**Model Components**

The Cropping System Model (CSM) is structured in a modular format in which components separate along scientific discipline lines and have interfaces which allow replacement or addition of modules. CSM now incorporates all crop models as modules using a single soil module and a single weather module. The new cropping system model now contains models of 40+ crops derived from the original SOYGRO, PNUTGRO, CERES-Maize, and CERES-Wheat crop growth models.

The following schematic illustrates the connection between the primary and secondary modules of the CSM. The main program controls all the timing for the model, while the Land Unit module is used to control processing and data transfer between all primary modules.

**Primary Modules**

Management module

Soil module

Weather module

Soil-Plant-Atmosphere module

Plant module

**Management module**

The Management module processes user inputs describing crop management. This includes plantings, irrigations, fertilizer applications, tillage events, addition of organic material (residues or manure) and harvests. The module thus is key in processing information associated with what are considered “treatments” in field experiments. The module includes provisions for rule-based automatic management such as to control planting dates when a given date and soil temperature threshold are attained.

There are currently seven types of field operations that are modeled in CSM.

Planting Event

Irrigation application

Fertilizer application

Tillage event

Organic matter application

Chemical application

Harvest event

**Planting event**

Planting can be based on either field records or on a set of rules for triggering automatic planting.

Field records include information such as date, plant density at sowing and emergence, planting method, row spacing, planting depth, and the weight of material planted. Transplanting material requires additional information about the transplant weight and nursery environment.

Automatic planting allows a planting window to be specified. When soil moisture and temperature conditions are within the specified ranges, and within the specified planting window, a planting event is triggered using the details specified in the field records section of File X.

**Irrigation application**

Irrigation can be based on either field records or on a set of rules for triggering automatic irrigation.

Field records

Automatic irrigation

For more details on specifying irrigation in DSSAT-CSM, see here.

**Fertilizer application**

Fertilizer applications are specified as field records either by “year + day of year” format or as days after planting. Fertilizer materials are specified as a code, which triggers a lookup of fertilizer properties from a table.

**Tillage event**

See here for information about tillage in DSSAT-CSM.

**Organic matter application**

Organic matter applications are specified based on field records in either “year + day of year” format or as days after planting. Residue material codes are listed in the Details.CDE file in the DSSAT root directory. Physical and chemical properties of these various materials are listed in RESCH\*\*\*.SDA in the Standard Data folder, where the “\*\*\*” refers to the DSSAT major release version number, e.g., “047” for DSSAT v4.7.

**Chemical application**

DSSAT-CSM accommodates chemical applications, including date of application, type of chemical, application method, and amount applied. Currently the model only responds to application of ethylene or ethephon (growth regulators) to force flowering in the pineapple model. All other chemical application information listed in an experiment file is considered to be documentation of the field experiment only and will not have an effect on the model processes. Codes for chemical applications are listed in the Details.CDE file in the DSSAT root directory.

**Harvest event**

Harvest events for annual crops can be specified on a particular date or days after planting based on field records. Automatic harvesting can be specified when the crop reaches simulated maturity date.

The perennial forage model allows “mow” events to be specified in an external file, allowing multiple harvests in a simulation.

**Soil Module**

The Soil module deals with simulation of the dynamics of soil constituents including:

Soil water

Inorganic soil N

Inorganic soil P

Inorganic soil K

Soil organic matter modules

CERES-Godwin soil organic matter module – This is the default soil organic matter module for the DSSAT-CSM for single-season simulations. It requires fewer inputs than the Century-based module and has a long history of use for simulation of cropping systems in DSSAT and other models.

CENTURY (Parton) soil organic matter module – A SOM–residue module from the CENTURY model was incorporated in the DSSAT crop simulation models that include more complex decomposition dynamics and a surface residue layer. By incorporating the CENTURY SOM–residue module, DSSAT crop simulation models have become more suitable for simulating low-input systems and conducting long-term sustainability analyses.

Greenhouse Gas Emissions Modules

Ceres Denitrification

DayCent Denitrification

N-gas emissions

Methane emissions

**Dynamic soil properties**

Flood N dynamics

**Weather Module**

The Weather module inputs daily weather data and also can generate long term (e.g., 30-year) series of daily weather data that reproduce the statistical properties of a shorter series of weather years. The minimum daily weather data required are solar radiation, minimum and maximum air temperatures, and precipitation. However, for more accurate estimation of evapotranspiration, humidity (e.g., as daily mean dewpoint temperature) and wind speed are required.

The minimum weather data include the metadata for the weather station, especially latitude, longitude, elevation, and sensor height, and daily maximum and minimum temperature, rainfall, and solar radiation. Although solar radiation is not commonly measured at many remote locations, it is a required input for the accurate simulation of photosynthesis and of potential transpiration using the Priestley-Taylor equation (Priestley and Taylor, 1972).

Additional optional daily inputs include dewpoint temperature, windspeed, photosynthetically active radiation, minimum relative humidity, and vapor pressure. Depending on the user selection of method for estimating reference evapotranspiration, the model will use these values if supplied, but provide default values if the data are not provided.

Hourly variables are synthesized by the module for solar radiation, relative humidity, temperature, and wind speed for use by those routines which simulate processes on an hourly time scale.

In some cases, the period of record of historical daily weather data is insufficient, and it is desirable to have the capability to generate synthetic weather data with the same statistical characteristics as the actual weather data at the location. The WGEN (Richardson and Wright, 1984) routines generate daily weather values for precipitation, maximum temperature, minimum temperature and solar radiation for use by the CROPGRO model. A first-order Markov chain model is used to describe the occurrence of rainfall on a given day and a gamma distribution function is applied to fit the amount of rainfall. The occurrence of rain on a given day will influence the temperature and solar radiation for that day and the probability of rain on the following day.

The environmental modification capability allows a user to modify weather values during a simulation to model the effects of climate change, growth chambers, solar shades, rain shelters, or other types of artificial manipulation of environment.

Atmospheric CO2 can be specified in several ways in the model:

The default method is to read measured values from a file. These values represent smoothed bi-monthly values from the Mauna Loa observatory. Daily values are linearly interpolated.

A default value can be used which allows a static CO2 value of 380 ppm (corresponding to 2005 values) to be used for an entire simulation.

Annual or daily CO2 values can be specified in the weather input file.

And the final method is to specify a CO2 value in the Environmental Modifications section of an experiment file.

**The Soil-Plant-Atmosphere module (SPAM) module**

The Soil-Plant-Atmosphere module (SPAM) module deals with competition for light and water among the soil, plants, and atmosphere. It models processes of soil evaporation and plant transpiration, thus providing estimates of crop water use as actual evapotranspiration (ET). Soil temperatures at layer depths are also estimated in this routine.

Actual evapotranspiration (ET) depends on total ETo demand, which is estimated using one of two options: Priestley-Taylor (1972), based on standard weather data input, or FAO-56 (Allen et al., 1998), which requires daily wind speed and relative humidity as additional inputs. After ETo is calculated, it is partitioned to the potential transpiration of the crop canopy (Ep) or potential evaporation of the soil (Es) as a function of the LAI and an energy extinction coefficient (Kep). Kep differs for each crop in CROPGRO. For the CERES crops, a “mixed” function of extinction of photosynthetically active radiation (PAR) is used. The actual soil evaporation depends on the potential Es and the soil water content, using either the older Stage 1 (square root of time method) or the Suleiman-Ritchie method (Ritchie et al., 2009).

The actual transpiration of the crop is the minimum of the potential Ep or the water uptake. Potential root water uptake from successive layers follows the approach described by Ritchie (1998), and it is dependent on root length density and the fraction of available soil water content in each layer. Total root water uptake is integrated over all layers, and transpiration is reduced if potential root water uptake is less than potential Ep. Under water deficits, the daily photo-assimilation is reduced as a function of actual transpiration (root uptake) over potential Ep, using a drought stress factor called SWFAC. Expansive processes are reduced somewhat sooner by a similar factor called TURFAC. See Boote et al. (2009) for a review of water balance, evapotranspiration, and simulation of water stress effects in the CROPGRO model.

**Plant Modules**

The original crop models of DSSAT were CERES-Maize, CERES-Wheat, SOYGRO, and PNUTGRO. These models evolved over time from many independent models to become a single agricultural systems model that encompasses all the original crop models as individual crop modules (Jones et al., 2001).

New crop modules are added to DSSAT via two methods. The first, easier approach uses the CROPGRO template and data from field experiments, journal articles, non-refereed publications and reports, and variety trials to calibrate the genetic parameters which control the growth and development characteristics of the new crop. This approach does not require modifying existing model software or computer code. The second approach is to create a completely new crop module within the CSM code, such as when growth or phenological processes are very different from those described by CROPGRO. In this case, both model coding and calibration of parameters are required. The CERES-Sugarbeet model is one example of a recently added module (Anar et al., 2019).

Crop models under development using the CROPGRO template include chia (Mack et al., paper submitted, 2019), quinoa, and carinata (Boote et al., in progress, 2019). Sweet corn (Lizaso et al., 2007) and sugarbeet (Anar et al., 2019) were added as new crop modules following the style of CERES models. Other models in CSM were adapted from an existing model to use the modular format of CSM (Jones et al., 2001), such as CANEGRO sugarcane (Singels et al., 2008), ALOHA pineapple (Zhang et al., 1997), and NWheat (Asseng et al., 2000). The CROPSIM model (Hunt and Pararaiasingham, 1995) was added to DSSAT-CSM as a template model for wheat, barley, and cassava. The CROPSIM template was also used to develop a new crop model specific for cassava called YUCA. The perennial forage model (Rymph, 2004) is based on the CROPGRO model, but it differs enough that it is a separate model. It is also a template model, allowing simulation of brachiaria and cynodon (Pequeno et al., 2018), and alfalfa (Medicago sativa) (Malik et al., 2018). The SIMPLE modeling approach by Zhao et al. (2019) will also be included or the development of models for crops for which limited data are available.

Generic plant sub-modules

These sub-modules can be accessed from any plant species module, although not all plant modules have been linked at this time.

Generic plant phosphorus uptake

Pest and disease damage

Crop species sub-modules

Crops currently available in DSSAT are listed below with links to further information as available:

CROPGRO annual crop module

Grain legumes:

Soybean

Peanut (Groundnut)

Dry bean

Chickpea (Garbanzo)

Cowpea

Pigeonpea

Velvet bean

Faba bean

Vegetables

Bell pepper

Cabbage

Green bean

Tomato

Fiber crops

Cotton

Oil crops

Canola

Safflower

Sunflower

Under development: Amaranth, Carinata, Chia, Flax, Lentil, Pea, Lima bean, Quinoa

CROPGRO perennial forage module

Legumes

Alfalfa (Lucerne)

Grasses

Bahia

Bermudagrass

Brachiaria

Under development: Guinea grass, Ryegrass

CERES-Maize module

Grain cereals

Maize

IXIM module

Grain cereals

Maize

CERES-Sweetcorn module

Vegetables

Sweetcorn

 CERES-Rice module

Grain cereals

Rice

CERES-Sorghum module

Grain cereals

Sorghum

CERES-Millet module

Grain cereals

Millet

CERES-Wheat module

Grain Cereals

Wheat

Barley

N Wheat module

Grain cereals

Wheat

Teff

SUBSTOR module

Tuber crops

Potato

AROID module

Root crops

Taro

Tanier

YUCA module

Root crops

Cassava

CROPSIM module

Root crops

Cassava

Grain cereals

Wheat

Barley

CERES-Beet module

Root/Energy crops

Sugar beet

CANEGRO module

Sugar/Energy crops

Sugarcane

CASUPRO module

Sugar/Energy crops

Sugarcane

 ALOHA module

Fruit crops

Pineapple

**How to Use the Model**

Note that you will need to install DSSAT with administrative privileges.

**Agronomic Studies**

DSSAT provides at least one real experimental data for each of the crops that can be simulated. This includes the daily weather data, soil surface and profile information, detailed crop management and some observations. More details can be found in the Minimum Data section. In order to run DSSAT for the example agronomy studies, open the DSSAT Shell from your desktop icon or App. In the middle panel you find the Selector for Crops. Select the type of crop you are interested in and then the specific crop. In the panel on the right-hand side a list of one or more experiments will appear. These are all real experiments that have been conducted in the past. Select the experiment you would like to simulate. By default all treatments associated with that experiment are selected. Then Click on the Run option on top of the DSSAT panel next to the lightning bold. A new window will open that will show all treatments that will be simulated. Select Run Model and the Cropping System Model of DSSAT will run in the background, starting at planting or the start of simulation date and ending when the model predicts harvest maturity or when the user has defined final harvest. The simulation of one single growing season should not take more than 1 second. Upon completion of all the simulations a “Simulations are completed” window pops up. Select the Analysis Tab and a list of output files will appear. For new users it might be best to select the “PlantGro.out” file first. This file includes daily outputs for most of the simulated plant growth variables, such as leaf, stem, seed, and root biomass, root length density for the different soil layers, leaf area index, drought stress and many others. Selecting “View” will show the detailed simulated output data, but “Plot” allows to display all data in a graphical format using the GBuild tool of DSSAT. Bolded variables mean that observed data from the experiment are available for a comparison between simulated and observed data. Select one or more variables you would like to plot as well as the treatments (“Runs”), and then click on “Next.” Both simulated and observed variables are shown, with the simulated data represented by the continuous line and observed by the symbols. Selecting “Statistic” will provide a statistical summary between simulated and observed. For time series data we prefer to use the “d-Statistic” and Root Means Square Error (RMSE).

DSSAT includes many different agronomic studies for most crops that have been conducted at many sites across the globe. For example, the maize model includes an Irrigation \* Fertilizer experiment conducted in Gainesville, Florida, USA (UFGA8201), an Irrigation \* Hybrid experiment conducted in Piracicaba, SP. Brazil (BRPI0202), a Temperature \* CO2 experiment conducted in Griffin, Georgia, USA (GAGR0201), a Nitrogen \* Phosphorus Experiment conducted in Wa, Ghana (GHWA0401), a Nitrogen \* Hybrid experiment conducted in Waipio, Hawaii, USA ( IBWA8301), a Nitrogen \* Plant Population experiment conducted in Ames, Iowa (IUAF9901MZ), and an irrigation experiment conducted for two years in Zaragosa, Spain (SIAZ9501 & SIAZ9601). Similar examples can be found for all other crops that are currently included in DSSAT. If you are interested in providing your data for inclusion in DSSAT, please do not hesitate to contact us. We are always interested in expanding the range of agronomic applications for different environments in order to help improve the performance of DSSAT and the Cropping System Model.

This Agronomic Studies section of DSSAT represented under the “Crops Selector” panel should only be used for crop model calibration, especially for the cultivar, variety, hybrid, or clone genetic coefficients, and model evaluation in response to different management inputs or environment. Any application should be conducted using the Seasonal, Sequence and Spatial Analysis options explained below.

**Seasonal and Risk Analysis**

Risk analysis is one of the main applications of DSSAT and allows users to evaluate alternate management practices for single growing seasons that account for both weather and economic uncertainty. The crop models were developed to address the Genotype \* Environment \* Management interactions. Using the seasonal analysis option of DSSAT, a user can compare the interaction of genotype and management for different environments, especially long-term historical weather data. In a standard risk analysis approach a user defines at least two or more management scenarios. Normally for the weather inputs at least 30 years of historical weather data are selected, analogous to climate normals that are based on 30 years of historical weather data. If long-term historical weather data are not available, a weather generator can be used. The Cropping System Model of DSSAT currently includes the WGEN and SIMMETEO weather generators. Externally generated weather data from MarkSim and other weather generators can also be used. The simulations are conducted for each unique combination of crop management and weather year. This provides a simulated distribution for yield, yield components, and other simulated variables. The economic uncertainty can be defined through prices files.

**Rotation and Long-term Simulations**

Cropping systems are not really defined by single growing seasons, but the long-term management practices that are implemented. This requires long-term simulations, starting with initialization of the cropping system environment with respect to soil water, nitrogen, phosphorus, potassium for the individual soil layers or horizon, soil surface residue and soil organic matter.

**Spatial Analysis**

DSSAT currently does not include tools that allow for the preparation of spatial input data and thematic map display of output data. Users should explore other tools, such as the CRAFT tool for spatial yield forecasting, MINK developed by the International Food Policy Research Institute (IFPRI), pDSSAT developed by the University of Chicago, and a new spatial modeling tool called DSSAT Pythia developed at the University of Florida.