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Small or medium scale focused research project

Sweet Sorghum
an alternative energy Crop

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Deliverable 5.5:

A sweet sorghum model adapted and validated in the target environments

Composition of the consortium
CIRAD
ICRISAT
EMBRAPA
KWS
IFEU
UniBO
UCSC
ARC-GCI
UANL
WIP

SAMARA is a deterministic cereal (except maize) crop model operating at daily time step elaborated by CIRAD (Dingkuhn *et al.* 2013). It requires daily agro-meteorological weather data as input (Rg or hours of sunshine, Tmin, Tmax, RHmin, RHmax, daily mean wind speed, daily total rainfall), as well as hydrological top soil properties (volumetric water content of air-dry soil, at wilting point, at field capacity and at saturation = water logging; and percolation rate under flooded condition and soil depth as limit to the root front). SAMARA does not consider soil bulk density and swelling/shrinkage.

SAMARA is implemented as a modular system on the ECOTROP platform that also accommodates SARRAH Heinemann *et al.*, 2008; Kouressy *et al*., 2008) and EcoPalm (Combres *et al*., 2012), programmed in Delphi language, and implemented under Windows.

This model is different from other agronomy-scale (plot) crop models in the way it treats assimilate partitioning among sinks, also involving more detail of morphology and phenology. Plant and organ growth is not only limited by carbon assimilation (source or supply) but also demand, which is the accrued organ sink capacity for growth and respiration on a given day. Since organ potential size and number (leaf appearance and tillering rates, panicle size) may be genetically limited, or more or less responsive to resources and stresses, demand can be inferior to supply. The state variable Ic (Index of internal competition = supply / demand) measures the source-sink situation daily and feeds back on morphogenetic and physiological processes, such as reserve storage of mobilization, tiller initiation or senescence, leaf size, leaf senescence, internode elongation, root growth and pre-floral panicle dimensioning. Carbon demand for root growth depends on the available soil volume, among other things (e.g., set by soil depth and plant spacing). It can happen that assimilates cannot be used entirely for lack of sinks and storage, resulting in feedback inhibition of photosynthesis, effectively reducing radiation use efficiency (RUE). It can also happen that sink development is excessive (e.g., profuse tillering), causing much senescence and also reduced RUE. Such crowding effects cannot be well simulated with crop models having fixed partitioning and senescence patterns.

This concept, adapted from the EcoMeristem model (Luquet *et al*., 2006, 2007, 2012), thus deviates from the classical "prescriptive" partitioning concept that assumes constant RUE in the absence of physiological stresses. SAMARA therefore permits simulating phenotypic plasticity that may be adaptive or not, and simulating different adaptation strategies such as aggressive or more conservative use of resources. According to SAMARA, the growth and yield potential of a genotype is not only a function of potential photosynthetic rate and light interception (source), but of the dynamics and resource responsiveness of the morphogenetic process itself (demand). The model thereby considers water resources and drought / logging / submergence / thermal stresses, but not mineral nutrition.

SAMARA deviates from EcoMeristem in its agronomic skills, while being less detailed in plant architecture. SAMARA provides for many crop management options including transplanting vs. direct seeding, or flexible and diverse water management options (stress cycles, alternate wetting and drying, deficit irrigation), and mulching. The modified big-leaf simulation of light interception in SAMARA also implements a simple notion of clumping (heterogenous leaf area distribution in space). Lastly, it is possible to output ecological balances such as canopy scale transpiration efficiency, plot-level water use efficiency and irrigation efficiency, and radiation use efficiency.

SAMARA was developed to study in-silico plant type (ideotype) concepts submitted to different climatic/soil environments and management practices. As such it permits evaluating the adaptive and agronomic value of many of the traits breeders are interested in, alone and in combination. The strength of SAMARA is the simulation of physiological interactions among traits and with the

environment and management. SAMARA is thus a tool for pre-breeding research, including target population of environments (TPE) characterization and *in-silico* ideotype development.
For purposes such as agronomic decision support or mapping of climatic yield potential, SAMARA is over-parameterized with regards to genotype characteristics. Although an effort was made to separate frequently used parameters of rarely used ones, the number of parameters is very large and calibration of some is difficult because their values are not directly measurable. (A parameter optimization tool for the most difficult ones is under development.)
SAMARA can be a valuable didactic tool for crop physiologists and agronomists. “Playing” with parameter values teaches users how adjustment processes in the plant (e.g., tillering vs. leaf size), trade-offs among traits (e.g., plant height vs. harvest index) and trade-offs among cultural practices (e.g., plant spacing vs. varietal type) come about and affect the agronomic outcome.
Some specific didactic material for SAMARA model (presentations, commented code, description, guidelines for calibration…) was elaborated to facilitate the understanding of the different concepts of the model and the use of the model itself.

Here under is an example of calibration / validation of the model as well as a work of the effect of drought on the yield of a sweet sorghum variety sensitive to photoperiod.

Model calibration and validation

Like all the models, SAMARA-sorghum needs to be calibrated and validated for a given variety. This requires two distinct sets of data, one for calibration, the other for validation. Here after we worked with the biomass sorghum variety M81-E.

The first set of data comes from a field experiment conducted in 2012 in Florida by the Everglade Research and Education Center of Florida. It includes data on evolution of leaf area index, dry matter production of leaves, stems, panicules and grains. Simulations were based on daily meteo data (rain, atmospheric humidity, T°, global radiation, wind) as well as soil and cultural practices information.
Comparison of observed to simulated data for stem dry weight (Figure 1) as well as for total above ground dry weight (Figure 2) shows that the model can be calibrated to fit very well the observed data.

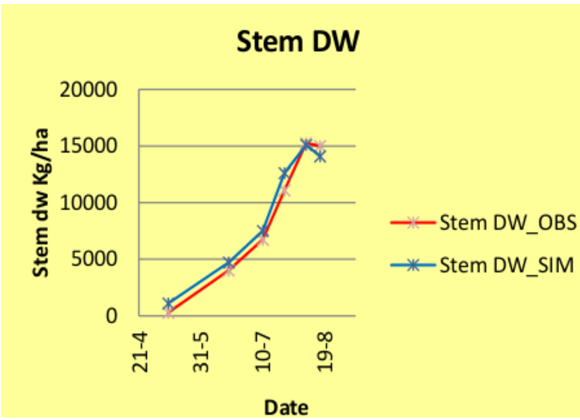

Figure 1: Evolution of stem dry weight

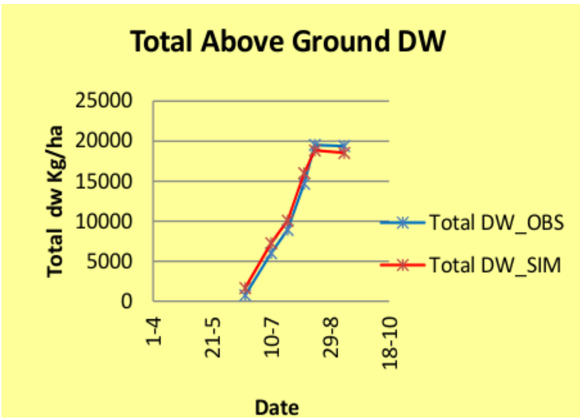

Figure 2: Evolution of total above ground DW

The Relative Root Mean Square Error (RRMSE) measured is less than 10% for stem and total above ground dry weights, confirming that the model is able to provide very good simulation of this variety.

Table 1.

SAMARA calibration for M81-E	BIAS	RMAE	RRMSE
LAI	0.05	0.10	0.09
Leaf dw (kg.ha^{-1})	- 34	0.17	0.17
Stem dw (kg.ha^{-1})	- 456	0.10	0.10
Total Above Ground dw (kg.ha^{-1})	- 513	0.10	0.09
Plant Height (mm)	140	0.12	0.14

The validation was made using data from experimentations conducted in 2009 and 2010. We had not the complete set of data, but we were able to compare cycle duration as well as biomass production. In the experimentation, there were 2 sowing dates and we can see on table 2 that the simulation for late planting is very good while the model overestimate the germination-maturity duration by 6%.
For biomass yield the data for early and late sowing were not individualized, but the mean of the two simulations is very closed to the observed mean (underestimation by 10%).
Partitioning of the biomass is correct for leaf and stem with a difference inferior to 10% while the grain production is a little high.

Table 2

Duration Germ-Mat (d.a.s.)	Obs	Sim
Early planting	119	126
Late planting	119	119
Means	119	123

Table 3

Total Above Ground Biomass (Mg.ha^{-1})	Obs	Sim
Early planting	+	21.2
Late planting	-	19.3
Means	22.0	20.3

Table 4

Biomass Partitioning (%)	Leaf	Stem	Grain Head
Means Simulated	15.4	70.7	13.9
Means Observed	14.0	76.0	10.0

An example of sweet sorghum crop simulations with Samara

The model was calibrated for a sweet sorghum variety (Magnon-woulé), and we studied the incidence of sowing date on drought effect on the yield in Mali (West Africa). In that region, the main constraint is drought, and farmers have to use adapted varieties as well as appropriate practices according to the shortness of the rainy season. To minimize drought effect, most of farmers plant varieties sensitive to photoperiod, for having an adequate flowering time occurring at the same time that the end of precipitation. Most of the sorghum varieties grown here are sensitive to photoperiod which is an important adaptive trait in that region.

SAMARA was used to simulate the effects of sowing dates on the growth of a traditional sorghum, Magnon-woulé, which is a late maturing photoperiod sensitive variety. This variety is mainly grown for its grains but it also can be used for fermented juice or fodder as it produces sweet stalks.

Simulations were run for 3 sowing dates: 10^{th} of June, 10^{th} of July and 30^{th} of July. The effects of sowing dates were observed on grain yield, stem reserves at flowering time as well as at full maturity (Figure 3). The highest stem carbohydrate reserve is obtained for the earliest sowing (10th of June) and harvested about 15 days after flowering. The yields are decreasing as sowing date is delayed either for grain or stem carbohydrate storage, but this variety gives a priority to the grains because the latest sowing date (30th of July) results in a reduction of 36% of the grain yields compared to the earlier sowing date, while stem carbohydrate storage is decreased by 65% if harvested after flowering and 90% if harvested at full maturity. This comportment is observed for varieties sensitive to photoperiod, which gives opportunity to farmers to re-sow late in the season without compromise the complete grain production. One important advantage is that grain maturity occurs after rainy season to prevent any high humidity favorable to fungus development on grain.

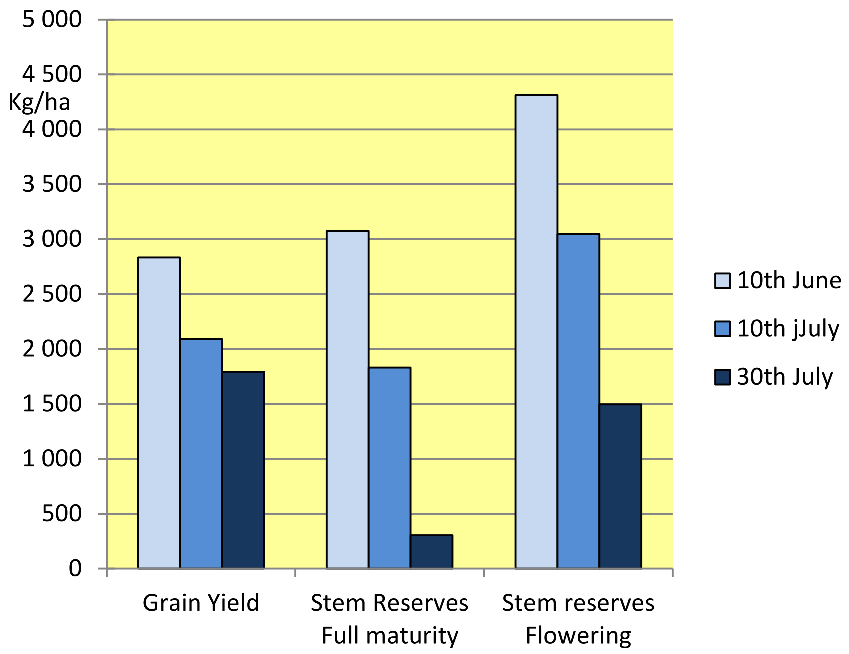

Figure 3: effect of sowing date on gain yield and stem reserves of a sweet sorghum variety in Mali

Perspectives and opportunities

SAMARA crop model is already available for use on sorghum research projects, either for grain, sucrose or biomass productions.

Further studies may be undertaken to confront the model to various situations and genotypes in order to evaluate the limits of its reliability. In the same way, we encountered a lack of data for the calibration of stem reserves so that any field or experimental measurements of carbohydrates reserves in the stems should be of interest to calibrate the model more precisely.

Furthermore in a near future, the model will take into account the atmospheric CO^2 for climatic change studies and better formalize drought impact on targeted productions (grain, sugar and biomass).

SAMARA can be used as a decision support tool for agronomists, crop physiologists and breeders as it enables to test many parameter values and see how adjustment processes in the plant (e.g., tillering vs. leaf size), trade-offs among traits (e.g., plant height vs. harvest index) and trade-offs among cultural practices (e.g., plant spacing vs. varietal type) come about and affect the agronomic outcome.

As a support to varietal improvement, SAMARA can be used to define the target population of environments (TPE) as well as new ideotypes according to current environments. It can also be used for climatic change mitigation studies.

As one of the objective is to develop the community of Samara users for improving model capacity to simulate cereals in different environments, Samara is free (no IPR). This model can be shared with the scientific community, but it requires at least a short training to understand the concepts and be able to play with it. Such training is usually organized by CIRAD once a year at Montpellier, France.

Documents

Dingkuhn, M., Pasco R., Soulie JC. Model description, guidelines for calibration,source code. CIRAD, 2013, 21 p.