An introduction to crop modelling

Practical refresher

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# Discovering a crop model - Mini-STICS

This exercise aims at making you discover how a complex crop model works.

We will discover different aspects of a crop model functioning:

* What is the difference between a ***driving variable*** and a ***parameter***?
* How are ***driving variables***, ***internal*** ***state variable*** (intermediate) and ***output state variables*** (model simulations) interconnected?
* What are the impacts of ***different climatic conditions*** on crop development and growth?
* What are the impacts of ***different initial conditions*** (soil water reserve in this case)
* How do all those aspects impact ***potential*** and ***actual crop growth*** ?

## Discover the concepts behind the mini-STICS soil-crop model

The STICS soil-crop model is fully described in :

“Conceptual basis, formalisations and parameterization of the STICS crop model. Eds : Nadine Brisson, Marie Launay, Bruno Mary and Nicolas Beaudoin. Edition Quae”

In this exercise, we propose you a simpler version of STICS, called Mini-STICS. You will find most of the required information about the formalisms and equations used in this version in two main reference articles.

* Brisson, N., et al., 1998. STICS: a generic model for the simulation of crops and their water and nitrogen balances. I. Theory and parameterization applied to wheat and corn. Agronomie18 (5-6), 311-346.
* Tremblay, M. and Wallach, D., 2004. Comparison of parameter estimation methods for crop models. Agronomie, EDP Sciences, 24 (6-7), pp.351-365. (The authors already made some simplification to the model.

We have specifically designed the miniSTICS model to simulate the impact of water stress on the development of a crop sensitive to vernalization and photoperiod (such as winter wheat). To do so, the model successively solves the different aspects of crop growth.

### Crop onthogenesis/phenological development

The STICS/mini-STICS model uses the concept of ***UPVT*** to simulate phenological development. UPVT stand for ***Unit of development*** that is dependent upon Photoperiodism – Vernalization – Temperature. UPVT is computed as follows :

where UPVT is the daily development unit (Degree days corrected by photoperiod and cold requirement) for ith day, UDEVCULT is the effective temperature for the development (Degree days), RFPI is a slowing effect due to the photoperiod on plant development and RFVI is a slowing effect due to the vernalization on plant development.

For its ontogenesis, i.e. to reach the successive phenological stages, a certain sum of UPVT is required.

Contrarily to Tremblay and Wallach (2004) and Brisson et al. (1998), we do not compute a sigmoïdal hypocotyl elongation. Instead, we use a simpler linear relation to simulate the time required between germination and crop emergence.

Finally, let’s note that for winter crop, crop can be sown in autumn and harvest following summer (Year+1).

### Root front growth

The root front growth is a function of thermal time :

where DeltaZ is the daily growth (for ith day) of root front, CROIRAC is a parameter controlling the growth rate, TCMIN is the minimum temperature for crop growth, and PFZ is a stress factor.

Contrarily to Brisson et al. (1998), PFZ only account for the water stress; if soil water content is above water content at wilting point, then root front can grow (PFZ = 1), else growth is stopped (PFZ = 0)

### Root density

Here, we follow the formalization of Brisson et al. (1998):

where LRACZ is the effective root density at zth depth , LVOPT is the optimum root density, ZRAC, is the depth reached by root front, ZDEMI is the depth where the root density is half of the surface root density, ZLABOUR is the depth of ploughing, ZPENTE is the dep where the root density is half of the surface root density for the reference profile and ZPRLIM is the maximum depth of the root profile for the reference profile

### Leaf area index

Here, we follow the formalization of Brisson et al. (1998):

Where DELTAI is the daily increase in leaf area, ULAI(i) is a physiological time units - please refer to the publication to have ULAI equation - for the calculation of the leaf area index between crop emergence and the stage where maximum LAI is reached (flag leaf extended), DLAIMAX is a maximum rate of the setting up of LAI, PENLAIMAX and VLAIMAX are parameter controlling the shape of the curve of DELTAIdev, DENSITE is the actuakl planting density and BDENS and ADENS are parameters accounting for competition between plant when density is important. Finally, SWFAC is the water stress sindex.

### Water balance and water stress

MiniSTICS incorporates some simplification to solve the water balance and water stress:

* As in Tremblay and Wallach (2004), we solve only two “big layer” of soil, a smaller first layer of maximum 30cm soil and a second greater layer soil layer of maximum 170cm (both soil bottom layer depths are adjustable);
* While we simulate root density for each cm of the soil profile (as in Brisson et al.), we solve the water balance/budget only at the scale of the two big layer. To do so, we consider the soil layer as a whole (as in Tremblay and Wallach), and we use simple water balance computation :

where *Entries of water* consist of rain (first layer) or leaching for upper layer (second layer)and where *Exists of water* consists of evaporation (first layer), water leaching (both layer) and water uptake by crop (both layer if colonized by roots), without discriminating fine scale soil processes of water transfer;

* The computation of the potential evaporation and transpiration is similar to what was proposed by Brisson et al. (1998).
  + The potential evapotranspiration (EO) is first computed based on atmospheric demand (itself based on Penman formalization).
  + EO is then partitioned into potential evaporation (EOS) and potential transpiration (EOP) based on LAI;
* The computation of the actual evaporation follows the one proposed by Brisson et al. (1998). Following rainfall, there are two stages of evaporation :
  + During the first stage, the soil is wet enough for potential evaporation to occur; ES(i) is then equaling EOS(i)
  + During the second stage, the evaporation (ES) is lower and its decrease depends on a climatic parameter (ACLIM) and the type of soil (amount of clay at the surface and water content at the field capacity) – we refer to Brisson et al. (1998) for futher explanation.

* Some adjustments were done to solve the computation of the actual transpiration and the water stress. Here we use a different solution as compared to Tremblay and Wallach or Brisson et al. In those papers, the water stress is solved using a stomatal closure threshold depending upon root system characteristics while here we consider an explicit user-defined parameter. Except for this, the approach is quite common :
  + The average soil water available(TETA) is computed over the root profile;
  + The threshold at which stomatal closure happens is defined by the user (in “Crop > Plant Stomatal Closure driving Transpiration” section) ;
  + A water stress index is computed as a bilinear equation (see graph “Fomalism > SWFAC – TETA”):
    - If the average water content offer by the soil (TETA) is greater to this threshold, the plant is not considered in stress, and Water stress index equals 1 (SWFAC = 1)
    - If the average water content offer by the soil (TETA) is lower to this threshold, the plant is considered to enter in stress; below this user-defined threshold, the water stress index equals :
  + Every day, the actual transpiration is the product of the potential transpiration (EOP) and the water stress index (SWFAC);
* The actual water balance is finally solved :
  + The requested water for plant growth is extracted in each layer proportionally to the root density actually in place in each layer (relatively to the total root density);
  + If a soil layer is too dry, more water can be extracted from the lower soil layer (unless deeper layer are also too dry and cannot compensate plant water need);
  + if both soil layer are too dry, actual evaporation is reduced to the maximum of what the soil can provide;
  + The water balance is then solved accounting for the actual entries and exists in each layer.

### Crop biomass growth

The solar radiation intercepted by the leaf apparatus is then converted into biomass, following Brisson et al. (1998):

where SRAD is the daily solar radiation, EXTIN is a coefficient of light extinction in the canopy, PARSURRG is the ratio of the photosynthetically active radiation to total radiation and RUE is the radiation use efficiency coefficient.

## Discover the mini-STICS soil-crop model environment

Please open the following url in your web browser “<https://plantmodelling.shinyapps.io/ministics/>”

The web application is structured as follow :

* In the left margin, you will find two panels, named respectively “Model” and “About”. You are currently in the “Model” panel. You can explore the “About” panel for more details and explanation about miniSTICS or the license ;
* The “Command center” contains two buttons, respectively to run the model and reset simulations. When you hit “reset simulations”, you will keep in memory the last simulation. To restore the parameters values to their initial values, you will need to refresh the web page (presh “F5” or click the “refreh” button of your browser).
* Below the “Command center”, you have the tabs that control the settings of the model (tab “General”) and the ***parameters value*** (tabs “Sowing”, “Soil” and “Crop”).
* On the right part of your screen, you will have access to various tab to display the model results; each tab refer to a family of processes being displayed. Please note that in each category of process displayed, you have the opportunity to select different ***variables***.

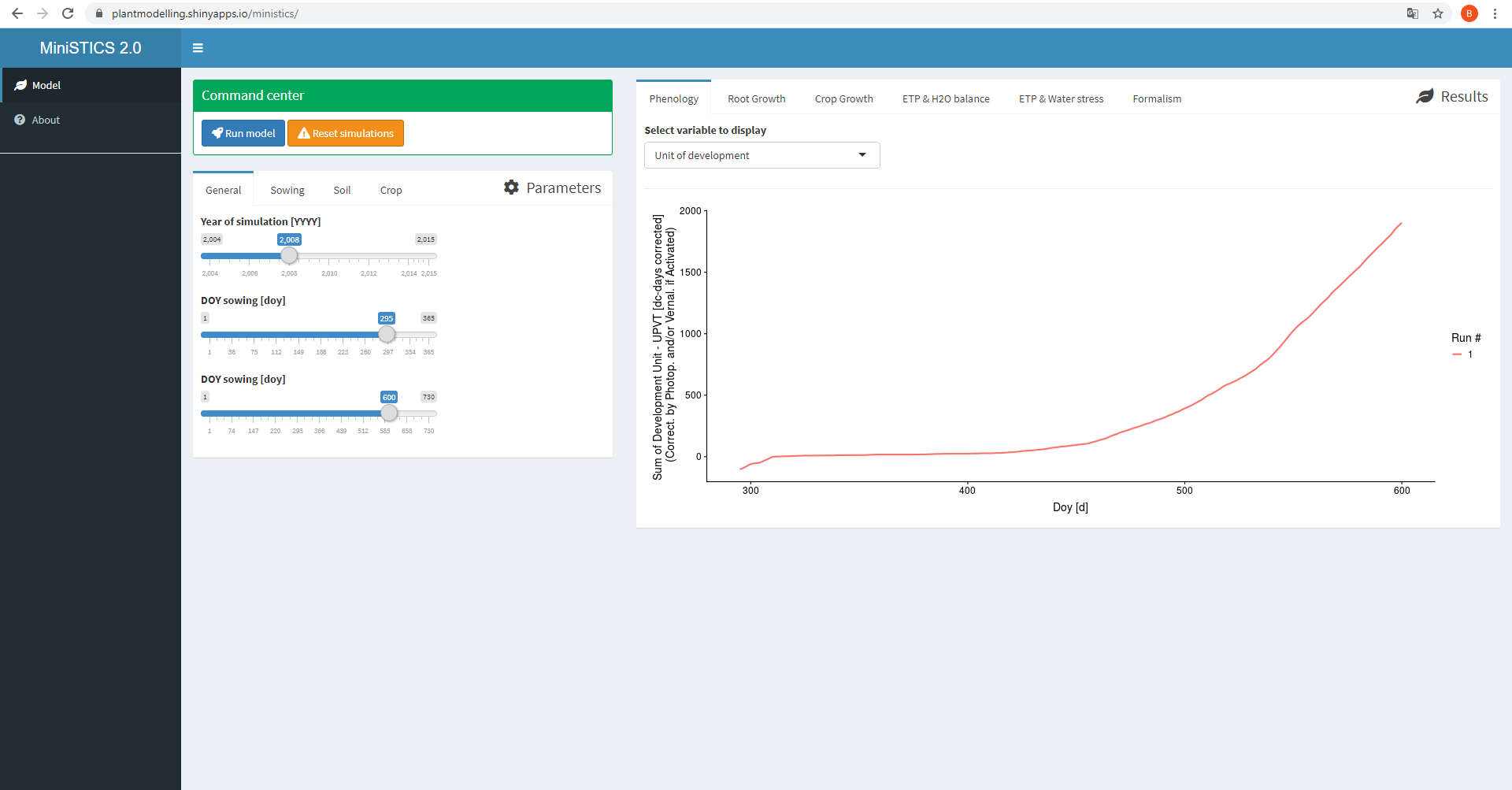


Figure 1: Overview of the miniSTICS model - online version.

Behind the crop model, lies a climatic database containing observation between 2004 and 2015. The climatic time series of data are called the ***driving variables***. They will impact crop growth and soil processes.

After/while reading Brisson et al. (1998)[[1]](#footnote-1), you are invited to “play” with the model. You will see that some variables are not explicitly outputted for the user; they are only intermediate value computed to further calculate the impacts on model outputs. They are called ***internal state variables.*** Contrarily, the variable that are made explicitly available to the user are called ***output state variables***. Such variables express the evolution of the state of various aspects of the agro-ecosystem (it might refer to the state of the crop (development, leaf area index, etc.), the soil status (soil water content, etc.), etc.

## Manipulate the mini-STICS soil-crop model

After having completed the lecture of Brisson et al. (1998) and having play a bit with miniSTICS, please refresh the webpage (presh “F5” or click the “refresh” button of your browser). Please follow now the instructions and answer some questions.

Based on model formalization and suggested parameter change(s), try to understand why the output variables has either ***not changing***, either ***increasing***, or either ***decreasing***.

* Refresh; Run the model; Go to “General > Biomass Growth > Radiation Use efficiency” and change the RUE to 4.0; Run again the model.
  + What can you tell about the phenology (Sum UPVT)?
  + What can you tell about the root front growth?
  + What can you tell about the water stress Index?
  + What can you tell about the total dry matter produced (potential and actual)?
* Refresh; Run the model; Go to “Soil > Soil Profile description” and change the value to the Bottom layer depth of 2nd Horizon to 70cm (your soil available water is now only in the 0-100cm volume);
  + What can you tell about the phenology (sum UPVT)?
  + What can you tell about the root front growth?
  + What can you tell about the water stress Index?
  + What can you tell about the total dry matter produced (potential and actual)?
* Refresh; Run the model; Go to “Crop > Year of simulation” and change the year to 2006; Run again the model; Go to “Crop > Year of simulation” and change the year to 2014; Run again the model
  + What can you tell about the phenology (sum UPVT) for the 3 cropping seasons?
  + What can you tell about the root front growth for the 3 cropping seasons?
  + What can you tell about the water stress Index for the 3 cropping seasons?
  + What can you tell about the total dry matter produced for the 3 cropping seasons?
* Refresh; try to modify different parameter values and discover what their roles in the model are, and how they act on the output variables. You need to remember that a parameter might have a direct value on a stat variable, or that it act indirectly through another variable (internal or output) state change.

***Bravo, you have successfully completed this section.***

***You can now enjoy modelling !***

1. Brisson, N., et al., 1998. STICS: a generic model for the simulation of crops and their water and nitrogen balances. I. Theory and parameterization applied to wheat and corn. Agronomie 18 (5-6), 311-346. [↑](#footnote-ref-1)