WOFOST: simulation model for quantitative analysis of growth/production of annual crops

Wageningen University & Research

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WOFOST - introduction

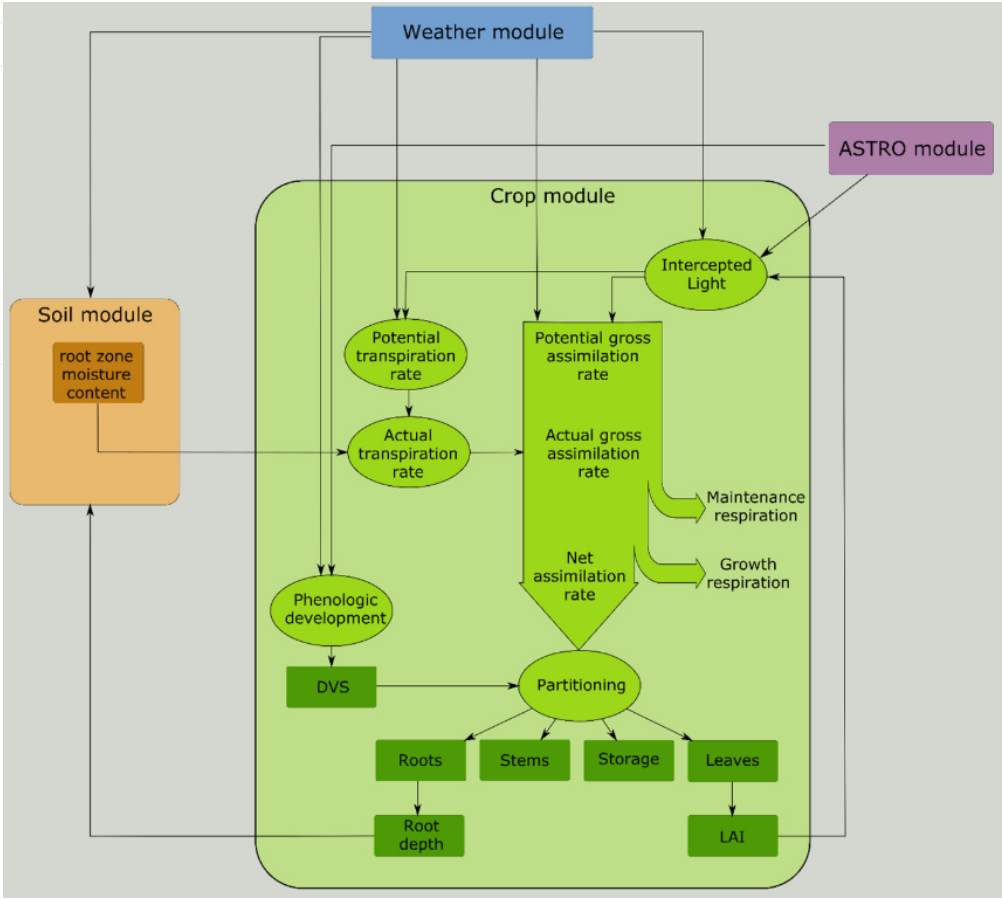
- **WO**rld **FO**od **ST**udies: quantitative analysis of growth and production of annual field crops for different production levels
- Mechanistic, dynamic (1 day), multi-crop, strict state-driving-rate approach
- Main modelled processes:
    - Phenological development
    - Leaf development and light interception
    - Assimilation and respiration
    - Transpiration
    - Partitioning of dry matter
    - Water balance

See for background on processes:

- 25 years of the WOFOST cropping systems model (includes reference data set to verify WOFOST implementation)
- WOFOST system description

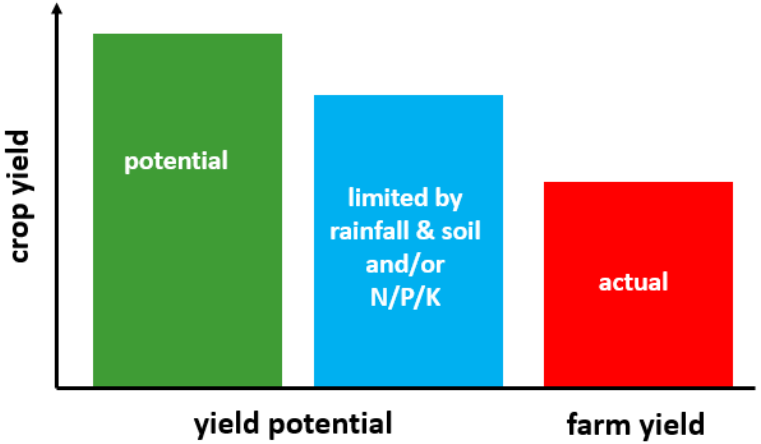
WOFOST – modelled processes

Process	Scalar	Tabular	Total
Phenological development	13	2	15
Leaf growth, senescence and assimilation	9	3	12
Root formation	4	2	6
Respiration	5	1	6
Transpiration	5	0	5
Storage organ formation	2	1	3
Stem formation	2	2	4



WOFOST - principles

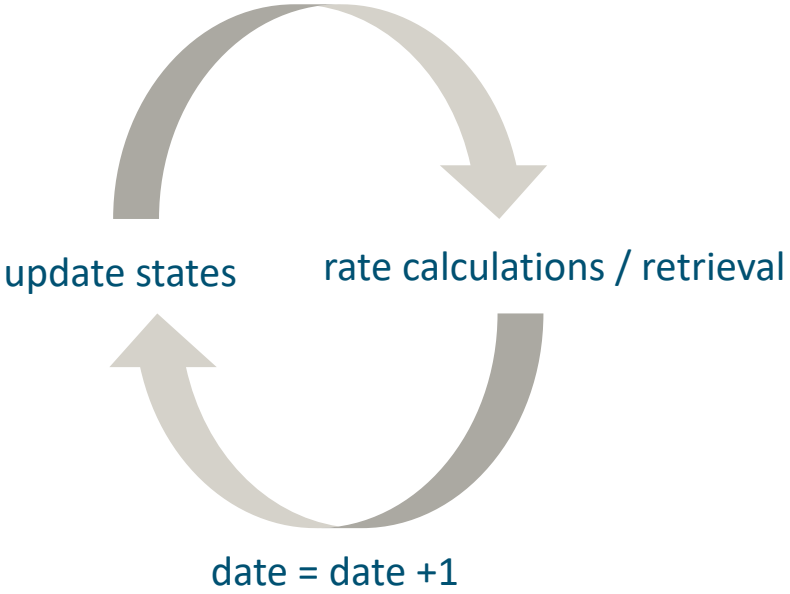
- Production levels:
  - Potential production only limited by radiation, temperature, atmospheric CO_2 concentration, plant characteristics and planting date
  - Production limited by water (rain-fed)
  - Production limited by nutrients:
    - QUEFTS model: a post-processing step looking at basic supply and demand
    - (experimental) module for N/P/K-limited growth simulates plant N/P/K-uptake
  - Production reduced by factors like weeds, pests and diseases ~ actual yield at field level (not in WOFOST!)



WOFOST - principles

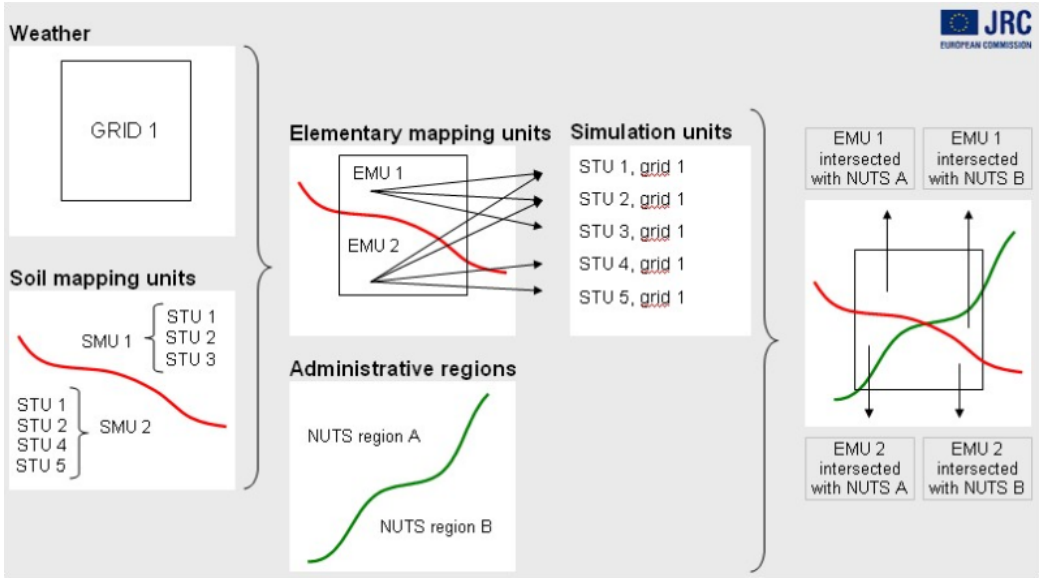
- To ensure correct simulation the different types of calculations (integration, driving variables and rate calculations) are strictly separated

  -> First all states are updated, then all driving variables are calculated / retrieved (e.g. weather), after which all rates of change are calculated



WOFOST - scaling for regional applications

- WOFOST is a one-dimensional simulation model, i.e. without reference to a geographic scale
- The size of a region, to which WOFOST can be applied, is limited because of the aggregation effects caused by non-linear response of crop models to model inputs
- The model spatial domain is splitted into small spatial units where model inputs (weather, crop, soil, management) can be assumed constant

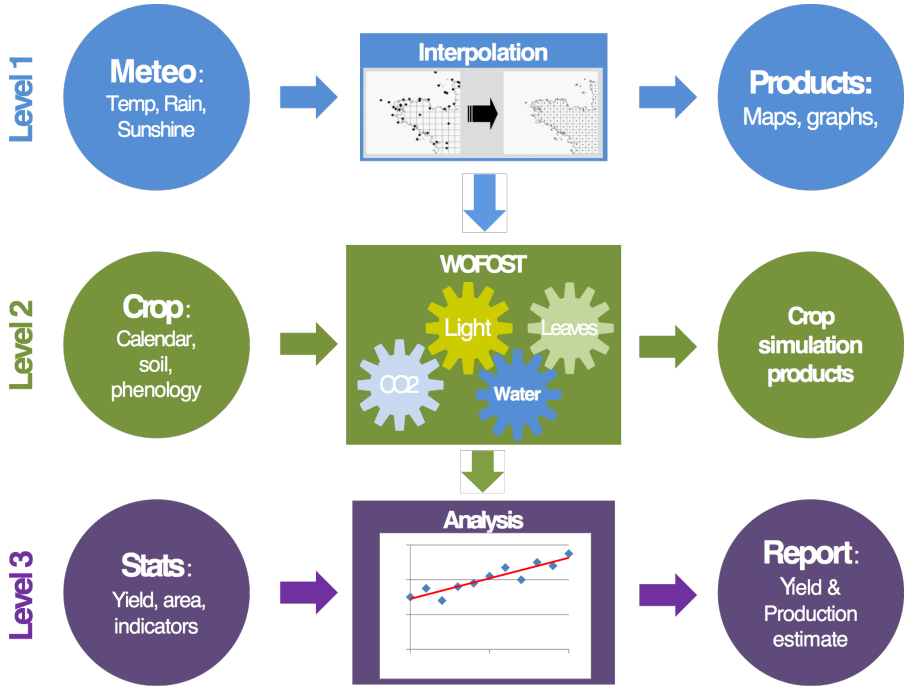


WOFOST – applications - MARS

- Backbone of MARS Crop Yield Forecasting System (MCYFS)
- Provides timely, independent and scientifically relevant:
  - Information on crop development and growth
  - Information on short-term effects of meteo events on crops
  - Seasonal yield forecasts of key crops (cereal, oil seed crops, protein crops, sugar beet, potatoes, pastures, rice) at EU and member state level
- Developed by WUR in 90s, acknowledged by EU parliament, operationally run by WUR since 2000

https://ec.europa.eu/jrc/en/research-topic/crop-yield-forecasting

WOFOST – applications - MARS



JRC MARS Bulletin

Crop monitoring in Europe

September 2019

Reduced yield outlook for maize and sunflowers

Grain maize yield forecast now on average

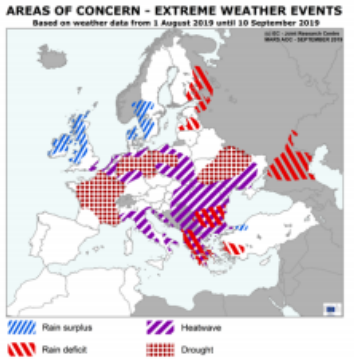
Hot and regionally dry conditions negatively impacted the final part of the – hitherto very positive - summer crops growing season in south-eastern Europe. This, combined with the poor condition of crops in large parts of central and western Europe has resulted in an overall mediocre yield outlook for summer crops at EU level.

Since 20 August – the end of the review period of the August issue of the Bulletin – most parts of Europe experienced at least one heatwave.

The high temperatures in south-eastern Europe - in several regions combined with a marked rain deficit - resulted in a substantial reduction of the hitherto very high yield expectations in Hungary, Romania and Bulgaria.

Drought conditions persisted in central and northern France, northern Germany, western Poland and north-western Czechia. Summer crops in these regions are significantly compromised, with yield expectations below the 5-year average. Pasture productivity has also been below-average in these regions.

The yield outlook for rice, as reported in section 4.2, is around average at EU level.



Crop	Yield (t/ha)				
	Avg 5yrs	August Bulletin	MARS 2019 forecasts	% Diff 19/5yrs	% Diff August
TOTAL CEREALS	5.53	5.57	**5.53**	-0.1	-0.7
Total Wheat	5.71	5.82	**5.82**	+1.9	+0.0
soft wheat	5.94	6.03	**6.03**	+1.5	+0.0
durum wheat	3.46	3.60	**3.59**	+3.9	-0.3

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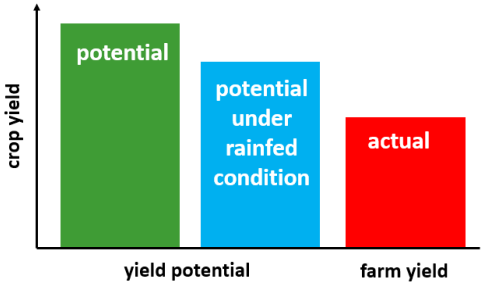
WOFOST – applications - GYGA

- GYGA explores possibilities for extra production and intensification under full irrigation & rainfed conditions for crops across the globe
- GYGA is an international initiative with:
  - National agronomists with local knowledge
  - Standard protocol for assessing yield potential (Yp), water-limited yield potential (Yw) and yield gaps (Yg)
  - Based on best available local data
  - Robust crop simulation models (WOFOST, CERES-MAIZE embedded in DSSAT 4.0 etc.)
  - Bottom-up approach to upscale results from location to region and country



Global Yield Gap Atlas

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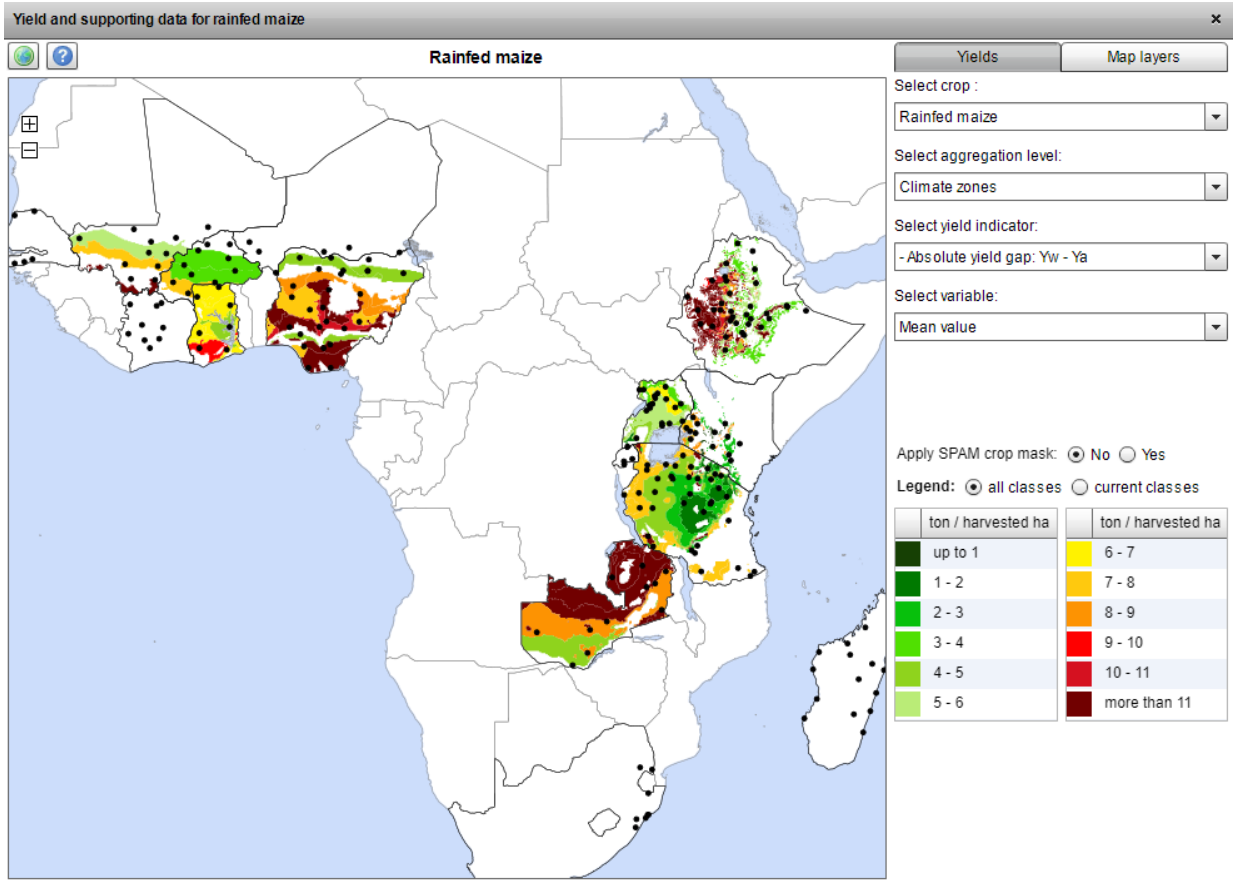
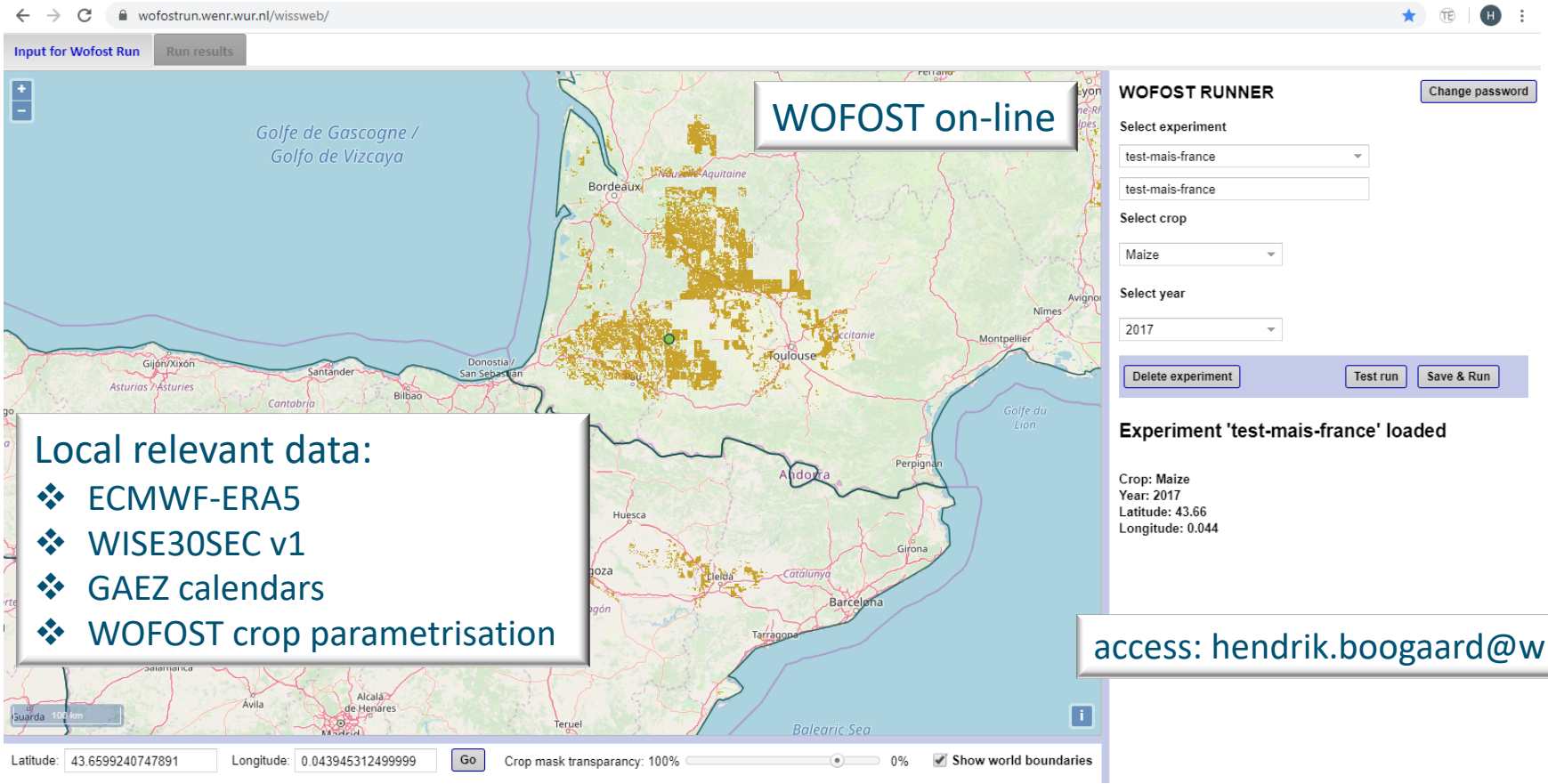
www.yieldgap.org

WOFOST – applications - GYGA

yield gap of rainfed maize



WOFOST – applications – on-line



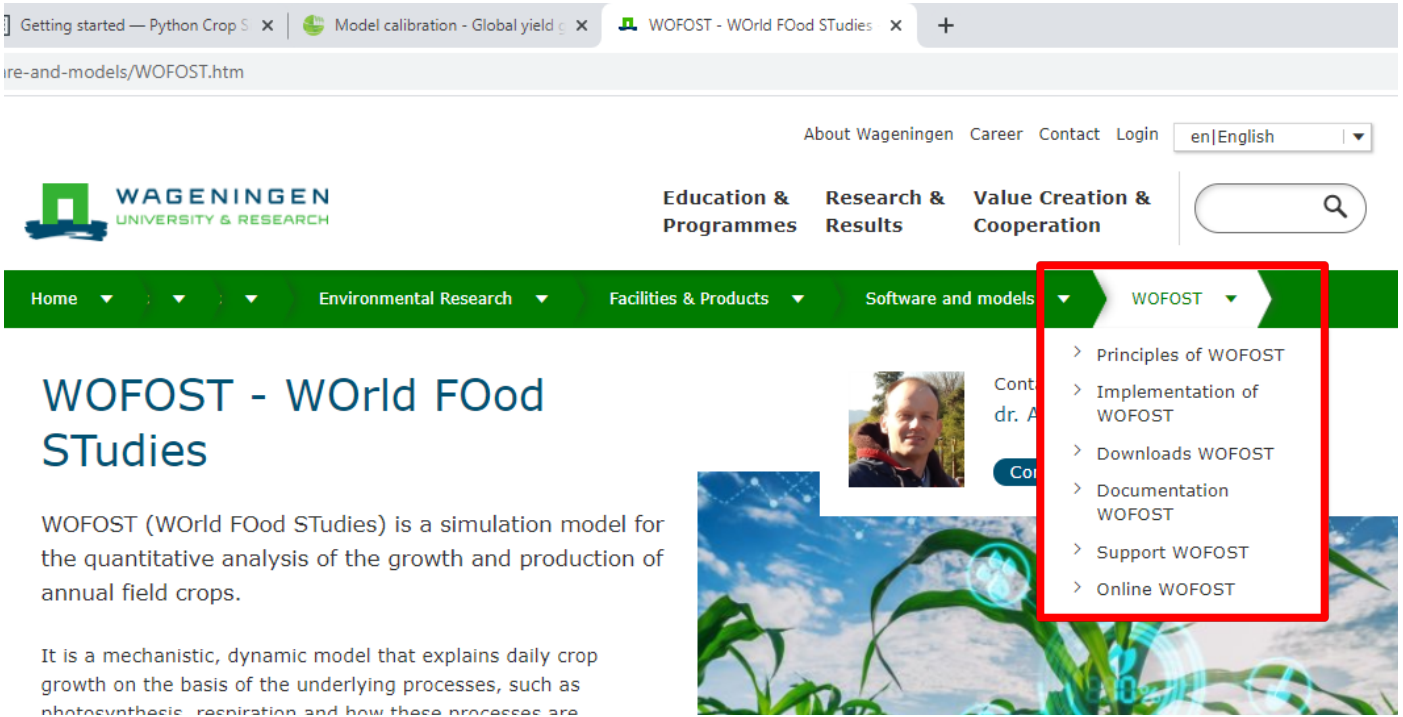
Local relevant data:

- ECMWF-ERA5
- WISE30SEC v1
- GAEZ calendars
- WOFOST crop parametrisation

access: hendrik.boogaard@wur.nl

WOFOST portal

URL: www.wofost.wur.nl



WOFOST portal

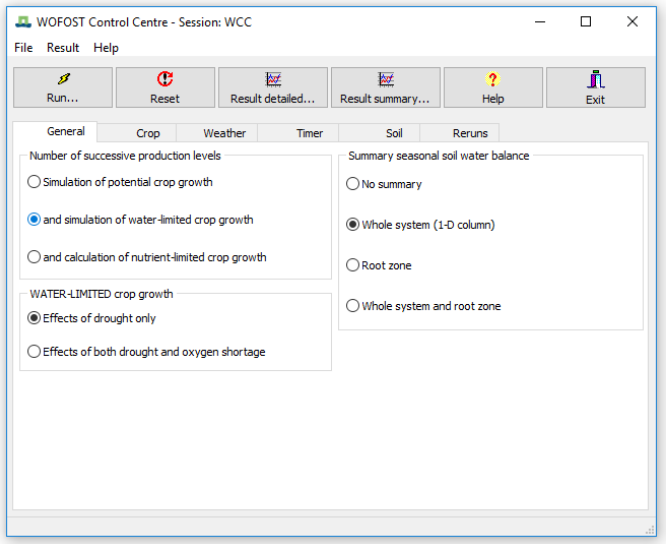
- More examples of applications
- Documentation:

+ Reference publications
+ Regional yield forecasting
+ Climate Change
+ Crop yield analysis
+ Satellite data assimilation
+ Sensitivity analysis of WOFOST
+ Selected papers on WOFOST calibration/validation studies for major crops

WOFOST – implementations

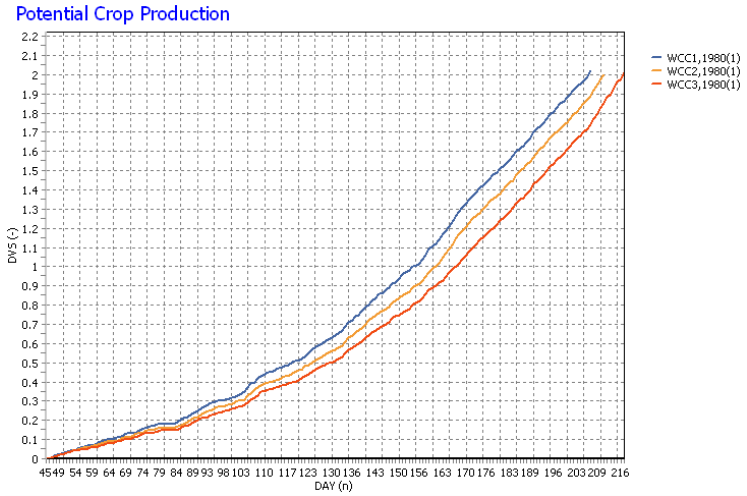
- Wageningen models e.g. WOFOST are distributed including full source code
- Large take up in application domain, but the many implementations also leads to redundancy, complex maintenance, reproducibility issues, hampering developments, difficulties in linking (sub) models etc.
- Current main lines at WUR:
    - WCC/WOFOST
    - WISS/WOFOST
    - PCSE/WOFOST

WCC/WOFOST (2.1 / 7.1.7)



- Original implementation of WOFOST written in FORTRAN77
- Still available, but not actively maintained anymore
- Rich GUI with rerun feature
- EUPL license

RUNNAM	TSUM1
WCC1	800.
WCC2	900
WCC3	1000

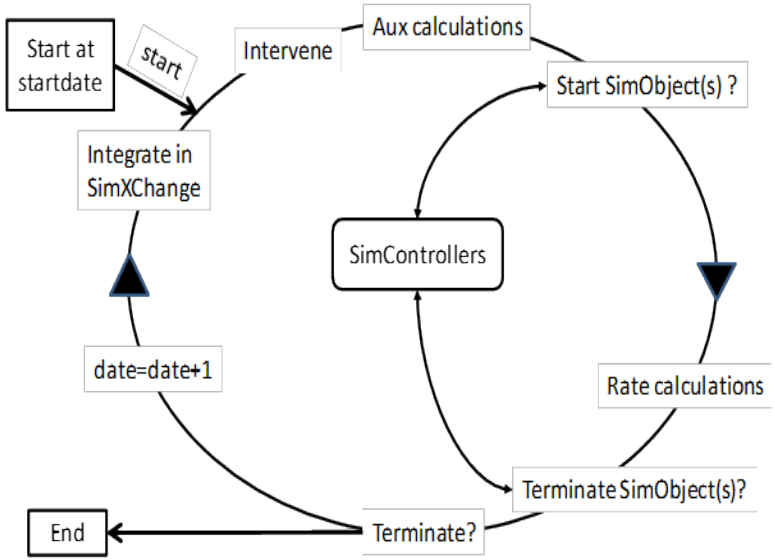


WISS/WOFOST

- Wageningen Integrated Systems Simulator (WISS)
  - Java-based, light-weight, continuous simulation framework for agro-ecological modelling (Euler integration with daily time steps)
  - Offering modularization, control, speed, computational protection and distributed computing (called as fast numerical function)
  - Using a “shared state” approach:
    - Specific object for managing states (thus not in modules)
    - Flexible querying during and after simulation
    - Override state variables without any code change of modules
    - Allows suspend and resume
    - Unit conversion, range checking

WISS/WOFOST

WISS soon available, contact daniel.vankraalingen@wur.nl



Re-implemented WOFOST in WISS, commercial license, for large applications

PCSE/WOFOST

- WOFOST implemented in the Python Crop Simulation Environment (PCSE)
- For scientific purposes
- More interactive and more flexible
- Link to WOFOST parameter sets implemented in YAML
- Use of Jupyter notebooks
    - Demonstration

WOFOST – concluding remarks

- ✓ Clear suite of WUR WOFOST implementations (plus portal & WOFOST on-line)
- ✓ WISS/WOFOST in combination with VREs opens opportunities for large scale modelling at field scale (e.g. assimilating EO-data)
- ✓ Scientific (WUR-wide):
  - ✓ winterkill
  - ✓ multi-layer water balance
  - ✓ dynamic modelling of nutrients
  - ✓ new parametrizations (e.g. wheat and potato)
  - ✓ grass modelling
  - ✓ adding heat stress and drought stress...

Thank you for your attention!

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