System simulation: Concepts and principles, introduction to CSMs and their uses for agricultural input use optimization

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Outline

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What’s **common** in both ?

Simulation versus model

- Simulation is the imitation of the operation of a real-world process or system over time.
- Requires the use of models; the model represents the key characteristics or behaviors of the selected system or process, whereas the simulation represents the evolution of the model over time.

- A thing used as an example to follow or imitate
- A simplified description, especially a mathematical one, of a system or process, $\longrightarrow$ assist calculations and predictions $\longrightarrow$ serve a specific aim.
- **Never** contain all features of reality.
- A system model is a representation of a system, many different expression that vary in degree of formalism could be considered models.
  - A picture
  - A text description
- Primary focus of system modeling is to use models supported by a **well-defined** modeling **language**.
- $\therefore \uparrow$ the formalism better will be the description of the system fitting as a model.

Crop (and cropping system) models

- Simplification of a crop
- Depending upon the model's goal, several formuations are available.
- Increasing importance:
  - Complexity of ecological problems
  - Improved understanding of quantitative relationships in crops
  - Improved computing power

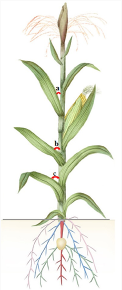


Figure 2: A diagram of proposed maize ideotype with specific shoot and root traits. Leaf angle (a < b < c) to maximize light capture; Uniform and moderate plant and ear height, etc. to enable mechanized harvest and lodging resistace; Steep, cheap and deep root system to improve water and nutrient uptake. (The roots in shades of different intensities; dark to light represent, respectively, primary roots, seminal roots, crown roots and brace roots.)

Selected types of models

Static A model that does not include the time dimension

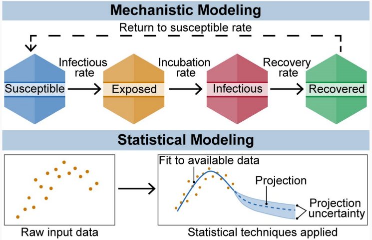
Dynamic A model that includes the time dimension

Descriptive/functional A model that shows the relationshp between the element of a system without any explaination. It is usually unrelated to system structure.

Explanatory/mechanistic A model that explains the behaviour of a system at an upper integration level by integrating processes of a lower integration level. Representation of the essential system structure.

Deterministic The predicted values are computed exactly.

Stochastic The predicted values depend on probability distribution.



Source: GAO illustration of standard mechanistic model (Mechanistic Modeling, top); GAO illustration of standard statistical modeling (Statistical Modeling, bottom). | GAO-20-582SP

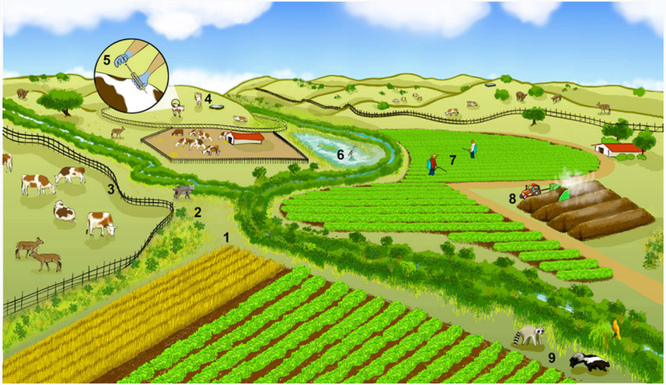


Figure 3: A farming landscape. A representation of processes that make up in farming.

A model of wheat crop

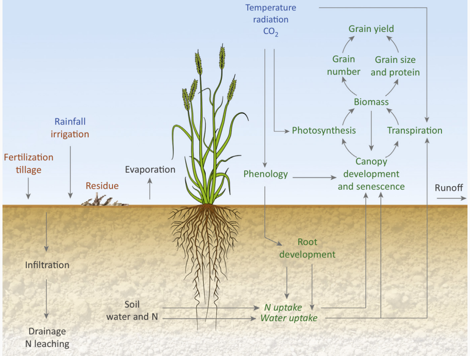


Figure 4: Corp models simulate crop growth and development (outputs) as influenced by climate conditions (typically solar radiation, temperature, and rainfall), soil characteristics (e.g., rooting depth, water holding capacity, nitrogen mineralization capacity) and crop management (e.g., sowing date, plant density, fertilization, irrigation) (inputs) based on mathematical equations and cultivar-specific parameters (inputs). While modern wheat crop models vary in their complexity, most simulate crop growth and development at a daily time-step to ultimately estimate grain yield. Crop processes include phenology driven by temperature and photoperiod, the establishment of the canopy that transpires water and intercepts light to produce the crop biomass, and the partitioning of this biomass into diffrent organs including grains. Modeling of soil water and nutrient varies between models, and ranges from simple approaches with no soil description to more complex approaches where soil layers are each described with specific properties. Source: Chenu et al. (2017).

Components of crop models

- First examples of crop growth models, mostly intended for use by the agriculture research community, were available during the 1970s.
  - applications oriented to management or field decisions (irrigation scheduling, pest and disease control, etc.)
- Now several modeling systems simulate,
  - soil water budget,
  - soil-plant nitrogen budget,
  - crop phenology,
  - canopy and root growth,
  - biomass production,
  - crop yield,
  - residue production and decomposition,
  - soil erosion by water,
  - and salinity
- These processes are affected by weather, soil characteristics, crop characteristics, and cropping system management options including crop rotation, cultivar selection, irrigation, nitrogen fertilization, soil and irrigation, water salinity, tillage operations, and residue management.

Process based modeling

- Crop models need to be **complete** and **responsive**.
- Process based models are easy to describe, most flexible (in terms of component addition and substitution).
  - Biomass accumulation based models are not always sufficient as changes depend on earlier effects (fallow period, previous crop, etc.)

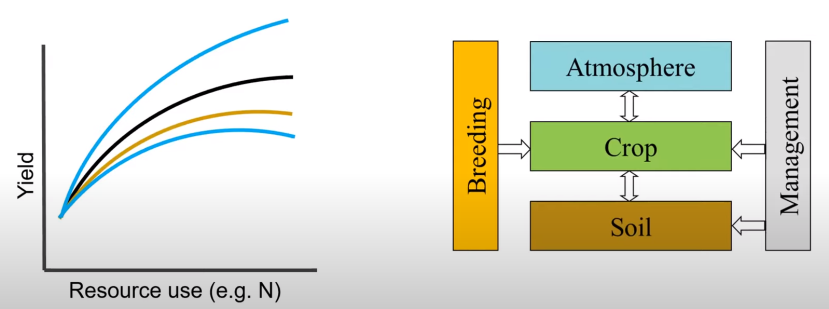


Figure 5: Resonse of yield to mangement can be simulated by an example response to crop yield yield by doses of Nitrogen. Quality of the interaction is generally same but the quantitative nature of interaction is complex.

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Biomass accumulation model

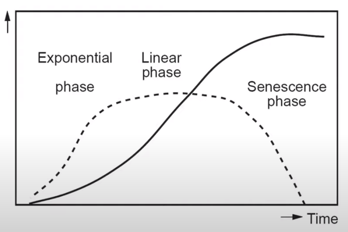

Figure 6: Simplified model of crop growth based on phenology.

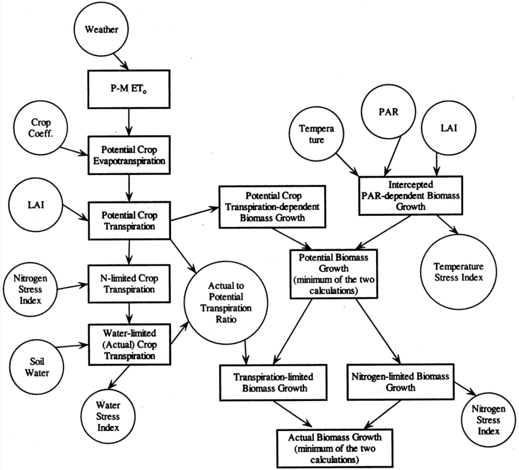

Figure 7: Flowchart of biomass growth calculations (in CropSyst). Source: Stöckle et al. (2003).

Example of crop models

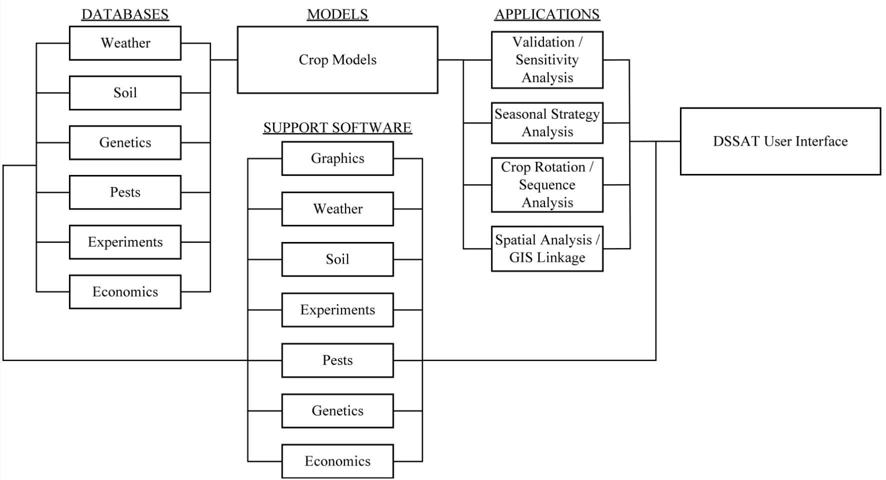

Figure 8: Diagram of database, application, and support software components and their use with crop models for applications in DSSAT.

Steps in crop modeling

- Broadly
  - Model operation
  - Model evaluation
    - calibration
    - validation

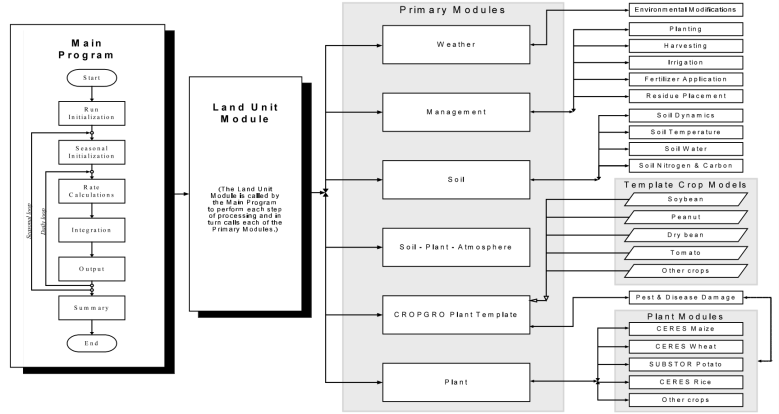

Figure 9: Overview of the components and modular structure of the DSSAT-CSM. Source: Jones et al. (2003).

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References

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