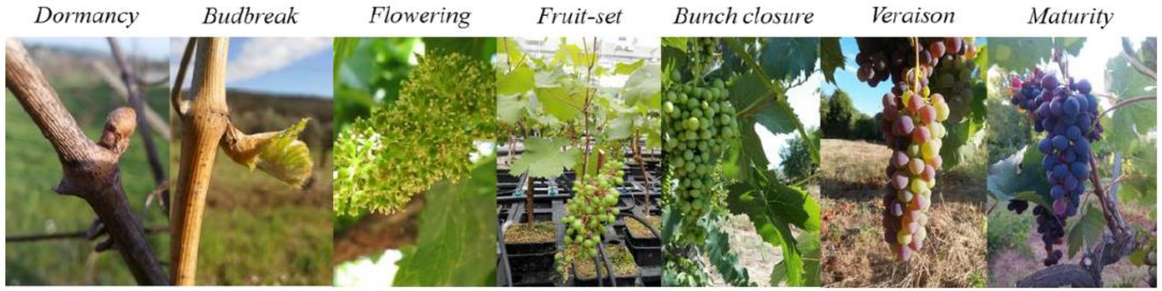


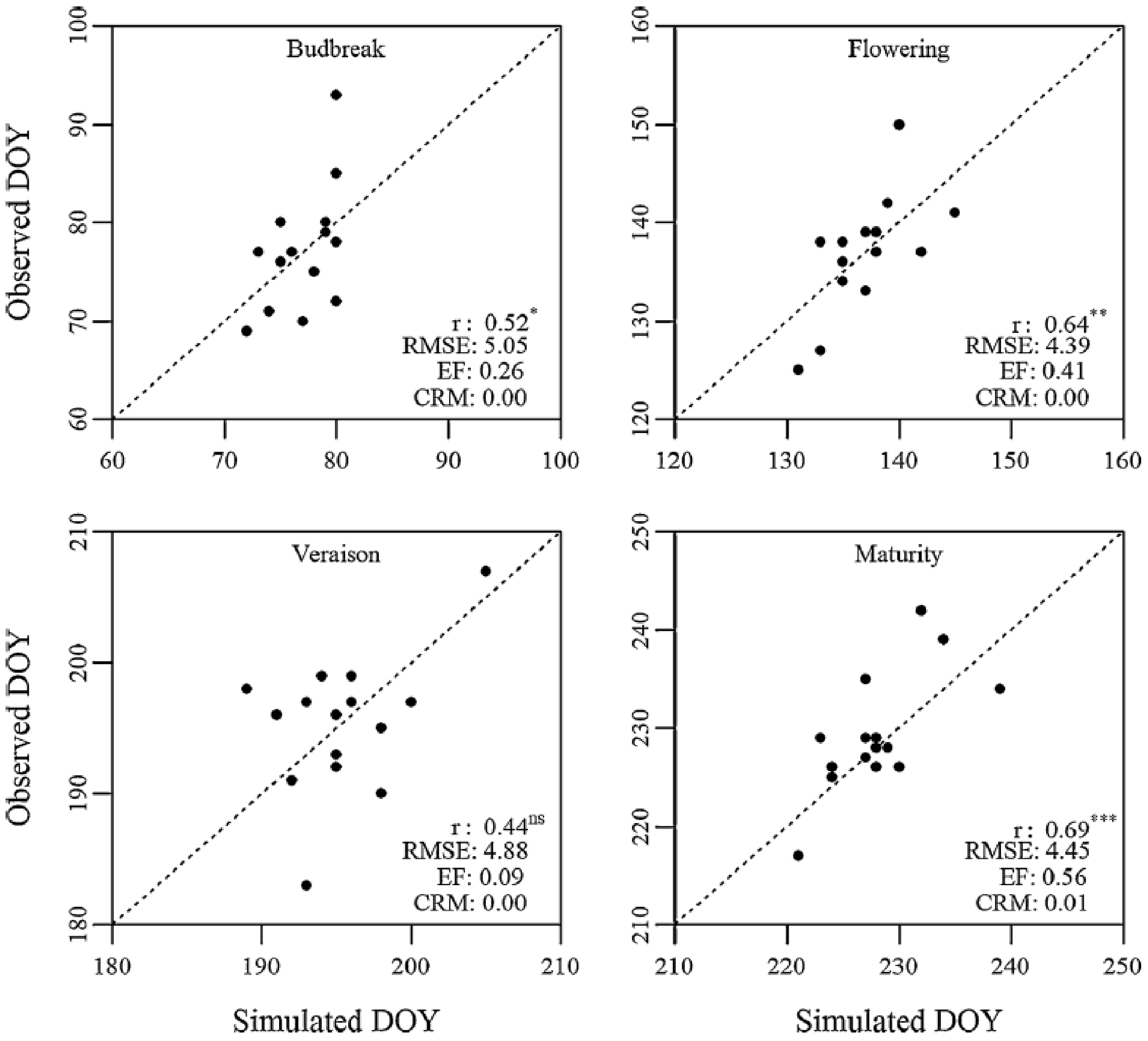
3. UNIFI.GrapeML Results

A Spanish case study

PHENOLOGY

Leolini et al. 2018b



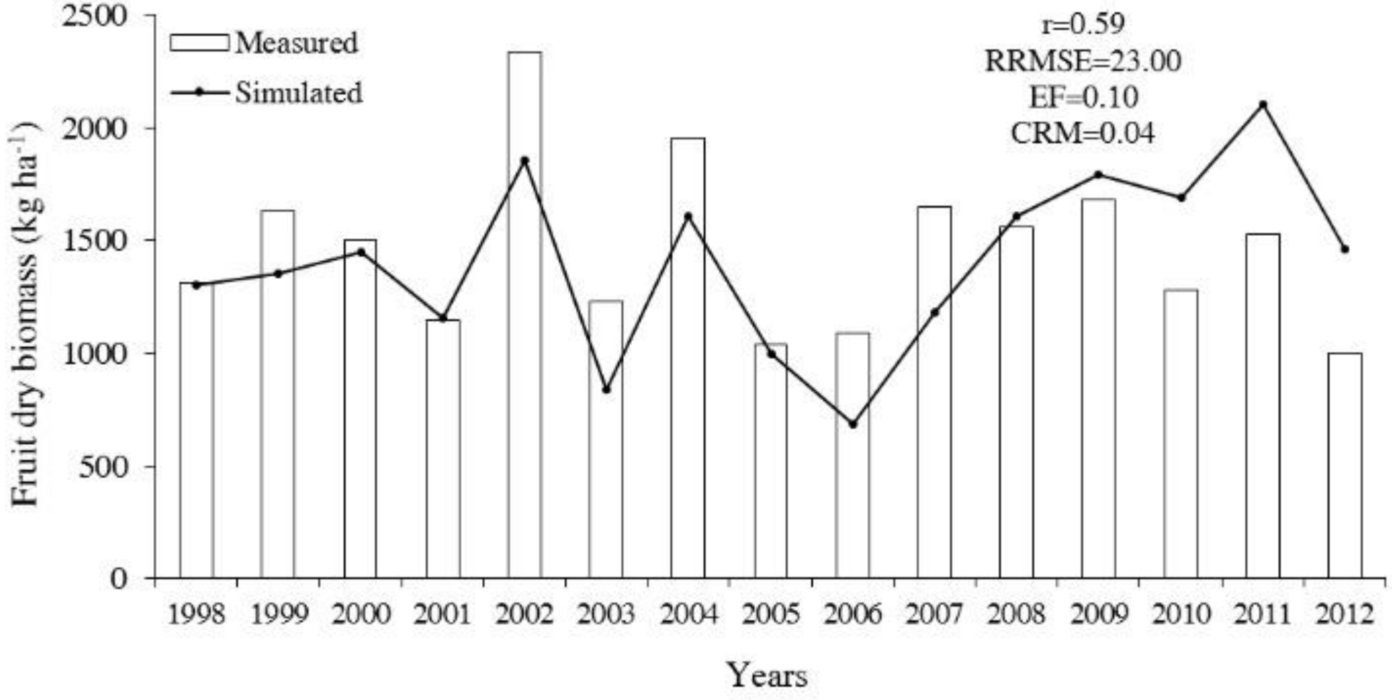


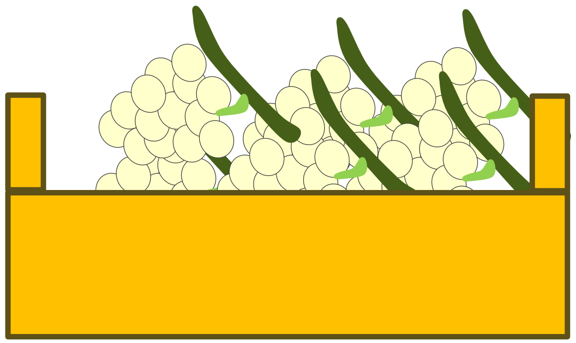
3. UNIFI.GrapeML Results

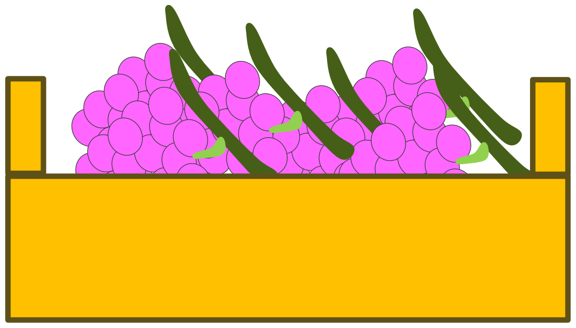
A Spanish case study

YIELD

Leolini et al. 2018b







CropSyst (Cropping Systems Simulation Model) is a multi-year and multi-crop simulation model that aims to evaluate the effect of cropping systems management on crop productivity and the environment (Stockle and Nelson, 1994; Stockle et al. 2003)

EFFECTS

Climate, soils and management

⇩

Cropping system productivity

IMPACTS

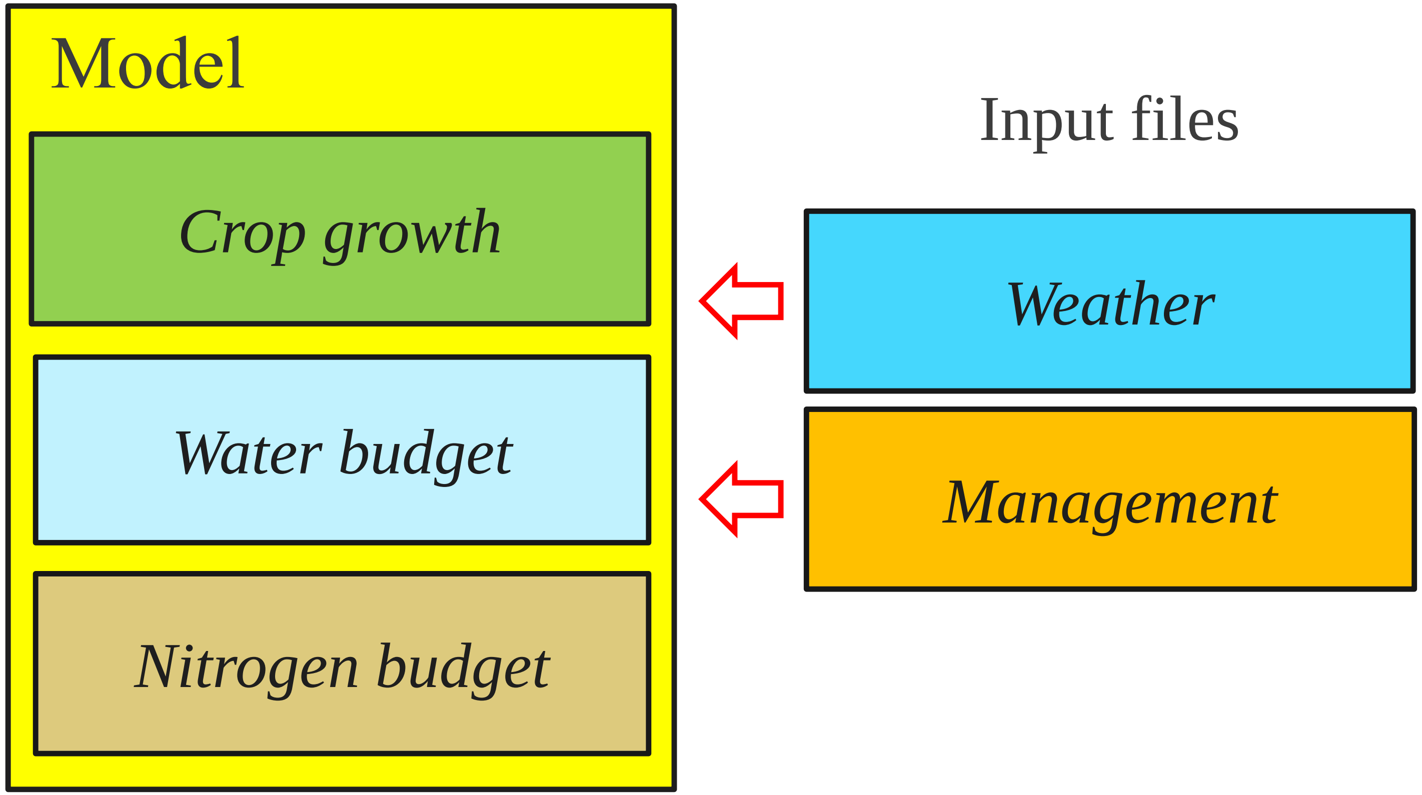
Cropping systems management

⇩

Environment

The model code is written in Pascal (DOS version) and C++ (Windows versions) programming language while its user-friendly interface allows an easy manage by different model users

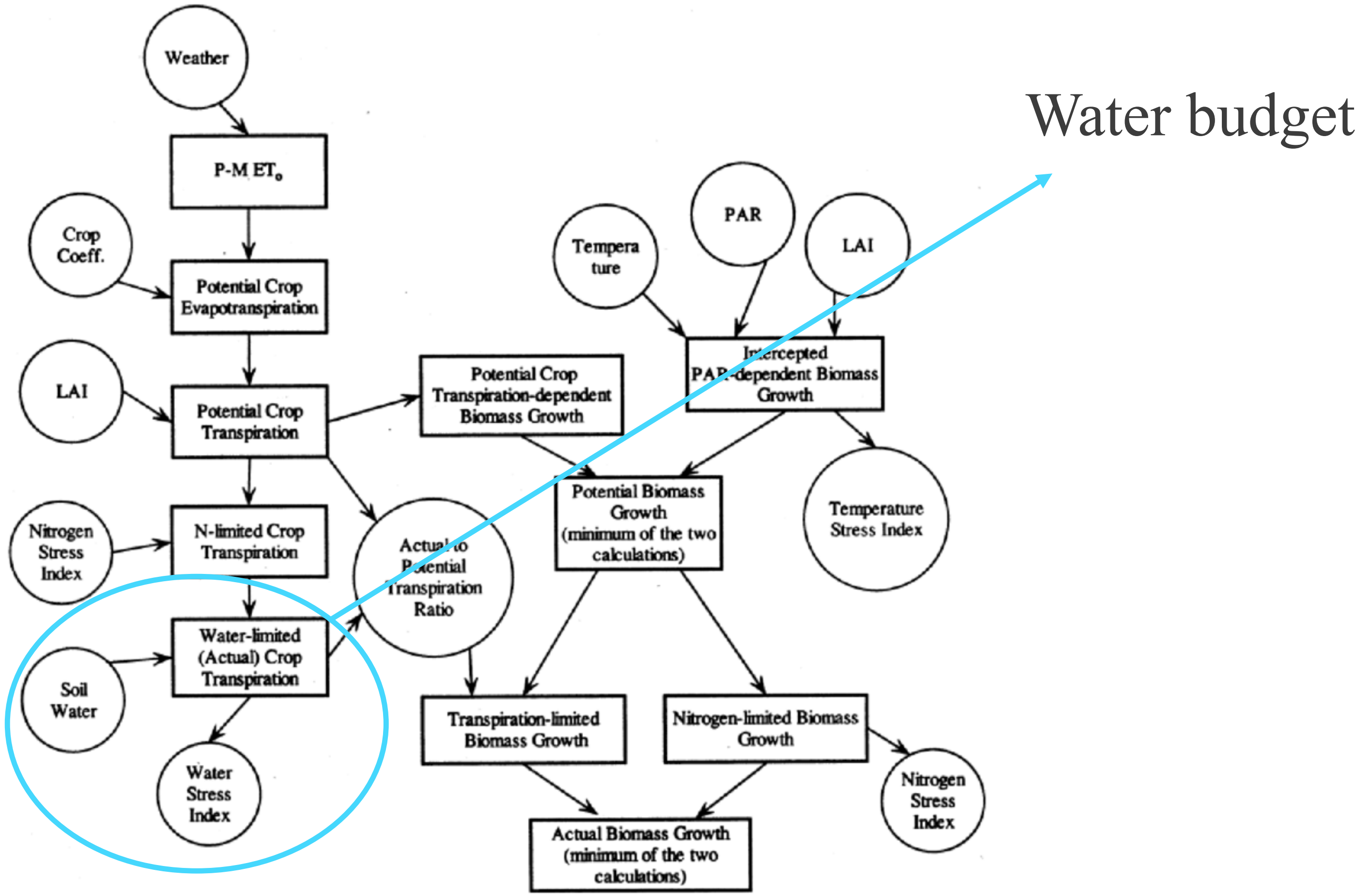
CropSyst is constituted by three main components (crop growth, water budget and nitrogen budget) and weather and management inputs



4. CropSyst description

CropSyst model workflow

CropSyst is constituted by three main components (crop growth, water budget and nitrogen budget) and weather and management inputs



Stockle et al. 2003

Clim4vitis

CropSyst model workflow

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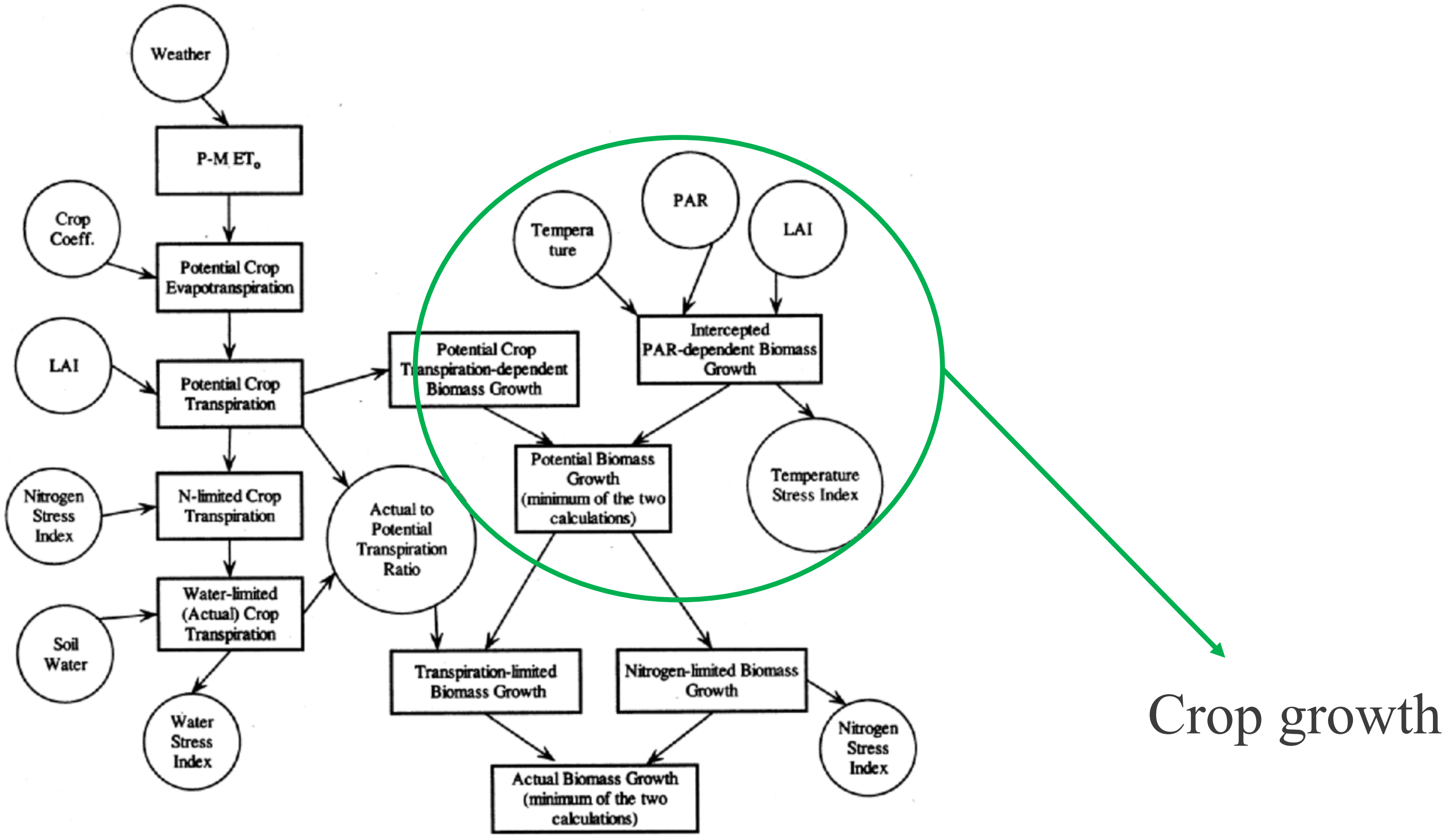

Stockle et al. 2003

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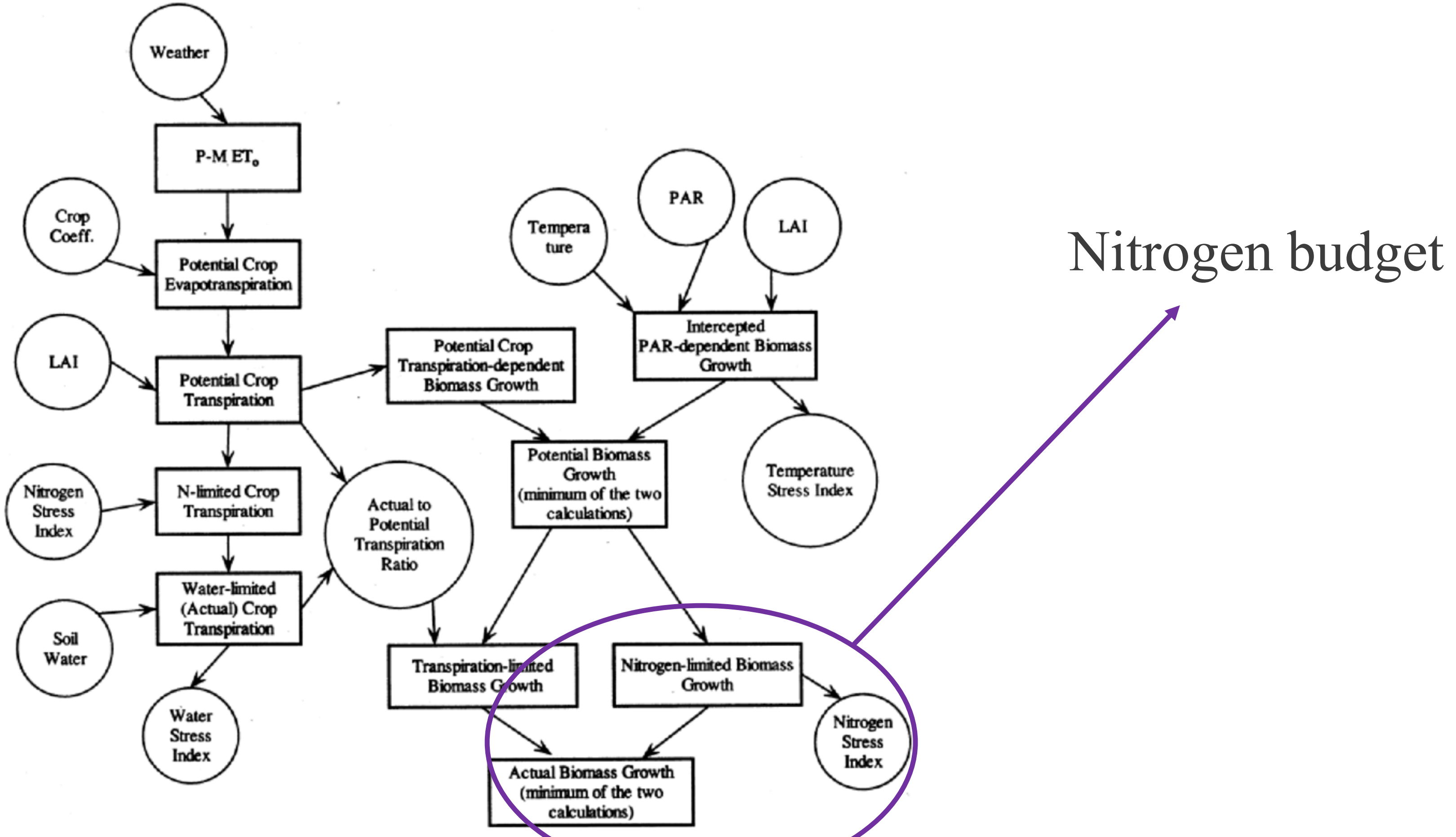


Stockle et al. 2003

4. CropSyst description

CropSyst inputs, outputs and parameters

INPUTS

Location File

- **Weather File**
  - Day Of Year
  - Precipitation (mm)
  - Maximum Air Temperature (°C)
  - Minimum Air Temperature (°C)
  - Global Solar Radiation (MJm^{-2})
- **Location File**
  - Latitude (decimal degrees)

INPUTS

Soil File

- **Soil File**
  - Description (Caption exchange capacity, pH, etc.)
  - Texture (Clay, Silt, Sand, Soil Layers,Thickness, etc.)
  - Hydraulic properties (Field capacity, Wilting point, Bulk density, etc.)

4. CropSyst description

CropSyst inputs, outputs and parameters

INPUTS

Management File

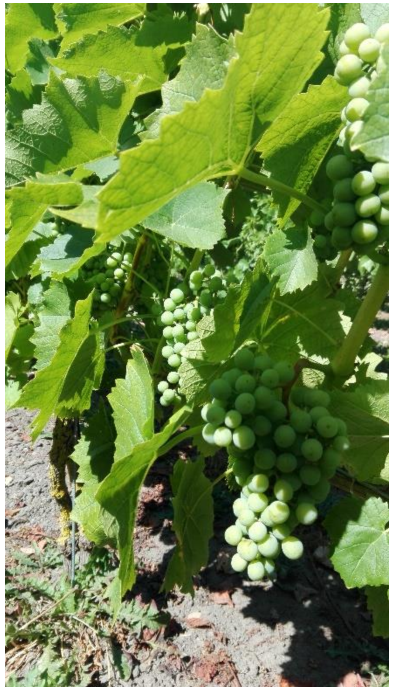
- **Management File**
  - Planting (Fixed or computed date)
  - Irrigation (Max irrigation application, Max allowable depletion, etc.)
  - Auto Fertilization (None, Optimal N allocated in crop tissues, Automatic)
  - Specific Fertilization (relative date or synchronization)
  - Clipping (Specific, Automatic or Periodic)
  - Conservation (Soil conservation practice factor, Parameters for runoff, etc.)
  - Tillage/Residue (Specific tillage operation and residue)
  - Harvest (starting and ending date, etc.)

4. CropSyst description

CropSyst inputs, outputs and parameters

INPUTS

Crop File

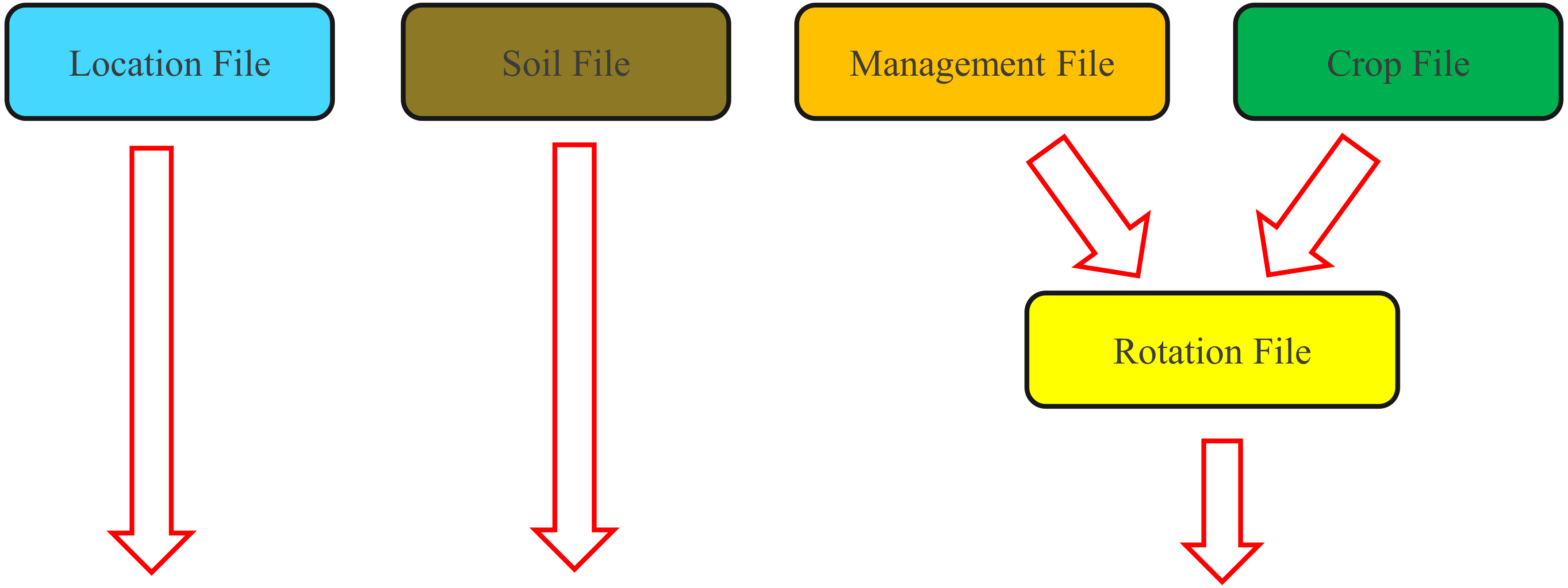


- **Crop File**
  - Classification (Type of crop)
  - Growth (Aboveground biomass, Light to aboveground biomass conversion, etc.)
  - Morphology (Max root depth, Initial green leaf area index, specific leaf area, etc.)
  - Phenology (Degree days for emergence, flowering, veraison, maturity, etc.)
  - Harvest (Max fruit load, Fraction of total solids, etc.)
  - Residue (Decomposition time constant, Area to mass ratio of residue cover, etc.)
  - Nitrogen (Nitrogen fixation, etc.)
  - Salinity (Soil solution osmotic potential for 50% yield reduction, etc.)
  - CO_2 (Baseline ref. atmospheric CO_2 concentration, etc.)
  - Dormancy (Avg temp for 7 days of consecutive dormancy, strating and ending date, etc.)
  - Hardiness (Sensitive to cold temperature)

4. CropSyst description

CropSyst inputs, outputs and parameters

INPUTS

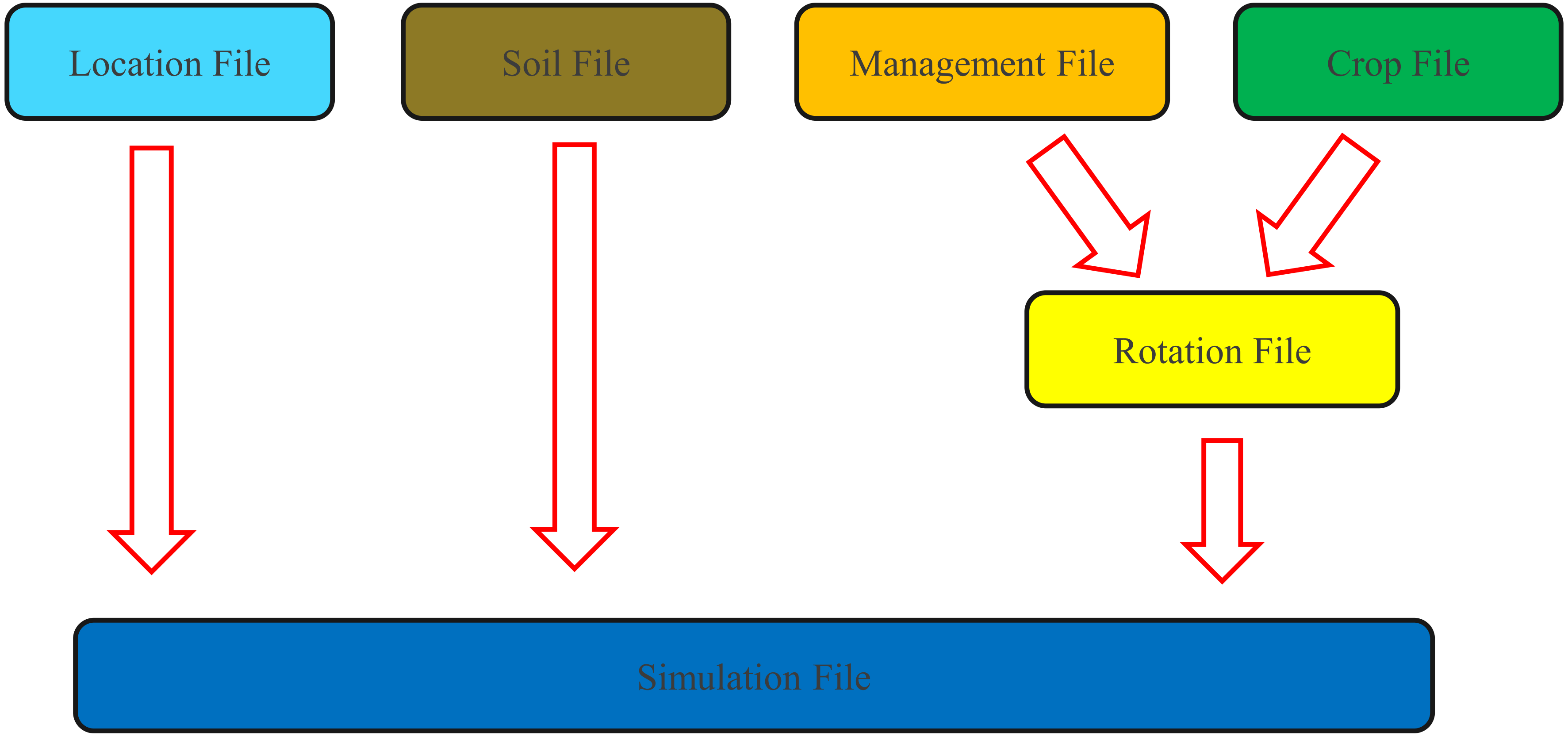


- **Rotation File**
  - Planting date
  - Rotation period (End, Year in each rotation cycle, etc.)

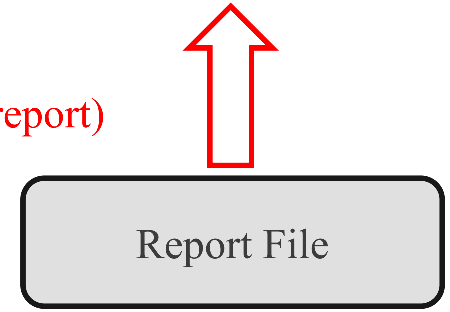
4. CropSyst description

CropSyst inputs, outputs and parameters

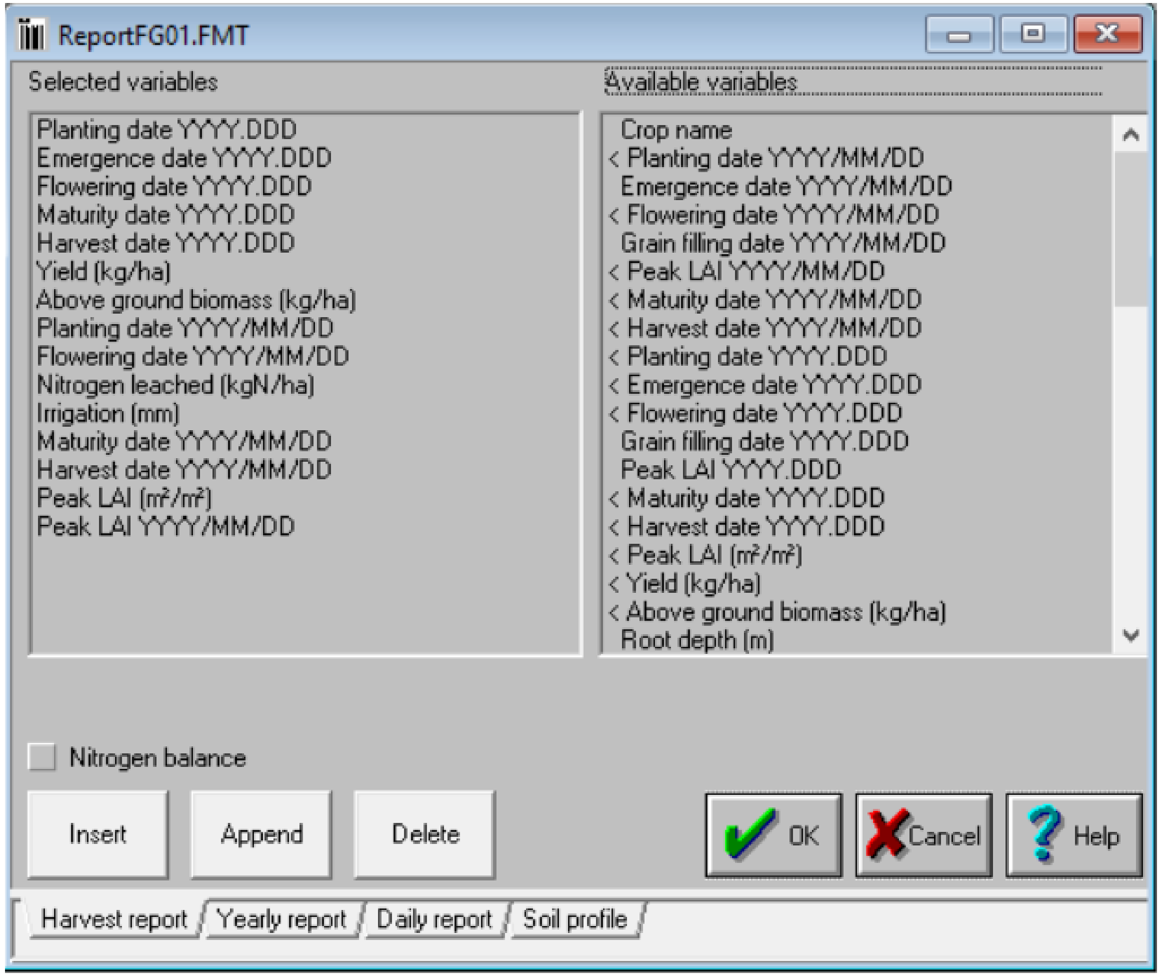
INPUTS

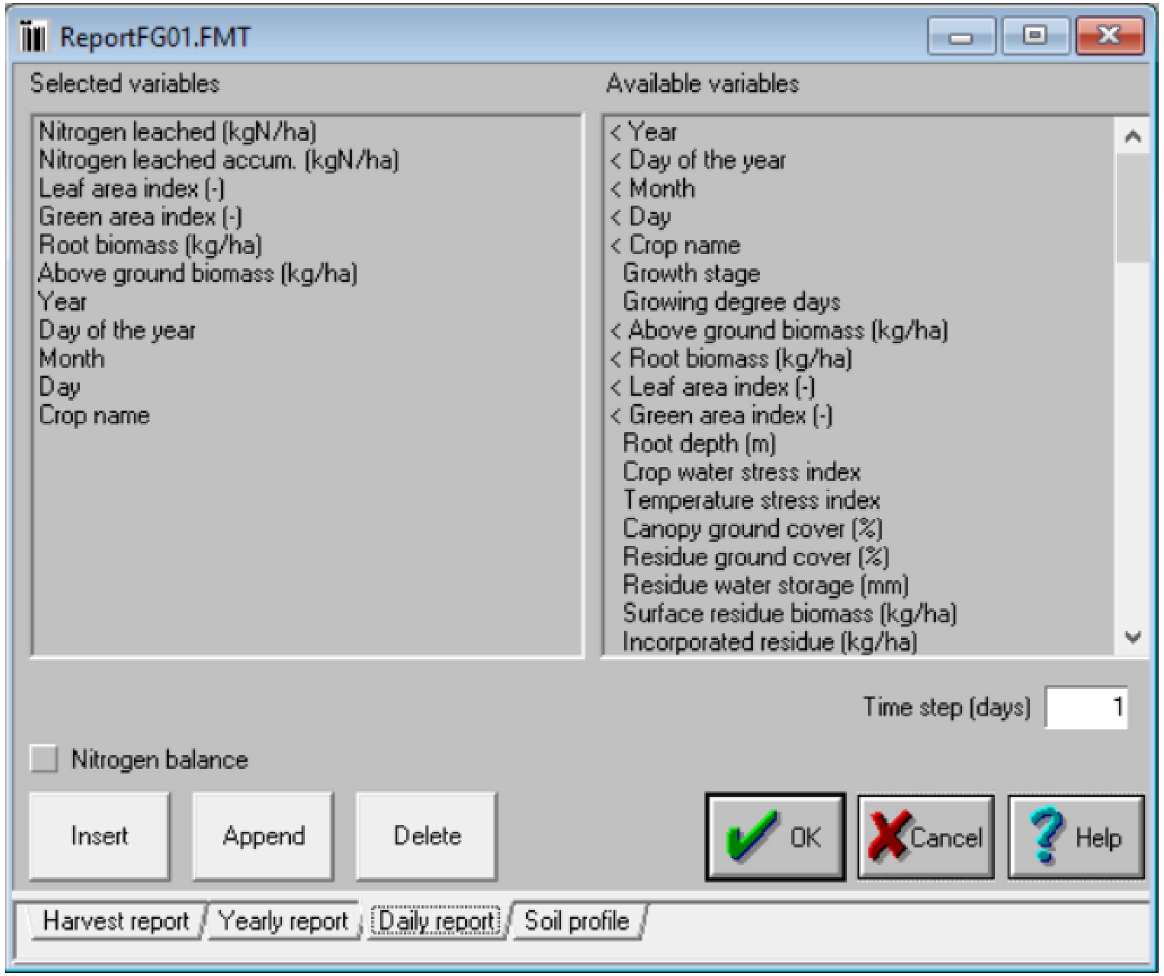


- **Report File**
  - Output selection (Harvest, Yearly, Daily, Soil report)



OUTPUTS

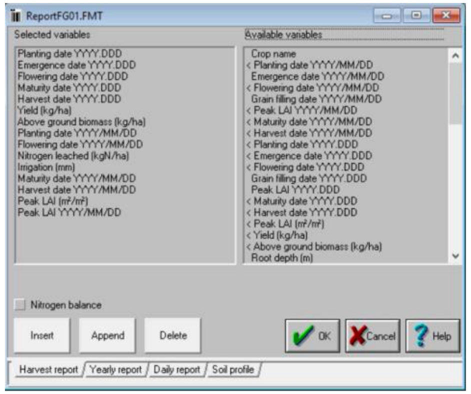

ReportFG01.FMT
Selected variables
Planting date YYYY.DDD
Emergence date YYYY.DDD
Flowering date YYYY.DDD
Maturity date YYYY.DDD
Harvest date YYYY.DDD
Yield (kg/ha)
Above ground biomass (kg/ha)
Planting date YYYY/MM/DD
Flowering date YYYY/MM/DD
Nitrogen leached (kgN/ha)
Irrigation (mm)
Maturity date YYYY/MM/DD
Harvest date YYYY/MM/DD
Peak LAI (m²/m²)
Peak LAI YYYY/MM/DD
Available variables
Crop name
< Planting date YYYY/MM/DD
Emergence date YYYY/MM/DD
< Flowering date YYYY/MM/DD
Grain filling date YYYY/MM/DD
< Peak LAI YYYY/MM/DD
< Maturity date YYYY/MM/DD
< Harvest date YYYY/MM/DD
< Planting date YYYY.DDD
< Emergence date YYYY.DDD
< Flowering date YYYY.DDD
Grain filling date YYYY.DDD
Peak LAI YYYY.DDD
< Maturity date YYYY.DDD
< Harvest date YYYY.DDD
< Peak LAI (m²/m²)
< Yield (kg/ha)
< Above ground biomass (kg/ha)
Root depth (m)
Nitrogen balance
Insert
Append
Delete
OK
Cancel
Help
Harvest report
Yearly report
Daily report
Soil profile

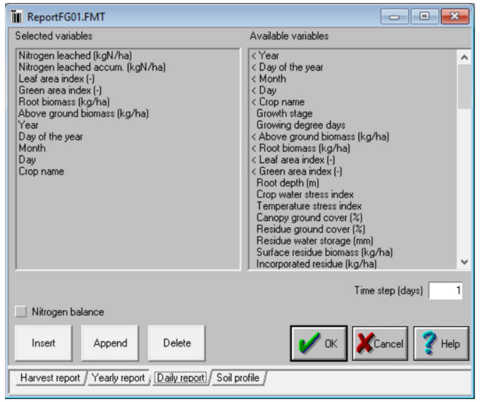

ReportFG01.FMT
Selected variables
Nitrogen leached (kgN/ha)
Nitrogen leached accum. (kgN/ha)
Leaf area index (-)
Green area index (-)
Root biomass (kg/ha)
Above ground biomass (kg/ha)
Year
Day of the year
Month
Day
Crop name
Available variables
< Year
< Day of the year
< Month
< Day
< Crop name
Growth stage
Growing degree days
< Above ground biomass (kg/ha)
< Root biomass (kg/ha)
< Leaf area index (-)
< Green area index (-)
Root depth (m)
Crop water stress index
Temperature stress index
Canopy ground cover (%)
Residue ground cover (%)
Residue water storage (mm)
Surface residue biomass (kg/ha)
Incorporated residue (kg/ha)
Time step (days) 1
Nitrogen balance
Insert
Append
Delete
OK
Cancel
Help
Harvest report
Yearly report
Daily report
Soil profile

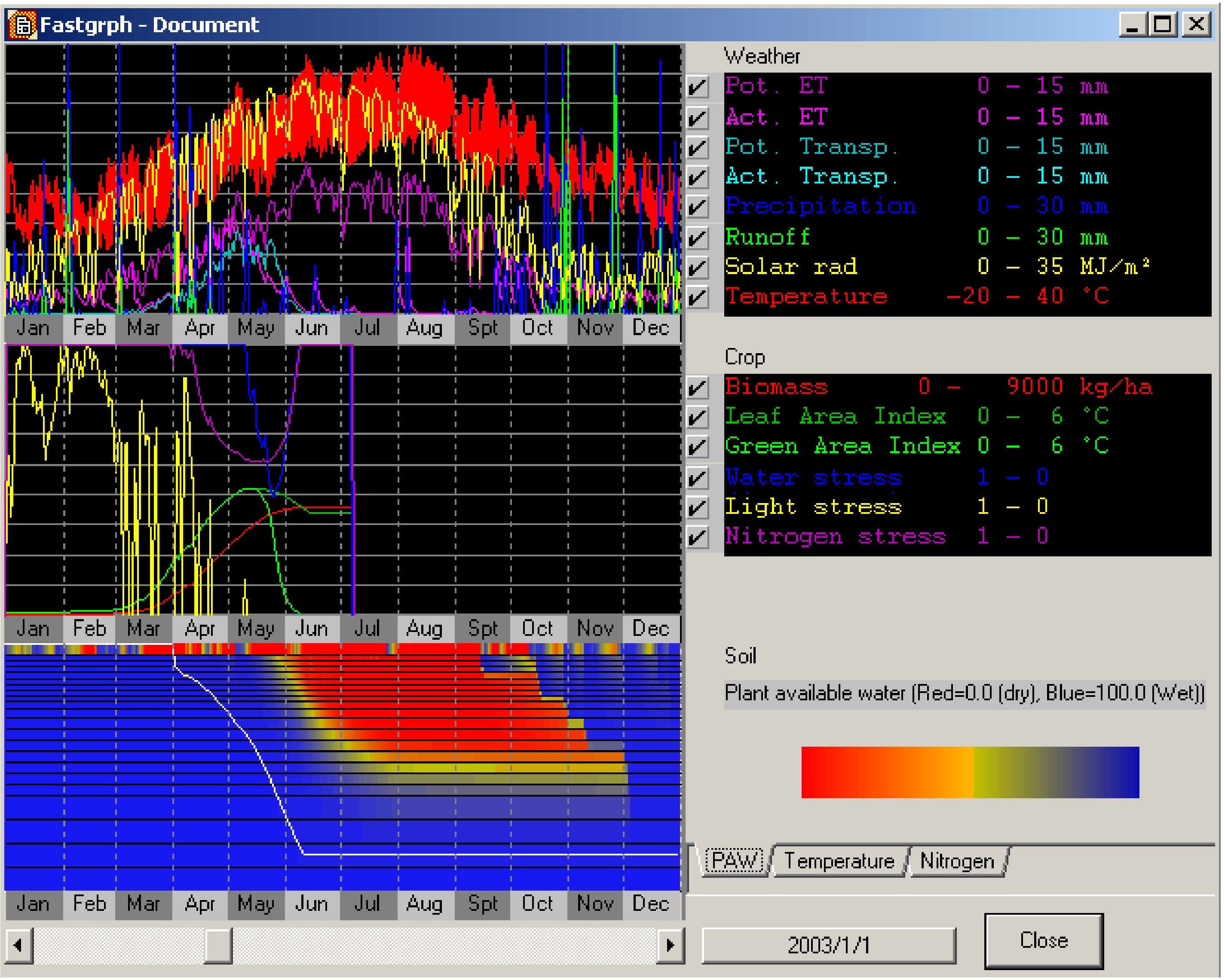
4. CropSyst description

CropSyst inputs, outputs and parameters

OUTPUTS

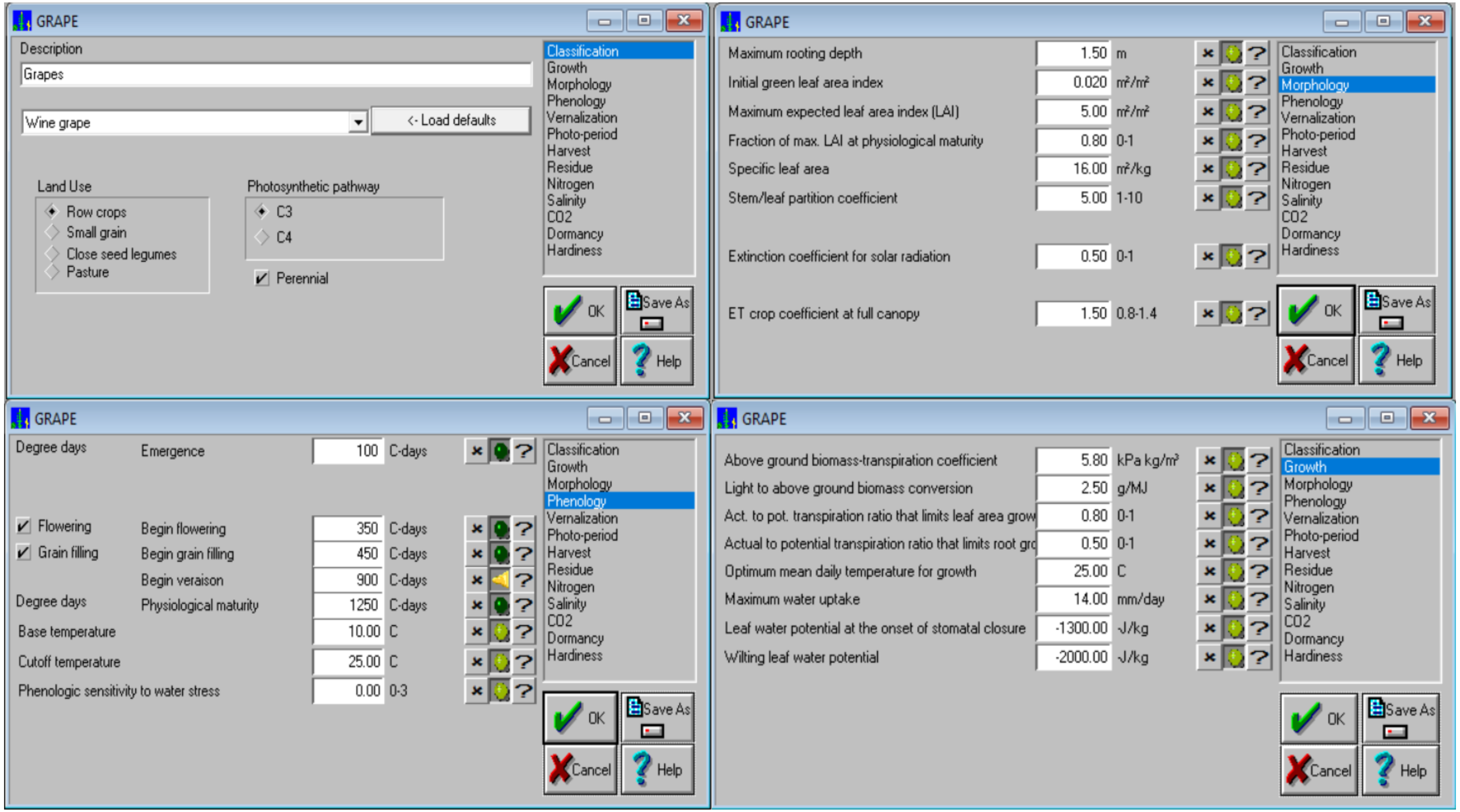






Wine grape parameters default can be loaded

PARAMETERS



A simple exercise – Input data

CropSyst model was tested for evaluating the responses of **grapevine growth and development** to different environmental conditions

Input

Weather data

- -Maximum Air Temperature (°C)
- -Minimum Air Temperature (°C)
- -Precipitation (mm)
- -Global Solar Radiation (MJ/m^2) *Estimated*

Tuscany

http://www.sir.toscana.it/

CropSyst model was tested for evaluating the responses of **grapevine growth and development** to different environmental conditions

Input

Soil data

Arbitrarily defined

Soil_1
10 cm = 60% Sand 15% Clay (*Sandy Loam*)
90 cm = 20% Sand 46% Clay (*Clay*)
Soil_2
10 cm = 45% Sand 15% Clay (*Loam*)
90 cm = 25% Sand 15% Clay (*Silty Loam*)
Soil_3
10 cm = 25% Sand 35% Clay (*Clay Loam*)
90 cm = 10% Sand 30% Clay (*Silty Clay Loam*)

Tuscany

CropSyst model was tested for evaluating the responses of **grapevine growth and development** to different environmental conditions

Input

Plant data

Sangiovese phenology collected for different sites from 2008 to 2010

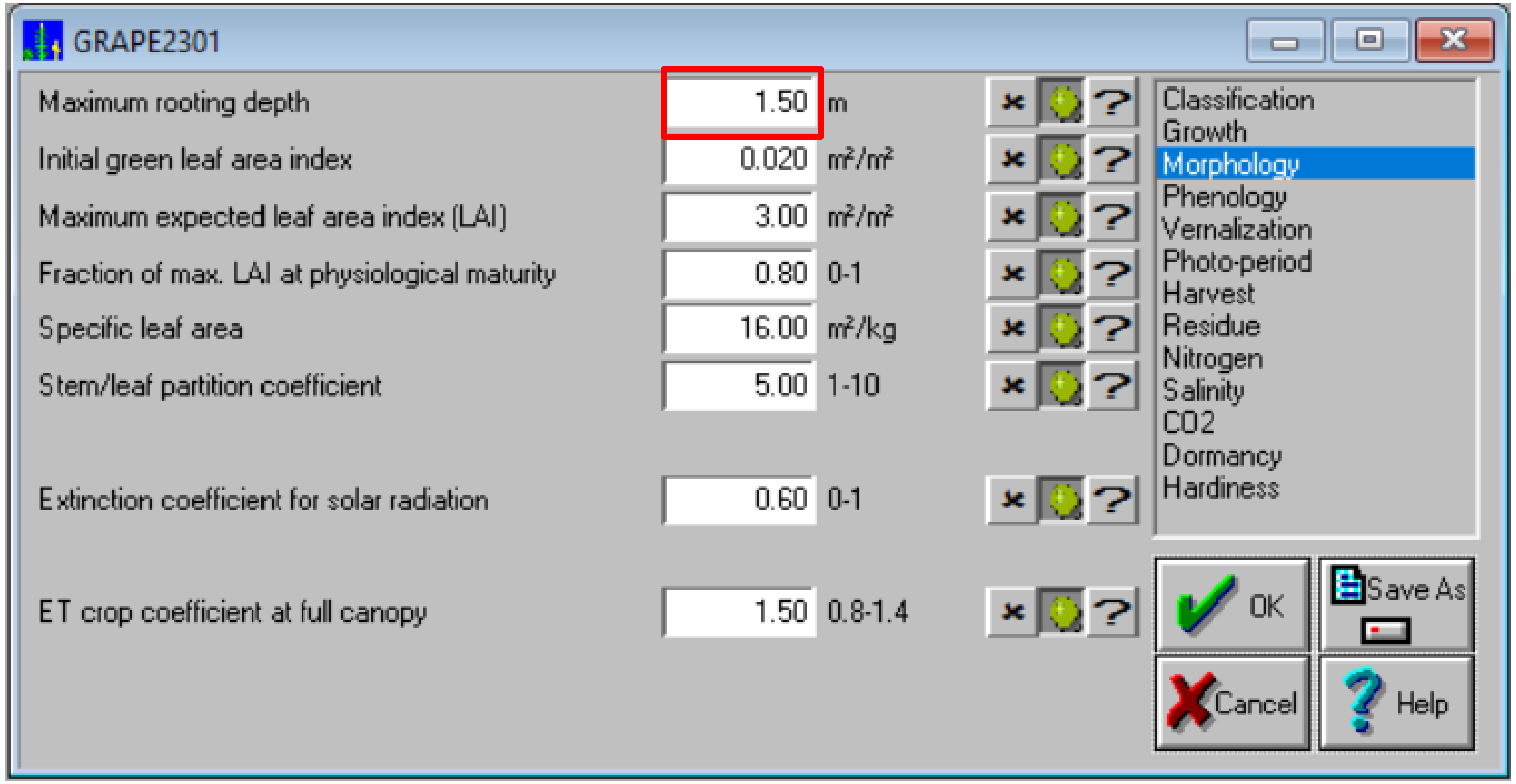
http://agroambiente.info.regione.toscana.it

Site	Year	B	IF	IV	M
Montalcino	2008	11/04	30/05	08/08	29/08
Rispescia	2008	11/04	23/05	25/07	08/08
Suvereto	2010	11/04	30/05	01/08	22/08
Peccioli	2009	04/04	30/05	-	08/08

B = Budbreak; **IF** = Initial Flowering; **IV** = Initial Veraison; **M** = Maturity

Tuscany

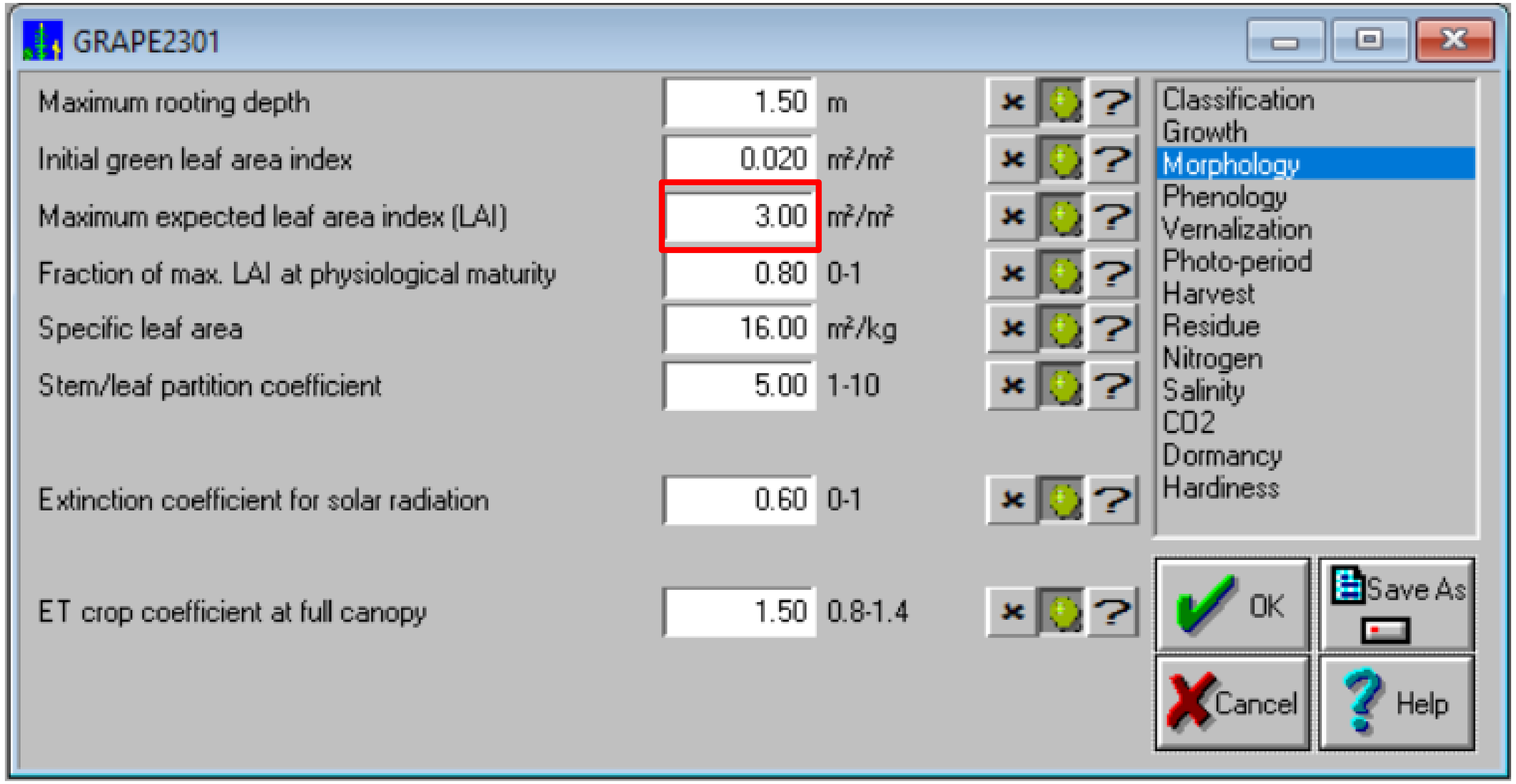
5. CropSyst Results
A simple exercise – Model parameters



Estimated considering the rooting depth of several cultivars (e.g. Smart et al. 2006)

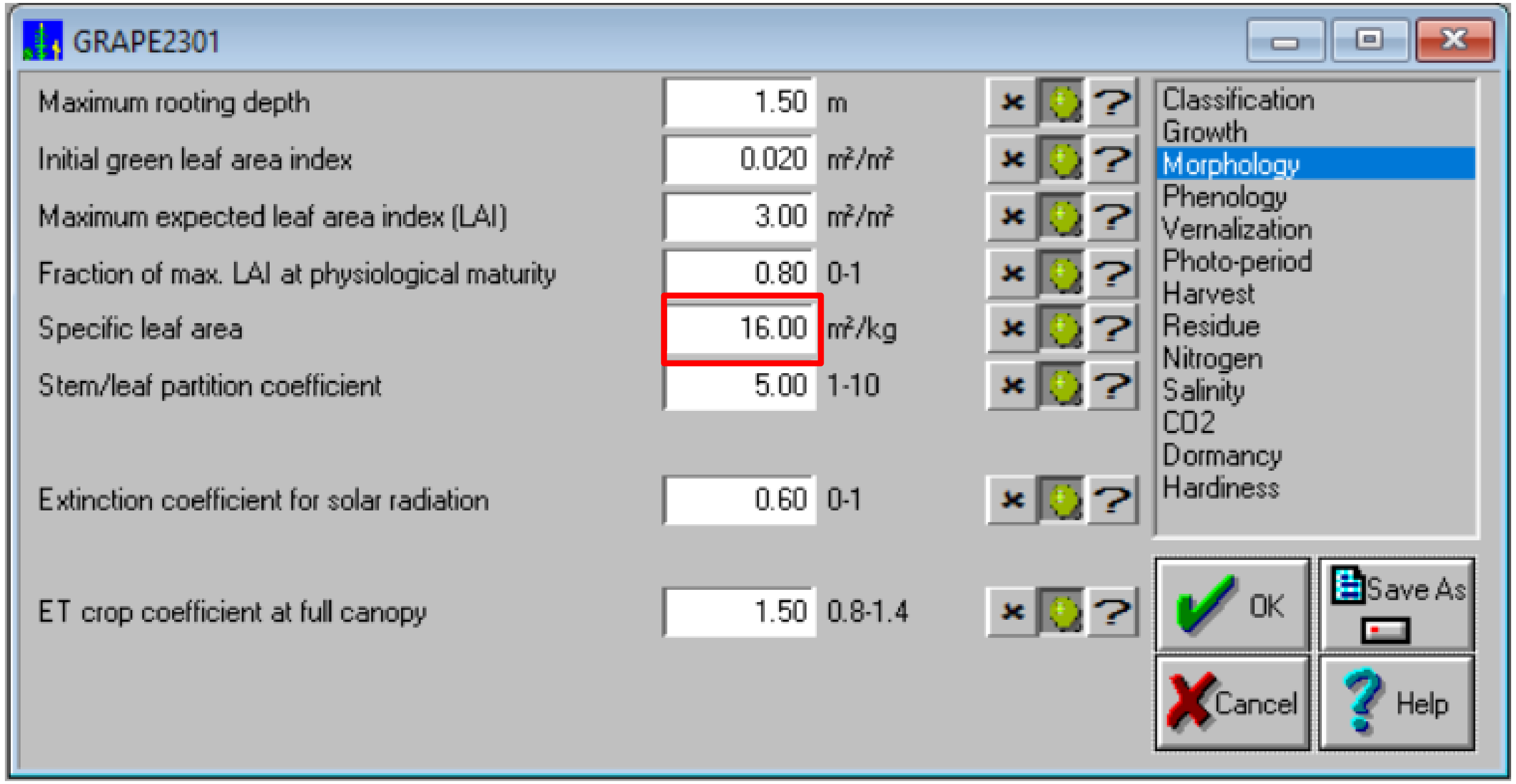
5. CropSyst Results

A simple exercise – Model parameters



Estimated considering different training system and vine spacing of Sangiovese (e.g. Palliotti et al. 2014, Filippetti et al. 2013, etc.)

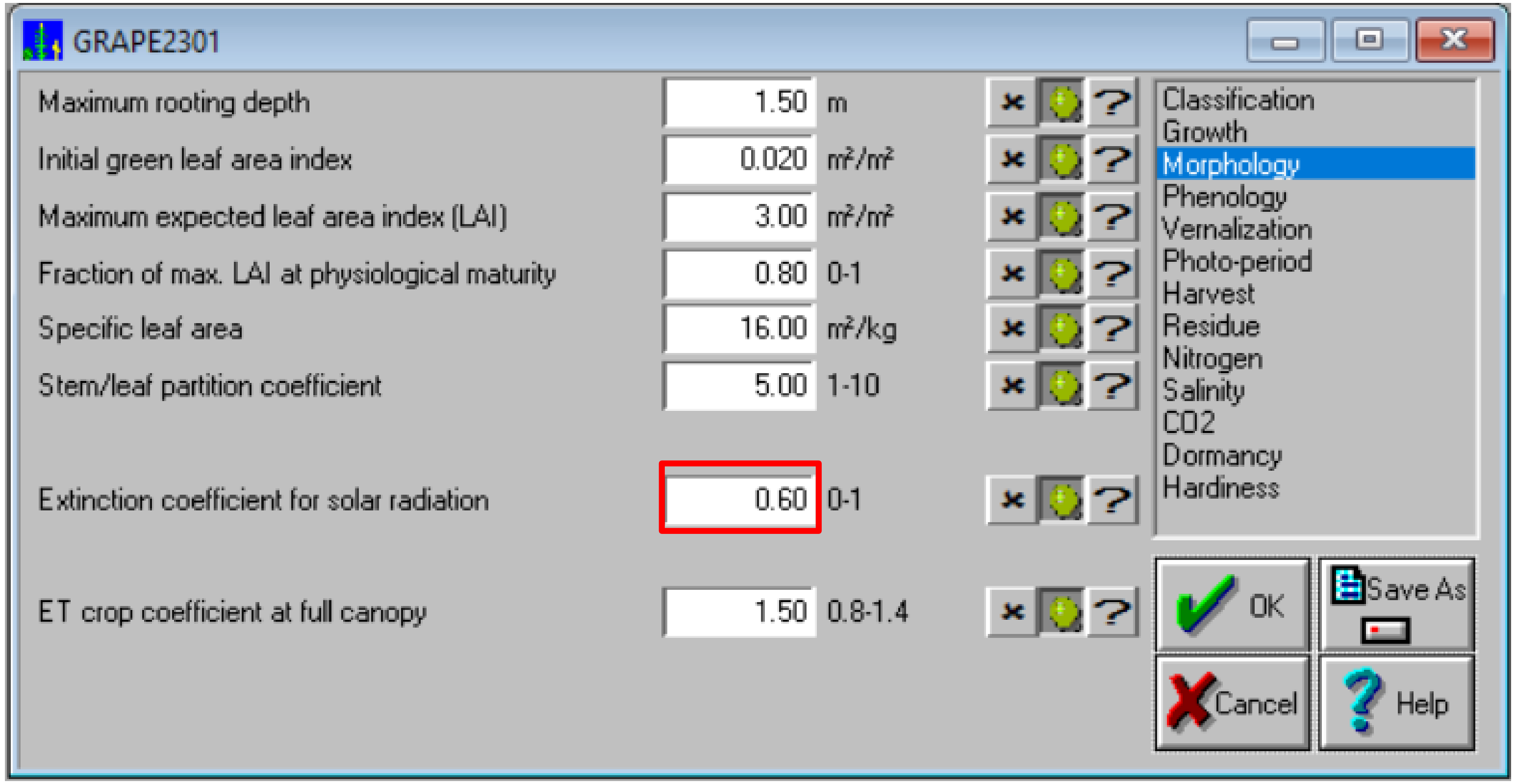
A simple exercise – Model parameters



Estimated from leaf area for primary shoots of Sangiovese (e.g. Palliotti et al. 2011)

5. CropSyst Results

A simple exercise – Model parameters

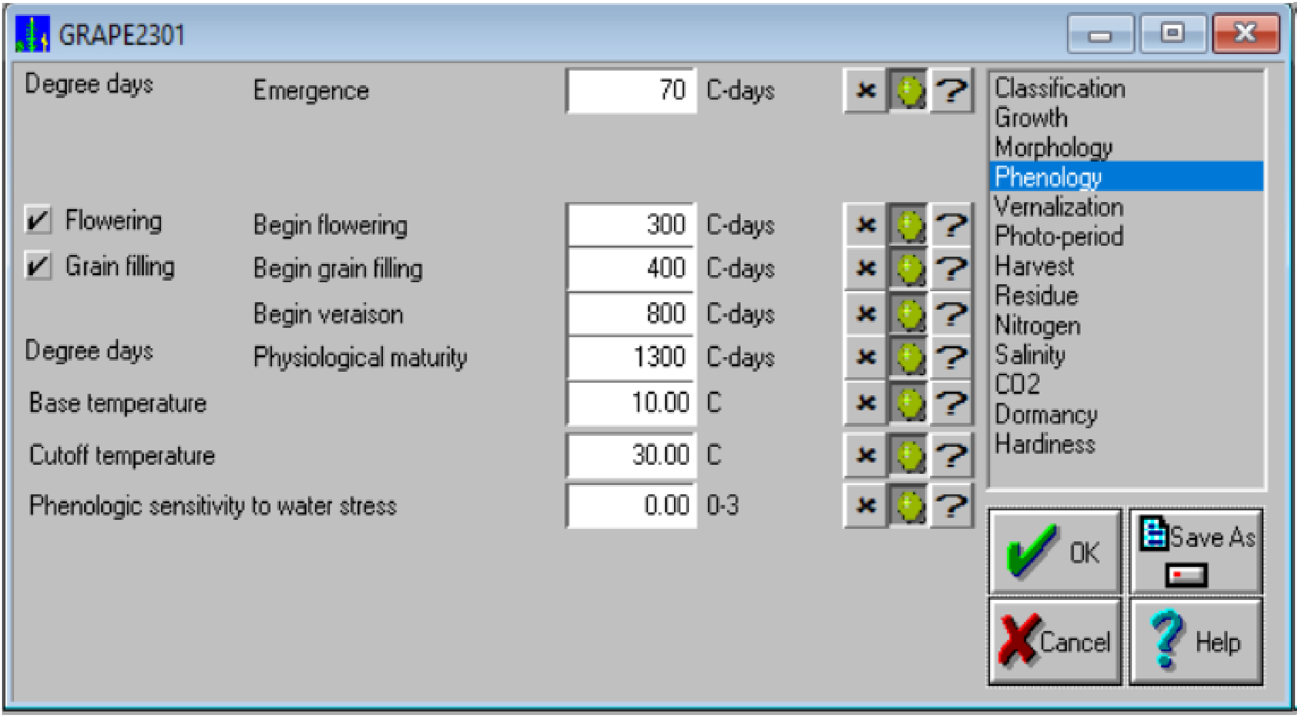


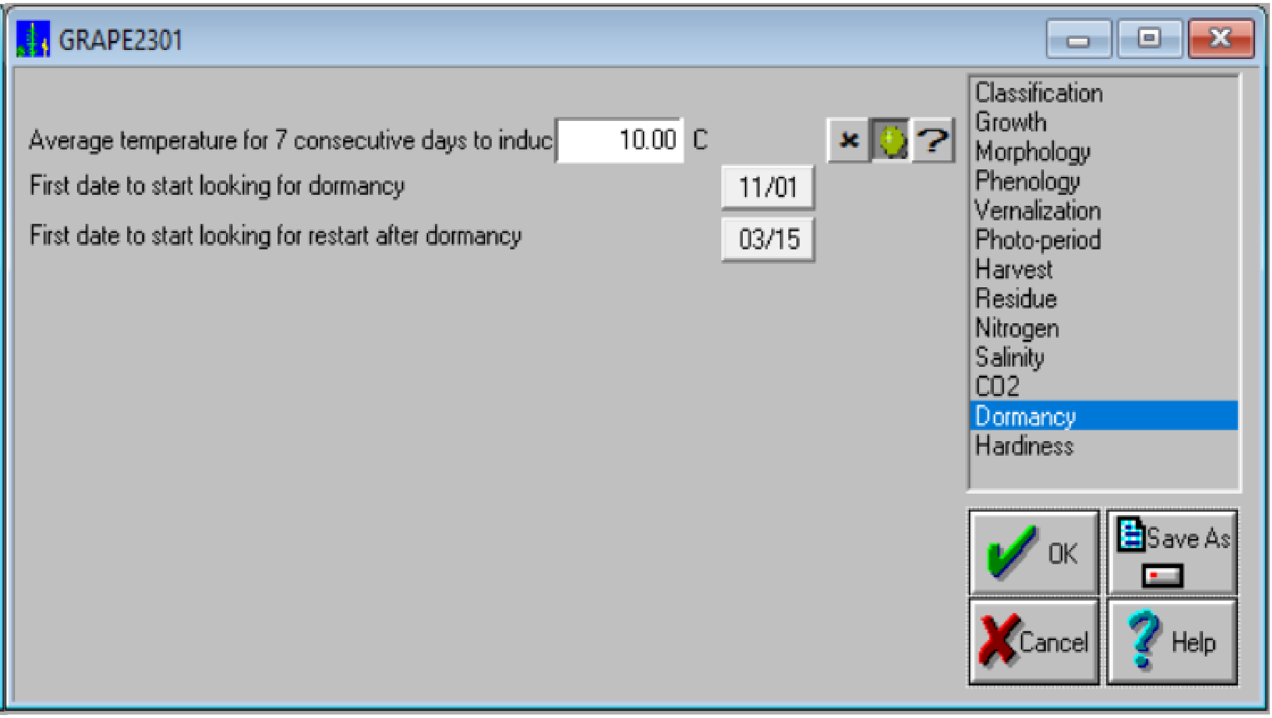
Derived by Poni et al. 2006 for Sangiovese

5. CropSyst Results

A simple exercise – Model parameters

Phenology and Dormancy values were calibrated based on the observed phenological data

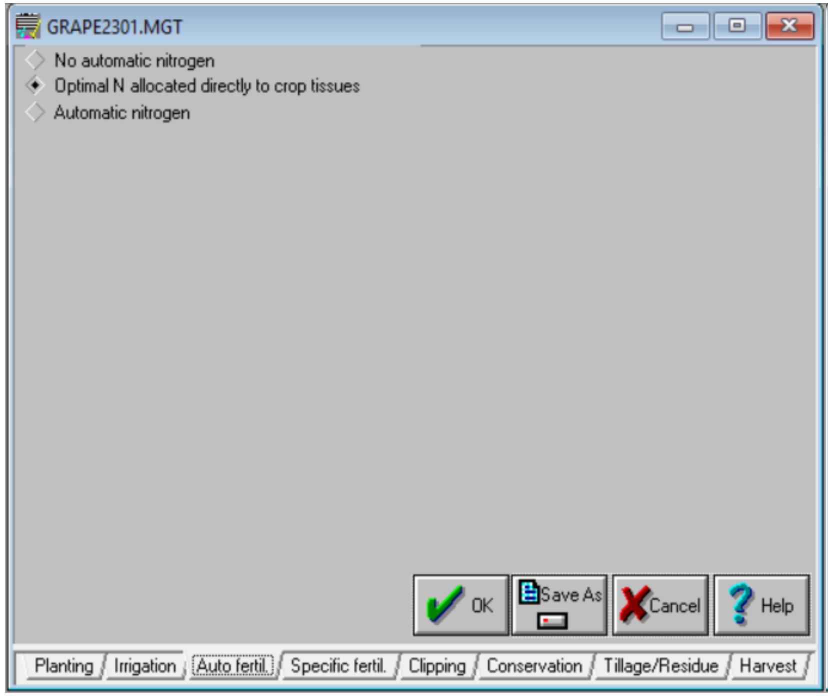


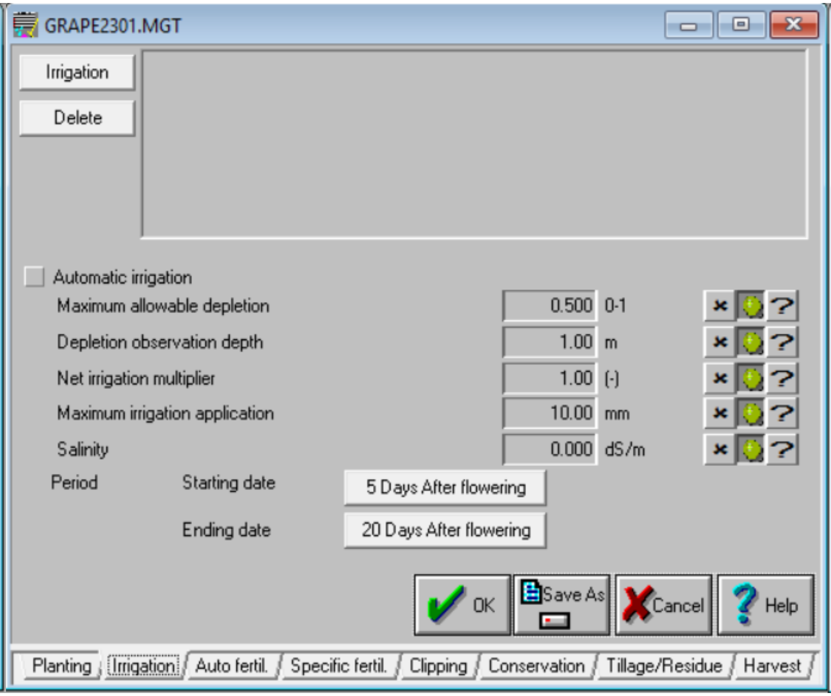


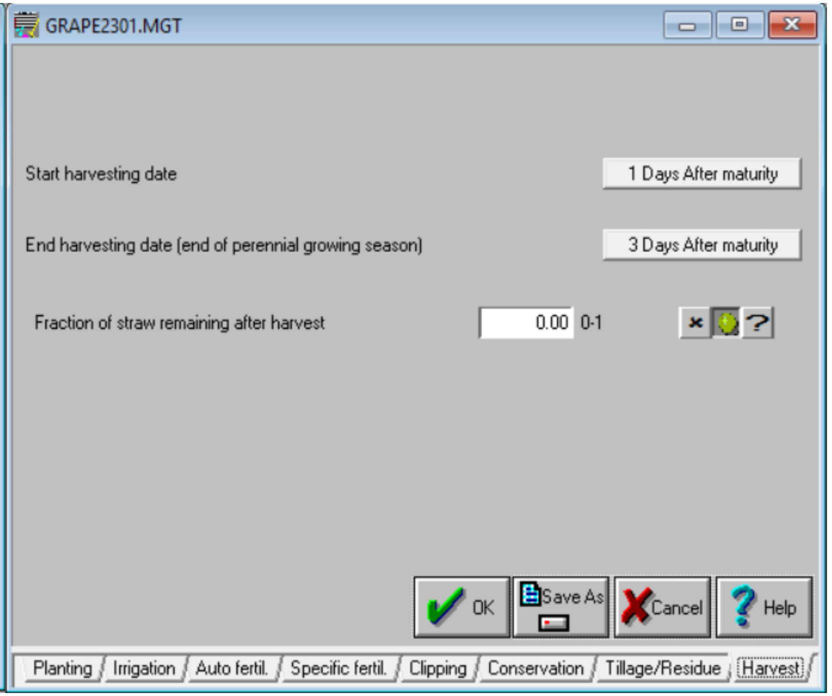
5. CropSyst Results

A simple exercise – Model parameters

The management file was set considering no irrigation and optimal nitrogen allocated to crop tissues and the harvest event from 1 to 3 days after maturity



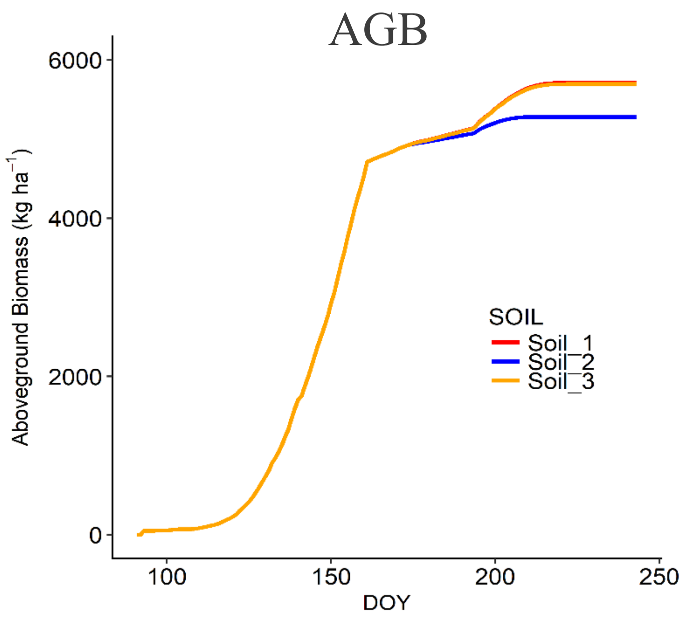


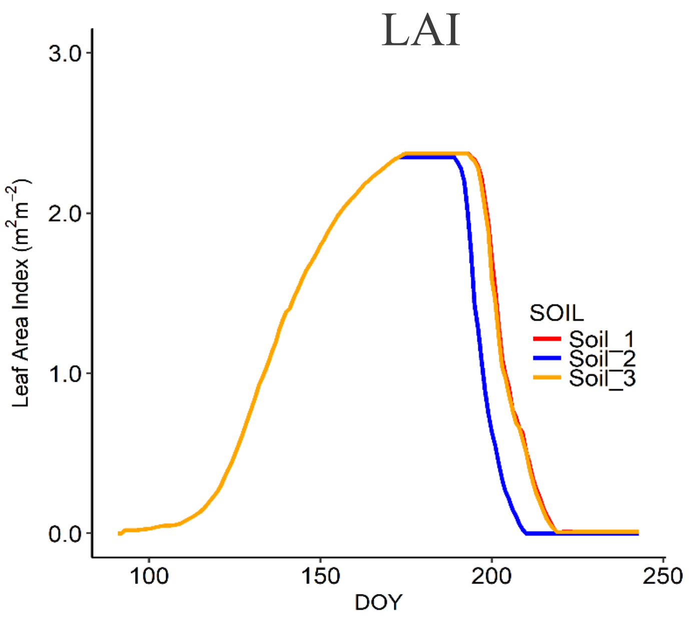


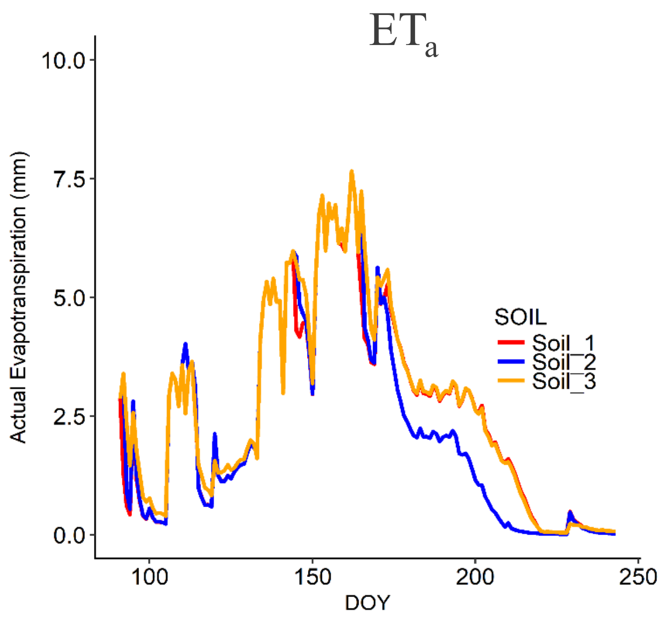
5. CropSyst Results

A simple exercise – Grapevine growth simulation

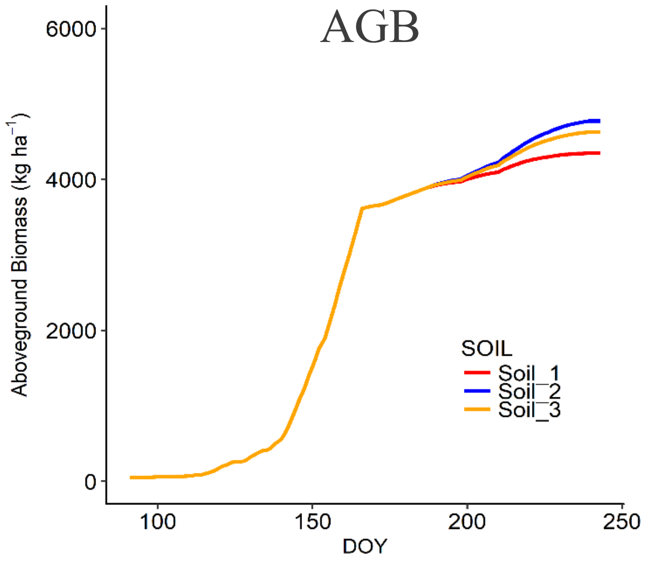
Rispescia (GR)

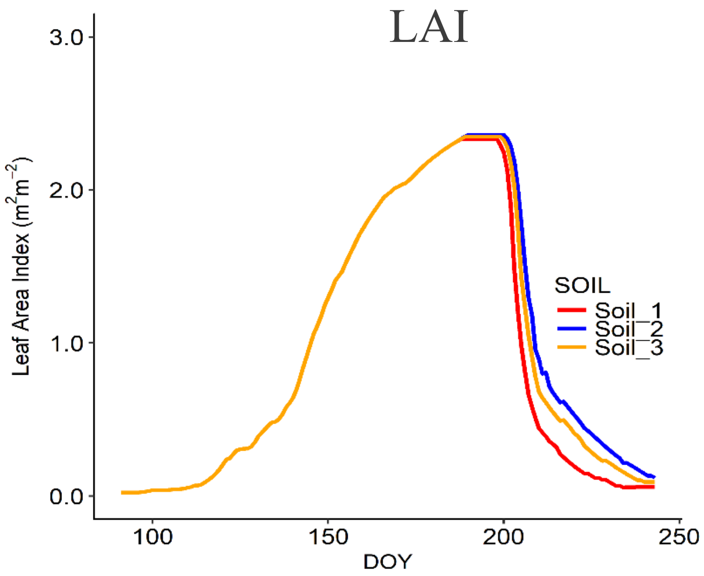


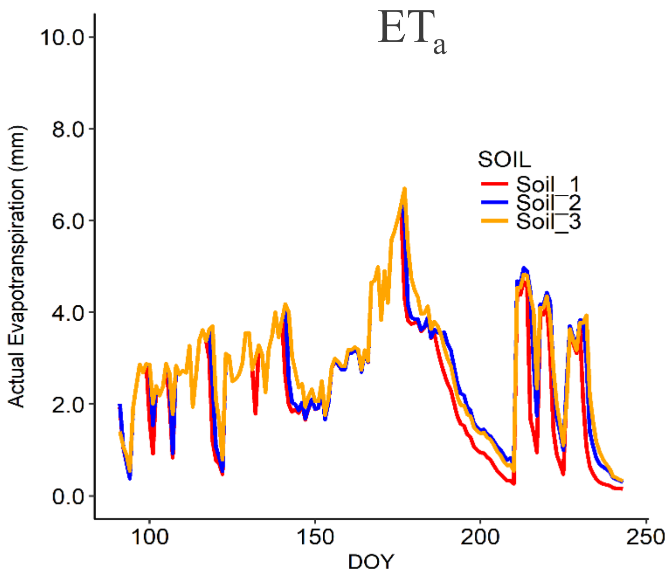




Badia (FI)



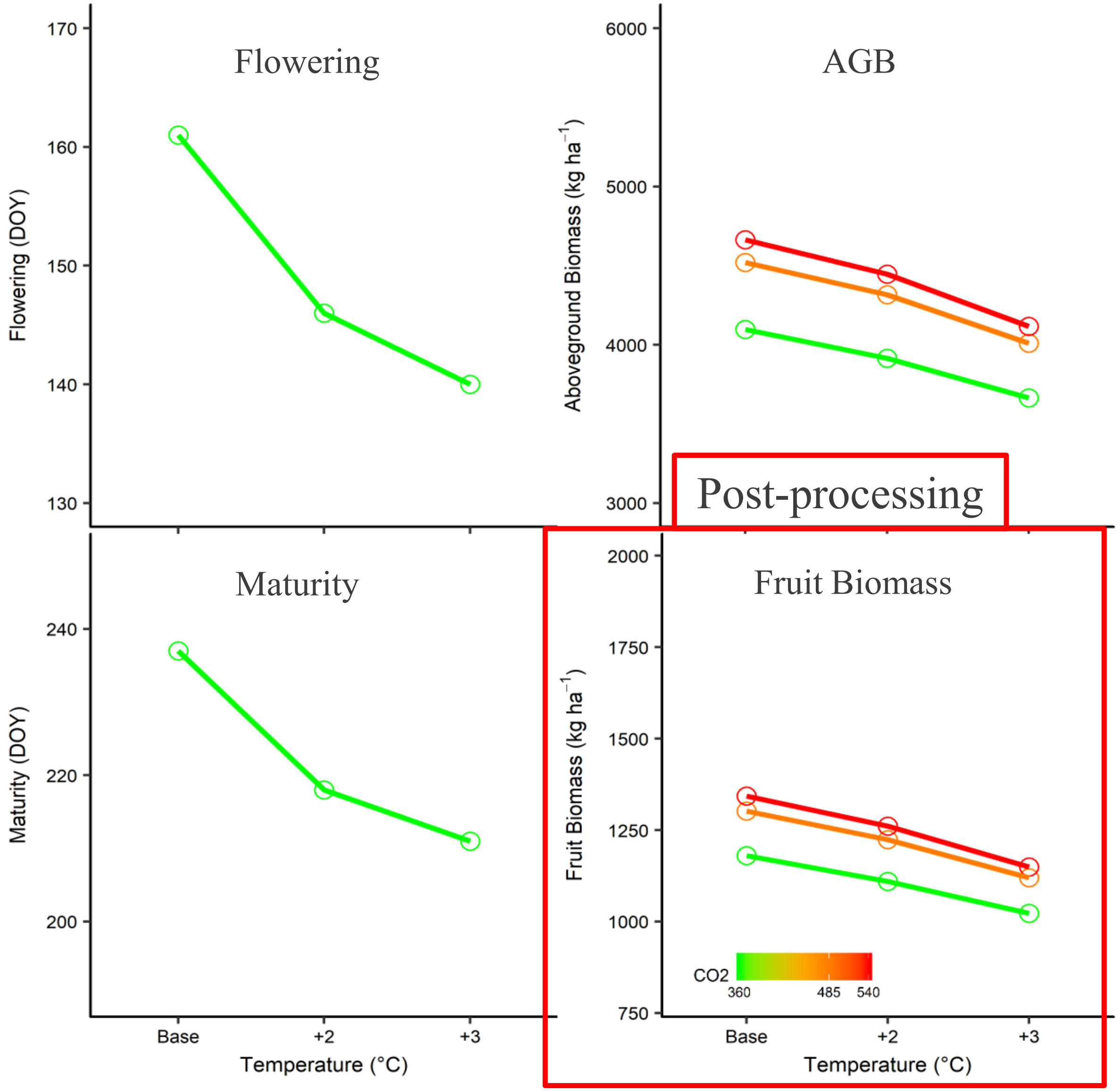




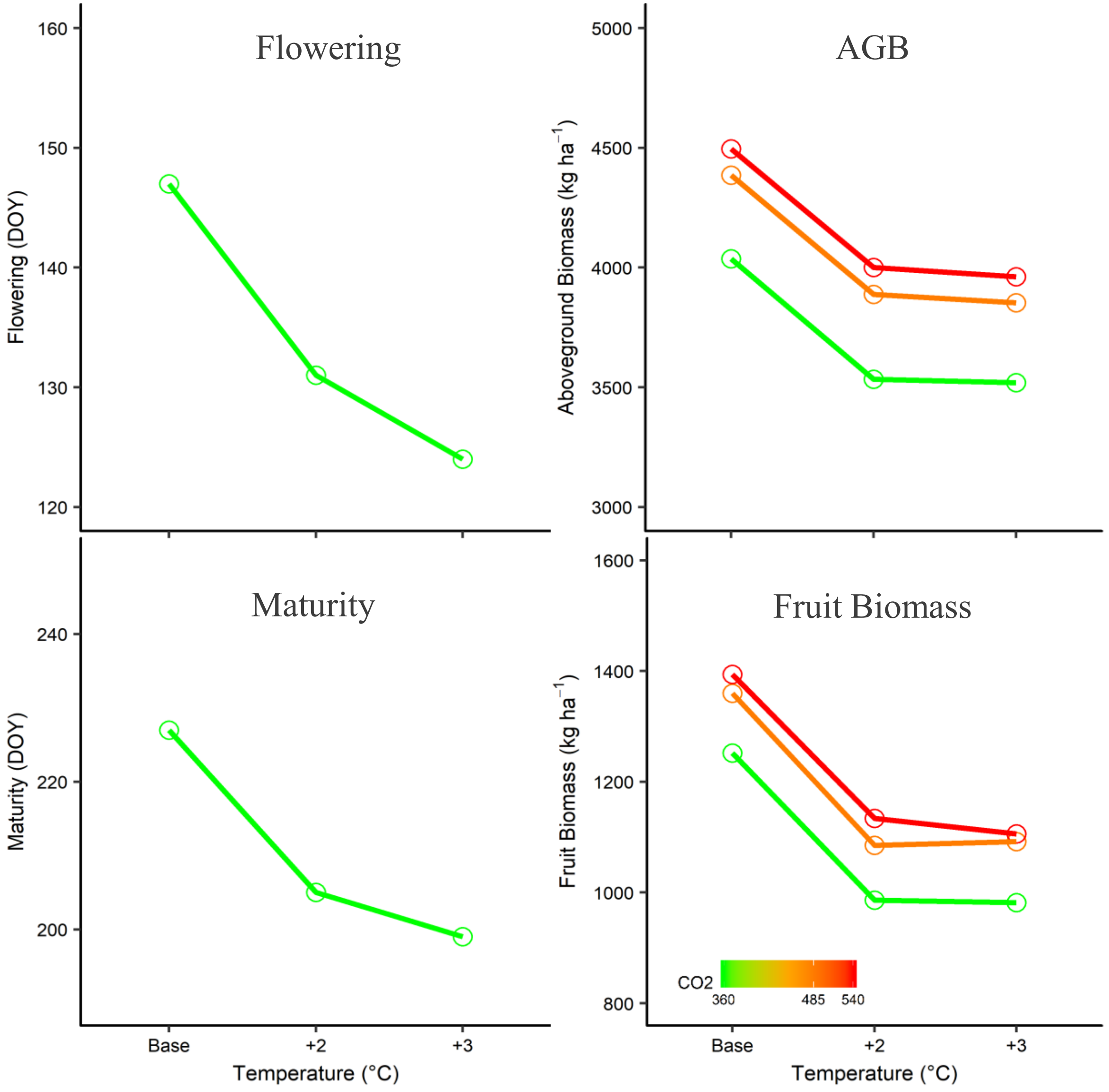
5. CropSyst Results

A simple exercise – Warmer conditions

Montalcino (SI)



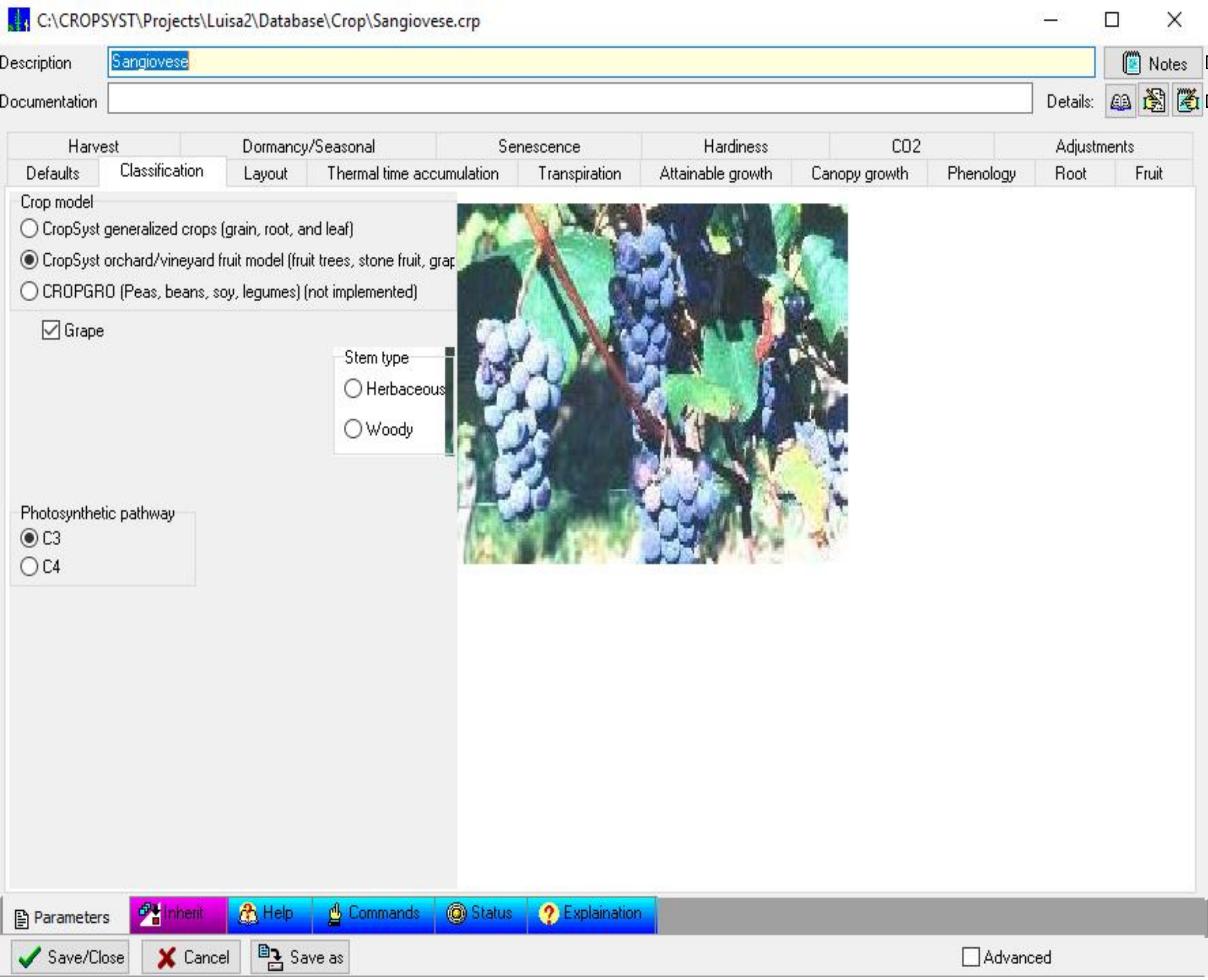
Peccioli (PI)

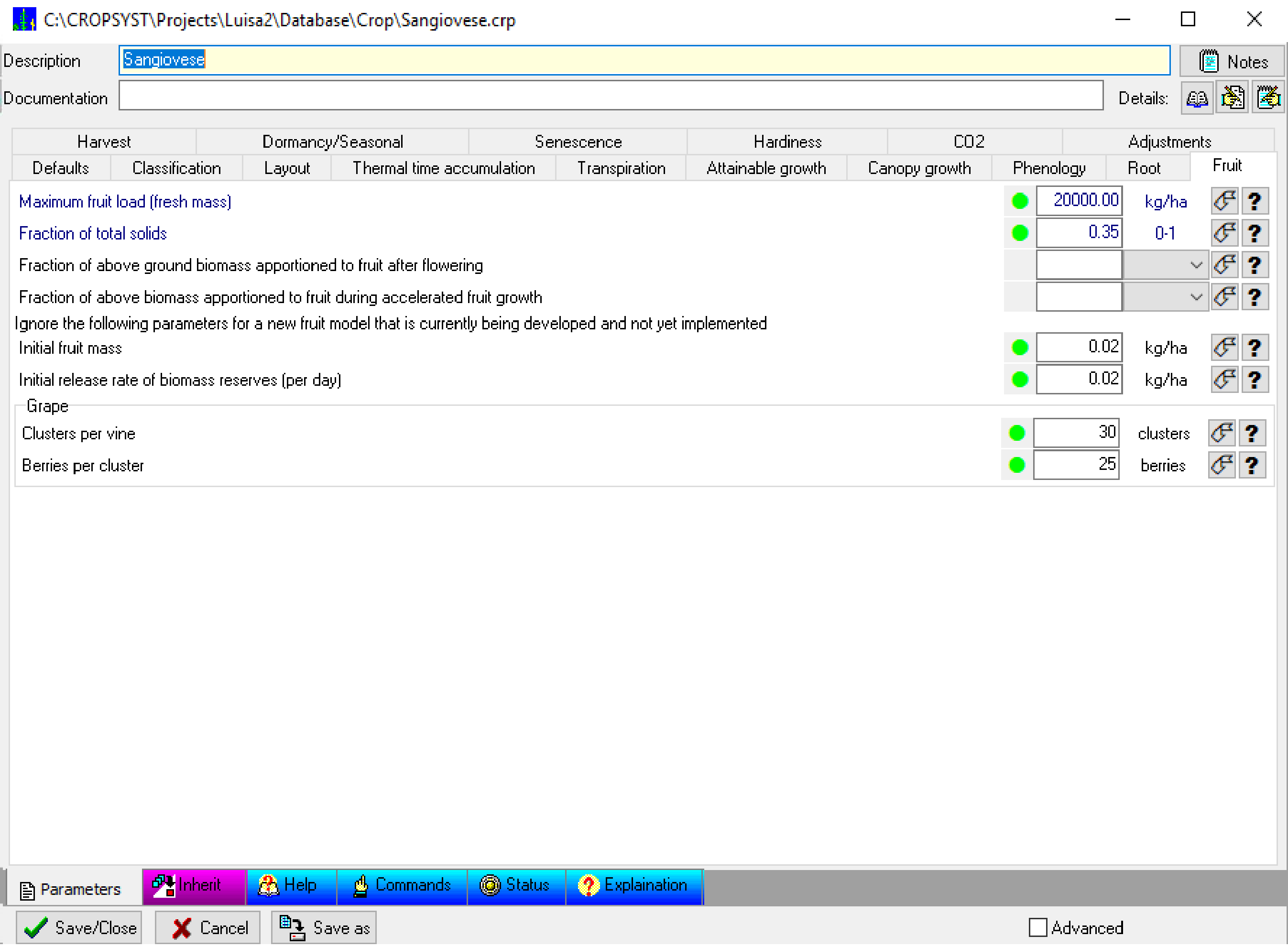


6. CropSyst 4

A specific submodel for winegrape

The orchard/vineyard model in CropSyst version 4





Clim4vitis

7. Conclusions

- UNIFI.GrapeML and CropSyst may be used for representing grapevine growth and development

- Both models can be calibrated for reproducing the grapevine cycle of different varieties (early, medium and late cycle)

- UNIFI.GrapeML is a new model, tested on Chardonnay in Spain and on Sangiovese in Italy

- CropSyst is a widely known model, tested on different crops with high performances. However, for grapevine, the CropSyst version 4 should be tested for evaluating the reliability of simulation and its application in warmer scenarios

- The available datasets and the calibrations on different varieties will play a key role for improving model reliability to predict viticultural suitability in Europe

8. Conclusions

Thank you for your attention

Clim4vitis

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UNIVERSITÀ DEGLI STUDI FIRENZE

LUXEMBOURG INSTITUTE OF SCIENCE AND TECHNOLOGY LIST

spi Sociedade Portuguesa de Inovação

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