DSSAT V4.5

DECISION SUPPORT SYSTEM FOR AGROTECHNOLOGY TRANSFER

Volume 1

Overview

Volume 1

DSSAT v4.5 Overview

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IBSNAT, The International Benchmark Sites Network for Agrotechnology Transfer, was a network consisting of the contractor (University of Hawaii), its subcontractors and many global collaborators. Together they created a network of national, regional, and international agricultural research for the transfer of agrotechnology among global partners in both developed and developing countries.

From 1982 to 1987, IBSNAT was a program of the U.S. Agency for International Development under a cost-reimbursement Contract, No. DAN-4054-C-00-2071-00, with the University of Hawaii. From 1987 to 1993, the contract was replaced with a Cooperative Agreement, No. DAN- 4054-A-00-7081-00, between the University of Hawaii and USAID.

In 1994, the International Consortium for Agricultural Systems Application or ICASA was established as a non-profit corporation in Honolulu, Hawaii. ICASA is governed by a Board of Directors consisting of former members of the IBSNAT network and international systems scientists. The ICASA network oversees the development of systems tools, including DSSAT.

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Volume 1

DSSAT v4.5 Overview

Table of Contents

Volume 1
Chapter 1

Introduction to DSSAT v4.5

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CSM Model Improvements
May 6, 2010

This document outlines the changes in the DSSAT Cropping System Model v4.5 since the release of v4.0.2. These changes include bug fixes, model structural changes and new capabilities. A summary of changes is listed below with more detailed information beginning on page 3.

<u>Summary of New Features:</u>

- New crop models:
  - CaneGro-South African sugarcane model (SCCAN045 – Abraham Singels, SASRI, South Africa)
  - CASUPRO sugarcane model (SCCSP045 – Fred Royce, University of Florida & Fernando Villegas, Cenicaña, Columbia)
  - Sweet corn model (SWCER045 – Jon Lizaso, Universidad Politecnica de Madrid)
  - Aroids model: Taro and tanier (TRARO045 and TNARO045 – (Upendra Singh, IFDC & Richard Ogoshi, University of Hawaii)
  - Cassava (CSCRP045 – L.A. Hunt, University of Guelph)
  - Alternate wheat & barley model (CSCRP045 – L.A. Hunt , University of Guelph)
  - Alternate maize model (MZIXM045 – Jon Lizaso, Universidad Politecnica de Madrid)
  - Cotton model
- Tillage routines modify soil parameters and mix soil constituents
- Phosphorus modules
  - Inorganic soil P module
  - Organic P added to CENTURY and Ceres-based organic matter modules
  - Generic Plant P module, currently linked to CROPGRO crops, maize and rice
- Effects of organic matter on soil properties are modeled
  - Runoff and infiltration reduced by mulch layer
  - Soil evaporation reduced by mulch layer
  - Soil water holding capacity increased with organic matter
  - Soil albedo modified by mulch cover
- Suleiman-Ritchie soil evaporation routine
- Atmospheric CO2 is read from external file
- Option for new soil layer distribution methods
- Banded, hill fertilizer applications for P fertilizer

The following is a very brief summary of changes and improvements made in DSSAT v4.0

DSSAT v4.0 is an upgrade of the DSSAT v3.5 system, which was released in 1999. One of the main changes and improvements in DSSAT v4 is that it has been completely redesigned and is now MS Windows-based. All shell, application programs and data entry and analysis tools have been rewritten to be compatible with the latest Windows standards. In addition, all crop models were combined into the Cropping System Model (CSM), which is based on a modular modeling approach. CSM uses one set of code for simulating soil water, nitrogen and carbon dynamics, while crop growth and development are simulated with the CERES, CROPGRO, CROPSIM and SUBSTOR modules. The CENTURY-based soil carbon and nitrogen model for improved performance in low input agricultural systems and for simulation carbon sequestration was added as a separate soil module to CSM. The crop models of DSSAT v3.5 are included in DSSAT v4.0 as legacy models for user comparison and analysis.

<u>DSSAT v4 includes:</u>

- More than 18 different crops simulated with CSM, including maize, wheat, rice, barley, sorghum, millet, soybean, peanut, dry bean, chickpea, cowpea, faba bean, velvet bean, potato, tomato, bell pepper, cabbage, bahia and brachiaria and bare fallow.
- The DSSAT v3.5 legacy models, including cassava, sunflower, sugarcane, taro, tanier, and pineapple.
- Identical soil modules for the simulation of the soil water, nitrogen and carbon balances.
- The CENTURY-based soil carbon and nitrogen module.
- The Crop Management Data tool XBuild for entering and editing of experimental data.
- The Soil Data tool SBuild for entering and editing of soil data.
- A new Weather Data Manager WeatherMan for entering, analyzing and generating weather and climate data.
- The Experimental Data tool ATCreate for entering and editing detailed growth, development and yield data as well as soil water, nitrogen, and carbon measurements.
- The Graphics program GBuild for graphical display of simulated and experimental data.
- A seasonal analysis program for analysis of biophysical and economic data for single season simulations.
- A sequence analysis program for analysis of biophysical and economic data for crop rotations and multi-season experiments.
- The Introductory Simulation Tool ICSim for simple simulations and application of models as a teaching tool.
- The Evaluation and Diagnostics Program STATS for statistical analysis of simulated and measured vegetative and reproductive development and yield and yield component data.
- EasyGrapher, a simple graphing program for simulated data.
- The Weather Analogue program ANNA for analysis of weather trends.
- The CROPTest program for comparison and analysis of different versions of the crop simulation models.

DSSAT v4.0 has been developed through collaboration between scientists at the University of Florida, the University of Georgia, University of Guelph, University of Hawaii, the International Center for Soil Fertility and Agricultural Development, Iowa State University and other scientists associated with the International Consortium for Agricultural Systems Applications (ICASA).

- Tiledrain option
- CROPGRO
    - Species parameter and optional ecotype parameter for canopy light extinction
    - Cultivar parameters for maximum threshing percentage, seed protein content and seed oil content (previously in ecotype file)
    - Optional species parameters for N stress sensitivity
    - Optional species parameter for fresh weight calculations, currently implemented for sweet corn, tomato, green bean
- Sorghum
    - Added P3 and P4 coefficients
    - Externalized stem partitioning STPC=0.1
    - Externalized root partitioning RTPC=0.25
    - Include GDDE for P9 calculation
- Ceres maize
    - Added canopy height
    - New species parameters:
        - Phosphorus parameters
        - Critical N tissue concentration
        - Change in N concentration with growth stage
        - Plant lignin concentrations
    - New ecotype cultivars for cold sensitivity
    - Other changes – Jon or Ken to summarize?
- CSCER wheat/barley – Tony to summarize improvements
- CENTURY model
    - Initialization of organic matter improved
    - Daily water and temperature factors for decomposition improved

<u>Bug fixes:</u>

- Fixed initialization problem with flooded fields
- Fixed excessive N loss with root senescence in Ceres-maize model
- Fixed error in Penman Monteith potential evapotranspiration routine
- XLAI used in call to potential soil evaporation instead of XHLAI
- Soil temperature water factor equation fixed

<u>Format , input/output or model structural changes:</u>

- NTRANS and CENTURY routines split into organic matter modules and inorganic N and P modules. Common inorganic N and P modules are shared by both organic matter modules.
- Fertilizer and organic matter application routines moved out of NTRANS and CENTURY and into management module.
- Input module is a subroutine of CSM rather than a separate executable
- GenCalc runmode option
- Coding changes for portability to other operating systems (Linux, Unix) and compilers
- External simulations control file overrides controls in FILEX
- Input file format changes:

    - Cultivar parameter quality index added to all cultivar files (= number of experiments used in estimation of parameters)
    - Batch file lists full path for experiment file and includes treatment and rotation.
    - Crop model listed in DSSATPRO.V45 and optionally in FILEX.
    - Soil file – new field for exchangeable calcium, EXCA
    - Free format reads for soil profile and weather data. Data are still right-justified under headers, but are not limited to 6-character fields.
    - CENTURY –SOMFRACTIONS.SOL file revised and renamed to SOMFR045.SDA
    - CENTURY – SOMFIX045.SOL file renamed to SOMFX045.SDA
    - Residue characteristics file changed from SOILN040.SOL to RESCH045.SDA. Includes lignin content of various crops.
- New output files or format changes:
    - Management operations output files, MgmtOps.OUT (daily) and MgmtEvent (summary).
    - INFO.OUT for informational messages to the user
    - Days after simulation computed as DAS=0 for initial conditions, DAS=1 for end of first day of simulation. Days after planting, DAP=0 still represents planting day.
    - Water productivity added to Overview and Summary files.
    - Soil layer output tied to layer depth in output files. Headers reflect depths.

Table 1. Changes to v4.5 FILEX showing new option and method codes

```
*FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX  SLDP  ID_SOIL    FLNAME
 1 UFGA0001 UFGA       -99     0 IB000     0     0 00000 -99    180  IBSB910015 -99
@L ...........XCRD ...........YCRD .....ELEV .............AREA .SLEN .FLWR .SLAS FLHST FHDUR
 1         29.63000       -82.37000     40.00               0.0   0.0   0.0   0.0 FH001     10

*SOIL ANALYSIS
@A SADAT  SMHB  SMPX  SMKE  SANAME
 1   -99   -99   -99   -99  -99
@A  SABL  SADM  SAOC  SANI SAPHW SAPHB  SAPX  SAKE  SASC
 1    20   -99   1.5   -99   -99   -99   -99   -99   1.0
 1    40   -99   0.5   -99   -99   -99   -99   -99   0.4

*SIMULATION CONTROLS
@N GENERAL     NYERS NREPS START SDATE RSEED SNAME.................... MODEL...
 1 GE              1     1     S 78166  2150 BRAGG, IRRIGATED & NON-IR CRGRO045
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL   CO2
 1 OP              Y     Y     Y     Y     N     N     N     Y     D
@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO NSWIT MESOM MESEV MESOL
 1 ME              M     M     E     R     R     L     D     1     G     S     2
@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
 1 MA              R     R     R     R     M
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT DIOUT VBOSE CHOUT OPOUT
 1 OU              N     Y     Y     1     Y     Y     Y     Y     N     N     D     N     N
```

Field history code and duration (no defaults)

Stable organic C (%)

Model name

Verbose switch
VBOSE
‘0’ Only Summary.OUT
‘N’ Minimal output
‘Y’ Normal output (default)
‘D’ Detailed output
‘A’ All outputs

Switch for mulch effects
INFIL:
‘R’ Ritchie method incl. mulch (default)
‘S’ SCS method (same as ‘R’)
‘N’ No mulch effects modeled

Soil evap method switch
MESEV:
‘S’ Suleiman-Ritchie method (default)
‘R’ Ritchie-Ceres method

Soil layer distribution
MESOL:
‘1’ Model-specified soil layers
‘2’ Modified soil profile (default)
‘3’ Unmodified soil profile

Atmospheric CO_2
CO2:
‘M’ Actual CO2; Mauna Loa, Hawaii (Keeling curve) (default)
‘D’ Default static value (380 vpm)
‘W’ Read static value from weather file

DSSAT V4.5

Volume 1
Chapter 2

Input and Output Files

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Chapter 2

Input and Output Files

Table of Contents

List of Tables

List of Figures

1.0 INTRODUCTION

The files and file structures described here are designed to accommodate a diversity of crop models and applications. Their specifications are the basis of the data structures used in DSSAT v3 and v3.5. They have been constructed to facilitate the exchange of data among modelers and other users as well as a means of documenting experiments. The files can be used as direct input to crop models. They also may function as a medium to generate model-specific input files and keep intact the facility for data set interchange. Considerable thought has been given to designing a system to maximize the flexibility of input configurations. This flexibility has often meant specification of a consider-able number of "slots" for inputs.

2.0 File Structure

The files are organized into input, output and experiment performance data files (Table 1). A typical organization of these is depicted in Figure 1. The experiment performance files are needed only when simulated results are to be compared with data recorded in a particular experiment. In some cases, however, they could be used as input files to 'reset' some variables during the course of a simulation run. They could also be used to record time series of pests or pest damage to the crop, which could be used as input to crop models. The model output files are organized to allow users to select the information needed for a particular application. Similarly, model inputs are organized to allow some flexibility in their use with specific models. For example, there is a soil nutrient management section that users could eliminate when their crop model does not include a soil fertility component or when fertilizer was applied to eliminate nutrient stresses.

The DSSAT file structure has not changed significantly since v3.5. Much more detail about file structure is contained the DSSAT v3.5, Volume 2 documentation. That documentation is provided with DSSAT v4.5.

2.1 File Annotation

Each file should contain file headings, and, if the file is partitioned into sections, section headings. In addition, it is often desirable to add remarks to data contained within a file. These remarks may be header lines indicating the nature of following data items or may be comments on some aspects of the quality or source of the data. Headers may be used by the input components of a model to undertake particular operations, while comment lines would generally be ignored. The following symbols, placed in column 1, indicate the nature of the annotation:

- * file or section heading
- @ header line specifying variables occurring below
- ! Comment line.

Table 1 Crop Model Input and Output Files.

Internal File Name	Example File Name(s)	External Description
INPUT FILES		
Experiment		
FILEX	UFGA8801.SBX	Experiment details file for a specific experiment (e.g., soybean at UFGA): Contains data on treatments, field conditions, crop management and simulation controls
Weather and Soil		
FILEW	UFGA8801.WTH	Weather data, daily, for a specific (e.g.,UFGA) station and time period (e.g., for one year)
FILES	SOIL.SOL	Soil profile data for a group of experimental sites in general (e.g.,SOIL.SOL) or for a specific institute (e.g., UF.SOL)
Crop and Cultivar		
FILEC	SBGRO045.CUL[1]	Cultivar/variety coefficients for a particular crop species and model; e.g., soybean for the 'GRO' model,version 045
FILEE	SBGRO045.ECO[1,2]	Ecotype specific coefficients for a particular crop species and model; e.g., soybean for the 'GRO' model,version 045
FILEG	SBGRO045.SPE[1]	Crop (species) specific coefficients for a particular model; e.g., soybean for the 'GRO' model, version 045
EXPERIMENT DATA FILES		
FILEA	UFGA8801.SBA	Average values of performance data for a soybean experiment. (Used for comparison with summary model results.)
FILET	UFGA8801.SBT	Time course data (averages) for a soybean experiment. (Used for graphical comparison of measured and simulated time course results.)
[1] *These names reflect a standard naming convention in which the first two spaces are for the crop code, the next three characters are for the model name, and the final three are for model version.*		
[3] *Not all crop models use the ECO file.*		
OUTPUT FILES[4]		
OUTO	OVERVIEW.OUT	Overview of inputs and major crop and soil variables.
OUTS	SUMMARY.OUT	Summary information: crop and soil input and output variables; one line for each crop cycle or model run.
SEVAL	Evaluate.OUT	Evaluation output file (simulated vs. measured)
OUTG	PlantGro.OUT	Daily plant growth
OUTPC	PlantC.OUT	Daily plant carbon (CROPGRO crops only)
OUTPN	PlantN.OUT	Daily plant nitrogen
OUTD	Pest.OUT	Daily pest and disease damage
OUTSC	SoilC.OUT	Daily soil carbon
OUTSN	SoilNi.OUT	Daily inorganic soil nitrogen
OUTWAT	SoilWat.OUT	Daily soil water
OUTT	SoilTemp.OUT	Daily soil temperature
OUTSOMC	SOMLITC.OUT	Daily soil organic carbon (Century model only)
OUTSOMN	SOMLITN.OUT	Daily soil organic nitrogen (Century model only)
FLDN	FloodN.OUT	Daily flooded field nitrogen processes
OUTLFLD	FloodW.OUT	Daily flooded field management
OUTWTH	Weather.OUT	Daily weather
OUTSPAM	ET.OUT	Daily soil-plant-atmosphere
OUTETP	ETPhot.OUT	Daily leaf level photosynthesis (CROPGRO crops only)
OUTET	ET.OUT	Daily soil-plant-atmosphere output file
OUTM	MgmtOps.OUT	Daily management operations output file
	PlantP.OUT	Daily plant phosphorus output

	SoilDyn.OUT	Daily soil dynamics output file (temp)
	SoilOrg.OUT	Daily soil carbon output file
	SoilPi.OUT	Daily inorganic soil phosphorus output file
OUTSOMP	SOMLITP.OUT	Daily soil organic matter phosphorus output file
	FreshWt.OUT	Daily fresh fruit weight
	Mulch.OUT	Daily surface mulch output file
	MgmtEvent.OUT	Management event output file
PNBAL	PlantNBal.OUT	Seasonal plant nitrogen balance
	PlantPBal.OUT	Seasonal plant phosphorus balance
SCBAL	SoilCBal.OUT	Seasonal soil carbon balance
	SolNBalSum.OUT	Seasonal soil N balance summary
SNBAL	SoilNBal.OUT	Seasonal soil N balance (v4.02 and earlier)
	SoilNiBal.OUT	Seasonal inorganic soil N balance
	SoilNoBal.OUT	Seasonal organic soil N balance
	SolPBalSum.OUT	Seasonal soil P balance summary
	SoilPiBal.OUT	Seasonal inorganic soil P balance
	SoilPoBal.OUT	Seasonal organic soil P balance
SWBAL	SoilWatBal.OUT	Seasonal soil water balance
ERRORO	ERROR.OUT	Error messages
OUTINFO	INFO.OUT	Information output file
SLDET	SOMLIT1.OUT	Detailed Century SOM output
OUTWARN	WARNING.OUT	Warning messages
WORK	WORK.OUT	CSCER, CSP information output file

[4] *The example names for the output files (e.g., PlantGro.OUT) are for temporary files that are rewritten during each simulation run. Output files can be saved, however, and in this case the file names are made up of the usual institute, site, and experiment, with a suffix consisting of the letter "O" plus a 2-character identifier to designate file type (An example of a saved OVERVIEW output file would be UFGA8801.OOV, where the "OV" designates Overview.*

2.2 File Naming Conventions

A set of file-naming conventions have been adopted to facilitate recognition of different categories of data. The convention has two parts: 1) the file extension which is used to specify the type of file; and 2) the prefix which is used to identify the contents of the file. Following is a list of extensions and prefixes.

Extensions

.WTH	Weather data file
.SOL	Soil profile data file
.CUL	Cultivar/variety specific coefficient file
.ECO	Ecotype specific coefficient file
.SPE	Crop (species) specific coefficient file
.OUT	Output file generated by the crop model
.LST	A list file - provides a list of either experiments, weather data sets or soil data sets
.ccX	Experiment details file (i.e., FILEX)
.ccA	Average values of observation data
.ccT	Time course data (averages)

The 'cc' in the above extensions indicates a crop code (e.g., WH). The current crop codes used are listed below:

Currently available				Future			
Code	Crop	Code	Crop	Code	Crop	Code	Crop
BA	Barley	PI	Pineapple	AL	Alfalfa/Lucerne	NP	Napier grass
BH	Bahia grass	PN	Peanut	BS	Beet sugar	OA	Oats
BM	Bermuda grass	PR	Pepper	BW	Broad leaf weeds	PE	Pea
BN	Dry bean	PT	Potato	CN	Canola	PO	Perennial peanut
BR	Brachiaria	RI	Rice	CT	Citrus	PP	Pigeonpea
CB	Cabbage	SB	Soybean	CV	Clover	RP	Rhizoma peanut
CH	Chickpea	SC	Sugarcane	GR	Grass vegetation	SI	Switchgrass
CO	Cotton	SG	Grain sorghum	GW	Grass weeds	SS	Sesame
CP	Cowpea	SU	Sunflower	LT	Lentil	ST	Shrubs/trees
CS	Cassava	SW	Sweetcorn	NN	Banana	VI	Vine
FA	Fallow	TM	Tomato				
FB	Faba bean	TN	Tanier				
GB	Green bean	TR	Taro				
ML	Pearl millet	VB	Velvet bean				
MZ	Maize	WH	Wheat				

Prefixes

For most model input files and experiment observation files, the prefix is constructed from an institute code (2 characters), a site code (2 characters), the year of the experiment (2 characters) and an experiment number (2 characters). For example, an experiment conducted by the University of Florida (UF) at Gainesville (GA) in 1988 (88) would yield a file prefix of UFGA8801. The file prefix conventions used for output files and genotype coefficient files are shown in Table 1.

2.3 Missing Data

For all input files, the value '-99' is entered when required numeric data are missing or unavailable.

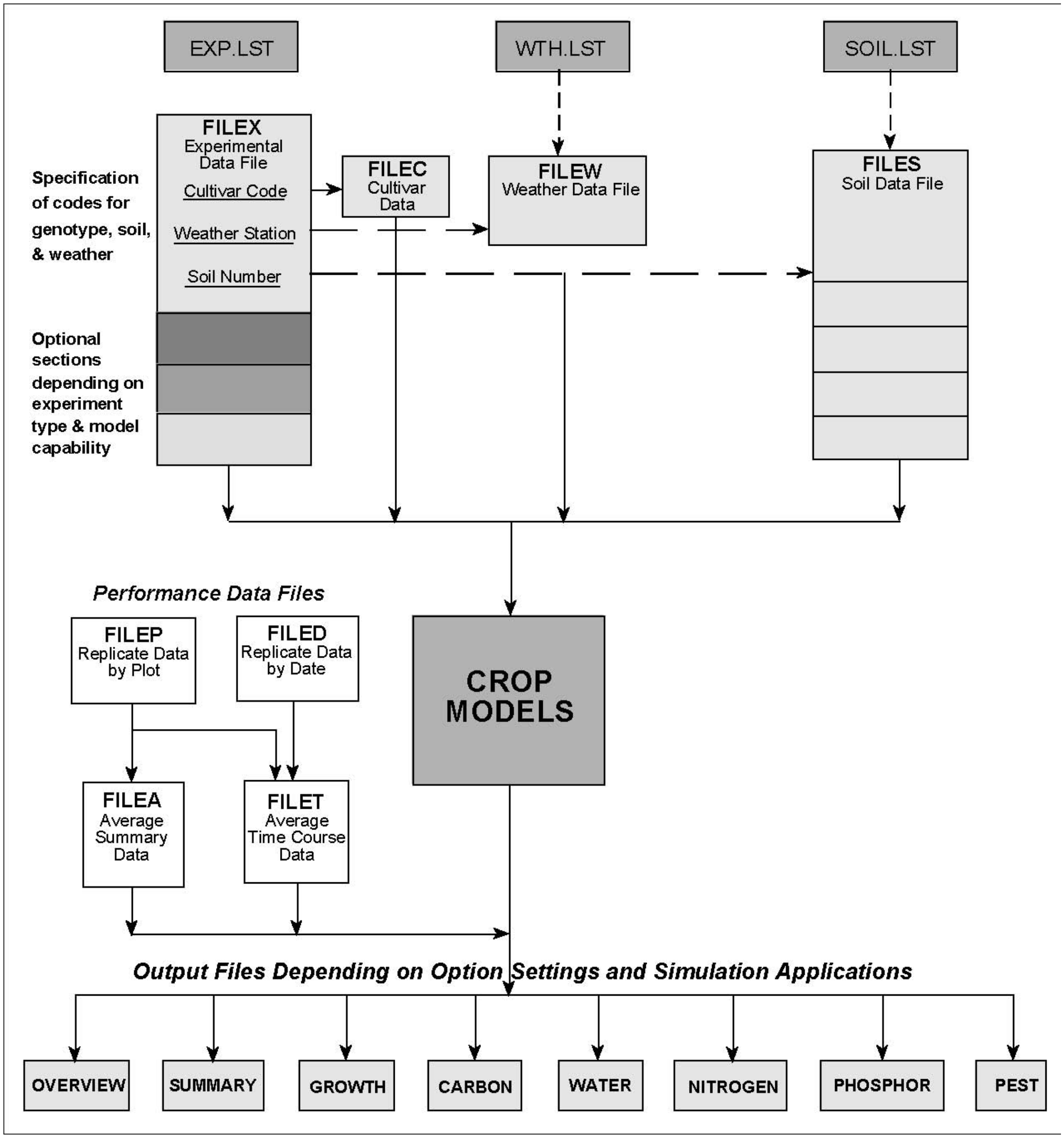

Figure 1 Overview of input and output files used by DSSAT crop models

3.0 INPUTS

Input files are further divided into those dealing with the experiment, weather and soil, and the characteristics of different genotypes (crop and cultivar) (Table 1).

3.1 Experiment Details File

One main file, referred to as FILEX (**Error! Reference source not found.**), documents the inputs to the models for each "experiment" to be simulated. Each experiment could be a real one for which there would be corresponding observed field data, or a hypothetical one defined for simulation. Thus, inputs for many real and hypothetical experiments can be stored for documentation and for use at different times. The file heading contains the experiment code and name, the treatment combinations, and details of the experimental conditions (field characteristics, soil analysis data, initial soil water and inorganic nitrogen conditions, seedbed preparation and planting geometries, irrigation and water management, fertilizer management, organic residue applications, chemical applications, tillage operations, environmental modifications, harvest management), and simulation controls. The experiment code uses the same convention as the file naming system to provide information on institute, site, planting year, experiment number, and crop. For example: UFGA8201MZ, is the code for maize experiment '01', planted in 1982 by the institute designated by UF (University of Florida) at site GA (Gainesville). The file can also contain the names of the people supplying the data set and information on the plot sizes, etc., used in the experiment. It may also contain any incidents that occurred during the course of the experiment that may affect the interpretation of the data. These latter items are not normally used by simulations models, but are provided for reference and assistance in interpreting simulation results. Documentation of these sections is included in **Error! Reference source not found.**, for use when required.

The structure of FILEX has been designed with the goal of maximizing the flexibility of input configurations while preserving the concept of entering only a minimum of inputs to run a simulation. The file can be easily configured to accommodate very different types of simulation runs. To enable this flexibility, the file description pro-vides slots for inputs and descriptive information which may be needed for some types of simulation runs but not for others. FILEX has been configured in such a way that only those data required for individual simulations need be entered.

In order for FILEX to accommodate a wide variety of experimental layouts, a broad definition of what comprises a treatment is necessary. For the purposes of data organization in FILEX, a treatment can be any factor of the experiment which varies. In addition to such things as combinations of fertilizer rates, varieties and irrigation levels, treatments can be different fields or different soils or different soil analyses or different weather. Thus if an experiment compared varieties across locations without water, nutrient and pest limitations, the locations of fields become treatments. This enables one experiment to utilize multiple weather data sets which was not possible when using the IBSNAT v2.1 model inputs and outputs (IBSNAT, 1990).

Most experiments will have more than one treatment. Many experiments will be conducted on only one site with treatments confined to such factors as fertilizer rates, varieties or irrigation treatments. Alternatively, an experiment such as a plant breeding experiment may span several sites where the sites and varieties are treatments. To accommodate these differing possibilities, FILEX has been designed with specific sections dedicated to particular categories of inputs. Only those sections required for the particular simulation need be present in FILEX.

Thus, data for the first treatment of an experiment are entered in the appropriate sections in FILEX. If, however, the experiment has more than one treatment, which is usually the case, then the data which are common to all treatments need not be repeated. This contrasts with the organization of inputs described for previous generations of IBSNAT models (IBSNAT, 1986 and 1990). In this newest version, only those data which are “new” for the treatment need be coded. For example, if an experiment examined the effect of five nitrogen rates, FILEX would contain sections for planting details and initial conditions and a section for fertilizer rate information for the first treatment. For the second treatment, the planting details and initial conditions would not be repeated but a second rate would appear in the fertilizer details section.

Please refer to the v3.5 documentation for detailed descriptions of data format and definitions.

DSSAT V4.5

Volume 1
Chapter 3

Overview of DSSAT v4.5 Cropping System Model (CSM)

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Chapter 1
Overview of DSSAT4 Cropping System Model (CSM)

Table of Contents

Chapter 1
Overview of DSSAT4 Cropping System Model (CSM)

List of Tables

List of Figures

1. Introduction

The DSSAT Cropping System Model (CSM) simulates growth and development of a crop over time, as well as the soil water, carbon and nitrogen processes and management practices. Figure 1 shows the main components of CSM. These include:

- A main driver program, which controls timing for each simulation,
- A Land unit module, which manages all simulation processes which affect a unit of land
- Primary modules that individually simulate the various processes that affect the land unit including weather, plant growth, soil processes, soil-plant-atmosphere interface and management practices.

Collectively, these components simulate the changes over time in the soil and plants that occur on a single land unit in response to weather and management practices. Unlike previous versions of DSSAT and its crop models, the DSSAT-CSM incorporates models of all crops within a single set of code. This design feature greatly simplifies the simulation of crop rotations since soil processes operate continuously, and different crops are planted, managed, and harvested according to cropping system information provided as inputs to the model.

2. Modular format

DSSAT-CSM was restructured from previous DSSAT crop models into a modular format, which is described by Jones et al. (2001) and Porter et al. (2000). The most important features of this approach are:

- Modules separate along disciplinary lines.
- Clear and simple interfaces are defined for each module.
- Individual modular components can be plugged in or unplugged with little impact on the main program or other modules, i.e., for comparison of different models or model components.
- The modular format facilitates documentation and maintenance of code.
- Modules can be written in different programming languages and linked together.
- Modules can be easily integrated into different types of application packages due to the well-defined and documented interfaces.
- The modular format allows for to possibility of integrating other components, such as livestock and intercropping, through well-defined module interfaces.
- Cooperation among different model development groups is facilitated. Each group can focus on specific modules as building blocks for expanding the scope and utility of the cropping system model.

As shown in Figure 1, each module has six operational steps, (run initialization, season initialization, rate calculations, integration, daily output, and summary output). The main program controls the timing of events: the start and stop of simulation, beginning and end of crop season, as well as daily time loops. This feature, an adaptation of van Kraalingen's (1991, 1995) work, allows each module to read its own inputs, initialize itself, compute rates, integrate its own state variables, and write outputs completely independently from the operation of other modules. Table 1 lists the primary and sub modules that are currently used in the cropping system model and summarizes their functions.

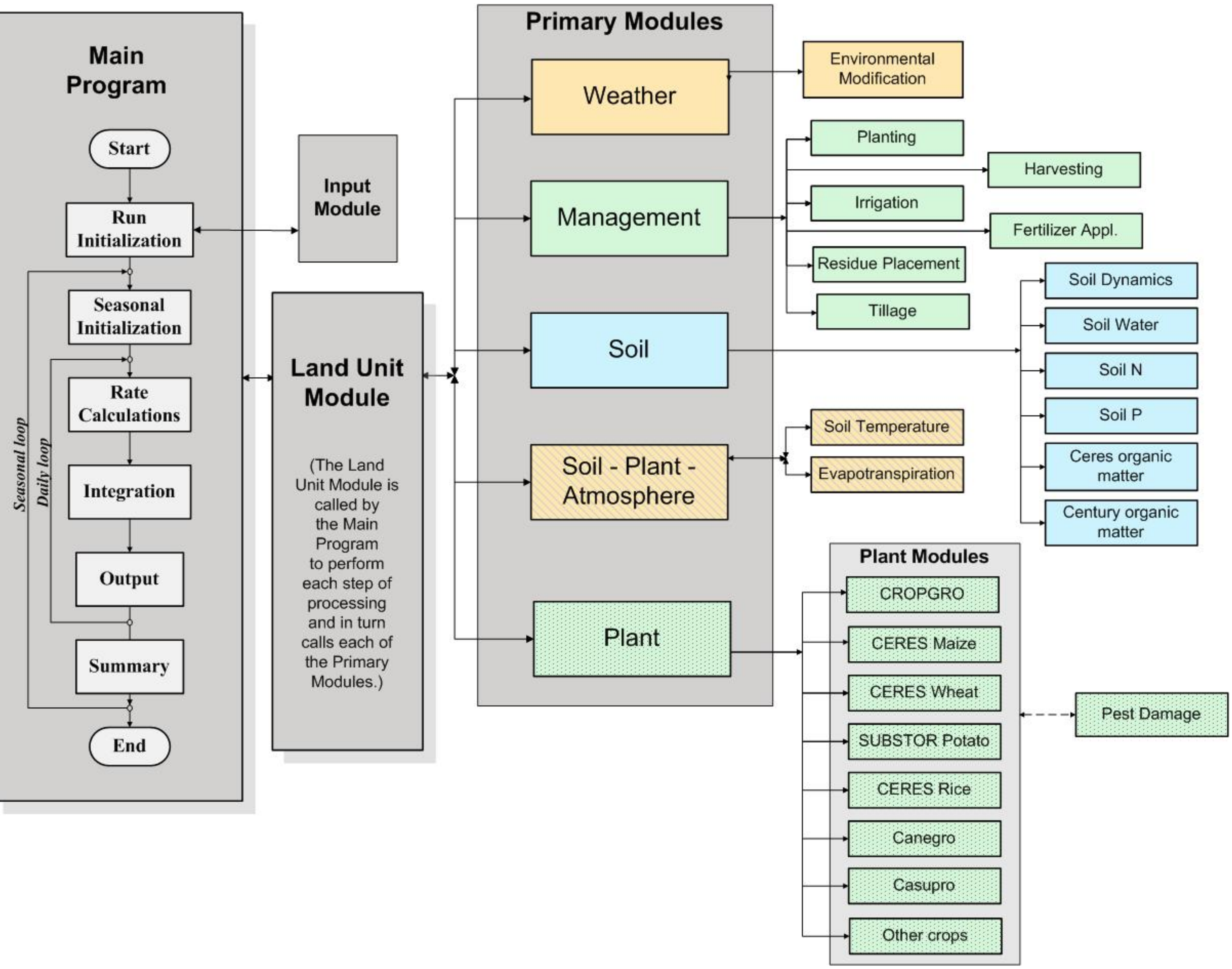

Figure 1. Overview of the components and modular structure of DSSAT-CSM.

Only a few "interface" variables are communicated to and from each module. This allows one to "unplug" a module and replace with a different one as long as it communicates the same variables to the rest of the modules, even if the parameters, state variables, and module input files are different. The concept of “interface variables” is critical to the modular approach used in DSSAT-CSM. Tables of interface variables are included with each primary module description in this document.

Sub modules operate exactly like primary modules in that each will usually perform two or more of the six steps (run initialization, seasonal initialization, rate calculations, integration, daily output and seasonal summary). There can be additional levels of sub modules, each behaving the same way. For example, the CERES-Maize sub module could have a phenology sub module. One could unplug this phenology module, and introduce a new one, if desired, without changing the rest of the CERES-Maize module. Any module or sub module can also have other subroutines as needed; there are no technical restrictions about how simple or complex a module should be.

There are two ways of interfacing crop growth routines in the DSSAT-CSM. A new plant growth routine can be introduced by interfacing it with the Plant module. This is the approach that was used to introduce the CERES maize, millet, sorghum, and rice models into DSSAT-CSM. These routines operated as stand-alone crop models in DSSAT v3.5.

The second way to introduce a new crop is through the use of a crop template approach. This can be implemented through the CROPGRO module and allows users to modify values in a species crop template file without changing any code. The CROPGRO development team has used this approach in creating models for different species, including faba bean (Boote et al., 2002), brachiaria grass (Giraldo et al., 1998), tomato (Scholberg et al., 1997), chickpea (Singh and Virmani, 1994) and velvet bean (Hartkamp et al., 2002), for example. A major advantage of this approach is that working with the crop template is less prone to errors as no changes to the model code are required. The major disadvantage to this method is that crops with very different life cycles from that described by the CROPGRO approach may not be adequately modeled.

The reorganization of the model code into a modular structure resulted in some differences in computation for some modules relative to DSSAT v3.5 models, even where no changes to algorithm were made. This is particularly evident in the soil water module. Previously, soil water content in each soil layer was updated sequentially throughout a day of simulation by each process affecting the soil profile. Drainage, root water uptake, soil evaporation, and plant transpiration each modified the soil water content sequentially and preferentially. With the modular structure, the various soil process rates are calculated using the value of soil water content at the end of the previous day. After all rates are calculated throughout the model, the rates are used to update the state variables. This change in order of calculations became important for some experiments, particularly where drought stresses limited plant growth.

The DSSAT-CSM now contains logic to convert dates from the 2-digit year, as specified in the input experiment files, to a 4-digit year. This 4-digit year is carried throughout the model and used in all output files.

Table 1. Summary description of modules in the DSSAT-CSM

Primary Modules	Sub Modules	Behavior
Main Program (DSSAT-CSM)		Controls time loops, determines which modules to call based on user input switches, controls print timing for all modules. Calls the input module (MINPT030.EXE) to read FILEX, soil file, and cultivar file and write the appropriate output information to a temporary input file (DSSAT40.INP).
Land Unit		Provides a single interface between cropping system behavior and applications that control the use of the cropping system. It serves as a collection point for all components that interact on a homogenous area of land.
Weather		Reads or generates daily weather parameters used by the model. Adjusts daily values if required, and computes hourly values
Soil	Soil Dynamics	Computes soil structure characteristics by layer. This module currently reads values from a file, but future versions can modify soil properties in response to tillage, etc.
	Soil Water Module	Computes soil water processes including snow accumulation and melt, runoff, infiltration, saturated flow and water table depth. Volumetric soil water content is updated daily for all soil layers. Tipping bucket approach is used.
	Soil Nitrogen and Carbon Module	Computes soil nitrogen and carbon processes, including organic and inorganic fertilizer and residue placement, decomposition rates, nutrient fluxes between various pools and soil layers. Soil nitrate and ammonium concentrations are updated on a daily basis for each layer.
Soil – Plant – Atmosphere (SPAM)		Resolves competition for resources in soil-plant-atmosphere system. Current version computes partitioning of energy and resolves energy balance processes for soil evaporation, transpiration, and root water extraction.
	Soil Temperature Module	Computes soil temperature by layer.
CROPGRO Crop Template Module		Computes crop growth processes including phenology, photosynthesis, plant nitrogen and carbon demand, growth partitioning, and pest and disease damage for crops modeled using the CROPGRO model crop Template (soybean, peanut, dry bean, chickpea, cowpea, faba bean, tomato, Macuna, Brachiaria, Bahiagrass).
Individual Plant Growth Modules	CERES-Maize	Modules that simulate growth and yield for individual species. Each is a separate module that simulates phenology, daily growth and partitioning, plant nitrogen and carbon demands, senescence of plant material, etc.
	CERES-Wheat / Barley	
	CERES-Rice	
	CERES-Sorghum	
	CERES-Millet	
	SUBSTOR-Potato	
	Other (future) plant models	
Management Operations Module	Planting	Determines planting date based on read-in value or simulated using an input planting window and soil, weather conditions.
	Harvesting	Determines harvest date, based on maturity, read-in value or on a harvesting window along with soil, weather conditions.
	Irrigation	Determines daily irrigation, based on read-in values or automatic applications based on soil water depletion.
	Fertilizer	Determines fertilizer additions, based on read-in values or automatic conditions.
	Residue	Application of residues and other organic material (plant, animal) as read-in values or simulated in crop rotations.

3. Modes of operation

Different types of applications are accomplished in DSSAT-CSM by using different modes of operation to call the Land unit module on a daily basis. The run mode is specified by the command line arguments when the model is called. If the model is run using the DSSAT shell, these command lines are transparent to the user. However, if the model is run as a stand-alone program, the use of command line arguments becomes important. Table 2 lists the various modes of operation for CSM.

The first five run modes listed (batch, sensitivity, sequence, spatial, and seasonal) are available from the DSSAT v4 shell. All modes are available when the model is run form the command line.

Table 2. CSM modes of operation

Run mode	Description	Command line arguments
Batch	Experiments and treatments are listed in a batch file	B *batchfilename* (1)
Sensitivity analysis	Screen user interface to interactively modify input parameters	E *FileX* *TN* (2,3)
Sequence analysis	Soil processes are continuous, crop sequence is listed in batch file	Q *batchfilename* (1)
Spatial analysis	Simulates one or more crops over space.	S *batchfilename* (1)
Seasonal analysis	Multiple years run with the same initial conditions	N *batchfilename* (1)
Interactive	Screen user interface for interactive selection of experiment and treatment	(none)
Run all treatments	All treatments of specified experiment are run	A *FileX* (2)
Debug	The input module is not called to read FILEX, soils files or cultivar file. Instead, the temporary input file (*inpfile*) is read.	D *inpfile* (4)
(1) *batchfilename* – name of batch file; typically “d4batch.dv4”		
(2) *FileX* – name of experiment file		
(3) *TN* – treatment number to be run		
(4) *inpfile* – DSSATv4.0 temporary input file, typically “dssat40.inp”		

4. CSM components

A brief overview of each of the main program and each of the primary modules is included herein. Detailed technical documentation for the modules will be presented in future chapters of this document.

4.1. Main program

The main program reads information from the DSSAT experiment file (FILEX) that describes a particular experiment or situation to be simulated (Hunt et al., 2001) and sets a number of variables for controlling a simulation run. Figure 1 presents the interaction between the main program and the Land unit module. It initiates the simulation by setting the DYNAMIC variable for initializing the run. The main program calls the input module, which reads FILEX, the soils file, and the cultivar file and writes the appropriate information for this run to a temporary input file (DSSAT40.INP) for use by the modules. The Land unit module is then called for run initialization.

The main program then starts a crop season time loop and calls the Land unit module for initializing variables that must be set at the start of each season. After initialization of the seasonal loop, the main program starts a daily loop and calls the Land unit module three times in sequence, first to compute rates, secondly to integrate, and finally to report daily outputs. After a crop season is completed, it calls the Land unit module to produce season-end variables and to create summary output files.

The main program controls operation of the various modes of simulation and provides the timing and simulation control variables to all modules. Much of this simulation control information is contained in the composite variables, CONTROL and ISWITCH (see **Error! Reference source not found.** for a list of composite variables that are passed among the DSSAT-CSM primary modules).

4.2. Land unit module

The Land unit module calls each of the primary cropping system modules as shown in Figure 1. At the start of each new crop season, it obtains management information from the DSSAT input file. The Land unit and primary modules link to sub modules, and thus are used to aggregate processes and information describing successive components of the cropping system. For example, the Soil module has three sub modules that integrate soil water, soil carbon and nitrogen, and soil dynamics processes. In turn, these sub modules are also comprised of sub modules.

4.3. CROPGRO template module

The CROPGRO crop template module in DSSAT-CSM is the same as that described by Boote et al. (1998a), although its components were modified to fit the modular structure. The interface variables linking this module to the Land unit module are defined in Table 3. The template approach provides a generic means for modeling crops. A single source code can be used to simulate the growth of a number of different crops by the use of species characteristics defined in an external species file.

Table 3. CROPGRO template module interface

Input Variable	Definition	Input Variable	Definition
CONTROL	Composite variable containing variables related to control and/or timing of simulation. (See **Error! Reference source not found.** for list of composite variables)	ST(L)	Soil temperature in soil layer L (°C)
EOP	Potential plant transpiration rate (mm/d)	SW(L)	Volumetric soil water content in layer L (cm3 [water] / cm3 [soil])
HARVFRAC	Two-element array containing fractions of (1) yield harvested and (2) by-product harvested (fraction)	TRWUP	Potential daily root water uptake over soil profile (cm/d)
ISWITCH	Composite variable containing switches which control flow of execution for model. (See **Error! Reference source not found.** for list of composite variables).	WEATHER	Constructed variable which contains daily weather data. (See **Error! Reference source not found.** for list of composite variables)
NH4(L)	Ammonium N in soil layer L (μg[N] / g[soil])	YREND	Date for end of season (usually harvest date) (YYYYDDD)
NO3(L)	Nitrate in soil layer L (μg[N] / g[soil])	YRPLT	Planting date (YYYYDDD)
SOILPROP	Composite variable containing soil properties including bulk density, drained upper limit, lower limit, pH, saturation water content. (See **Error! Reference source not found.** for list of composite variables)		
Output Variable	**Definition**	**Output Variable**	**Definition**
CANHT	Canopy height (m)	RLV(L)	Root length density for soil layer L (cm[root] / cm3[soil])
EORATIO	Ratio of increase in potential evapotranspiration with increase in LAI (up to LAI=6.0) for use with FAO-56 Penman reference potential evapotranspiration.	RWUMX	Maximum water uptake per unit root length, constrained by soil water (cm3[water] / cm [root])
HARVRES	Composite variable containing harvest residue amounts for total dry matter, lignin, and N amounts. (See **Error! Reference source not found.** for list of composite variables)	SENESCE	Composite variable containing data about daily senesced plant matter. (See **Error! Reference source not found.** for list of composite variables)
KSEVAP	Light extinction coefficient used for computation of soil evaporation	STGDOY(I)	Day when plant stage I occurred (YYYYDDD)
KTRANS	Light extinction coefficient used for computation of plant transpiration	UNH4(L)	Rate of root uptake of NH4, computed in NUPTAK (kg [N] / ha - d)
MDATE	Harvest maturity date (YYYYDDD)	UNO3(L)	Rate of root uptake of NO3, computed in NUPTAK (kg [N] / ha -d)
NSTRES	Nitrogen stress factor (1=no stress, 0=max stress)	XHLAI	Healthy leaf area index (m2[leaf] / m2[ground])
PORMIN	Minimum pore space required for supplying oxygen to roots for optimal growth and function (cm3/cm3)	XLAI	Leaf area (one side) per unit of ground area (m2[leaf] / m2[ground])

Currently, the CROPGRO plant growth and development model simulates seven grain legumes (soybean (*Glycine max* L. Merr.); peanut (*Arachis hypogaea* L.); dry bean (*Phaseolus vulgaris* L.*);* chickpea; cowpea; velvet bean and faba bean (*Vicia faba* L.)), and non-legumes such as tomato (*Lycopersicon esculentum* Mill.) (Scholberg et al., 1997; Boote et al., 1998a,b), cabbage, bell pepper, and two grasses: bahia and brachiaria. Development of a cotton model is proceeding.

An overview of the types of parameters contained in the species file is given in Table 4. These parameters are contained in a separate species file for each crop using the crop template approach of the DSSAT-CSM. Each species file contains information on base temperatures (Tb) and optimum temperatures (Topt) for developmental processes (rate of emergence, rate of leaf appearance, and rate of progress toward flowering and maturity) and growth processes (photosynthesis, nodule growth, N_2-fixation, leaf expansion, pod addition, seed growth, N mobilization, etc.). The file also includes information on photosynthesis, N_2-fixation, tissue composition, and growth and maintenance respiration coefficients.

Table 4. Summary of types of parameters used in the crop template approach.

Section	Description
Photosynthesis	Canopy assimilation coefficients for effects of solar radiation and CO_2. Light extinction coefficient. Functions that define leaf N and temperature effects on photosynthesis.
Respiration	Respiration parameters associated with various growth processes.
Plant composition values	"Maximum", "normal growth", and "final" protein concentrations of leaf, stem, root, shell, seed, and nodule tissues. Carbohydrate-cellulose, lipid, lignin, organic acid concentration of leaf, stem, root, shell, seed, and nodule tissues. Effects of temperature on seed lipid concentration.
Carbon and nitrogen mining parameters	Coefficients for carbohydrate reserves in stem tissue. Fraction of new leaf, stem, root and shell tissue growth that is available carbohydrate. Mobilization rates of carbohydrate and protein from vegetative tissue.
Nitrogen fixation parameters	Nodule growth and senescence parameters. Arrays that define the effects of temperature, soil water, and nodule age on nitrogen fixation and nodule growth.
Plant growth and partitioning parameters	Dry matter partitioning to leaf, stem, and root as function of vegetative stage. Coefficients for partitioning at emergence, final growth stage, stem senescence, during water stress, and nodule growth. Parameters that define leaf expansion response to temperature and solar radiation. Initial root depth and length, root water uptake parameters. Relative effects of temperature on pod set, seed growth and relative change in partitioning. Relative effects of soil water content on peanut pegging and pod addition.
Senescence factors	Senescence parameters related to vegetative stage, freeze damage, nitrogen mobilization, drought, canopy self shading.
Phenology parameters	Curves that define temperature effect on vegetative, early reproductive, and late reproductive development. Parameters for each growth stage: preceding stage, photoperiod function, temperature function, temperature and water sensitivity, N & P sensitivity
Canopy height and width growth parameters	Internode length and canopy width increase as a function of plant vegetative stage. Internode elongation as a function of temperature and photosynthetic photon flux density.

The CROPGRO crop template provides for ecotype and cultivar traits to be defined in read-in files. Table 5 lists cultivar coefficients and definitions (Boote et al., 1998a). Also included are definitions of frequently used traits from the Ecotype file.Cultivar differences are created by 15 "cultivar" traits. The cultivar traits include two daylength sensitivity traits, five important life cycle "phase" durations, light-saturated leaf photosynthesis, vegetative traits, and reproductive traits. There are 19 traits in the ecotype file that were proposed to vary less often, such as thermal time to emergence and first leaf stages, but some traits from this file have been used frequently to characterize cultivars.

Table 5. Genetic coefficients used in the CROPGRO crop template module for modeling different crops.

Trait	Definition of Trait
ECO#	Code for the ecotype to which this cultivar belongs (see *.eco file)
CSDL	Critical Short Day Length below which reproductive development progresses with no daylength effect (for short day plants) (h)
PPSEN	Slope of the relative response of development to photoperiod with time (positive for short day plants) (1/h)
EM-FL	Time between plant emergence and flower appearance (R1) (photothermal days)
FL-SH	Time between first flower and first pod (R3) (photothermal days)
FL-SD	Time between first flower and first seed (R5) (photothermal days)
SD-PM	Time between first seed (R5) and physiological maturity (R7) (photothermal days)
FL-LF	Time between first flower (R1) and end of leaf expansion (photothermal days)
LFMAX	Maximum leaf photosynthesis rate at 30 ^oC, 350 vpm CO_2, and high light (mg $CO_{2/}$ (m^2 s)
SLAVR	Specific leaf area of cultivar under standard growth conditions (cm^2/g)
SIZELF	Maximum size of full leaf (three leaflets) (cm^2)
XFRT	Maximum fraction of daily growth that is partitioned to seed + shell
WTPSD	Maximum weight per seed (g)
SFDUR	Seed filling duration for pod cohort at standard growth conditions (photothermal days)
SDPDV	Average seed per pod under standard growing conditions (#[seed] /pod)
PODUR	Time required for cultivar to reach final pod load under optimal conditions (photothermal days)
Frequently used important traits from the Ecotype file	
R1PRO	Increase in daylength sensitivity after anthesis (CSDL decreases by this amount (h))
FL-VS	Time from first flower to last leaf on main stem (photothermal days)
THRESH	The maximum ratio of (seed/(seed+shell)) at maturity. Causes seed to stop growing as their dry weight increases until shells are filled in a cohort.
SDPRO	Fraction protein in seeds (g [protein]/g[seed])
SDLIP	Fraction oil in seeds (g [oil]/g[seed])

Phenology is an important component of the CROPGRO crop template approach. This component uses information from the species file, which contains cardinal temperature values, as well as information from the cultivar and ecotype files, which contain physiological day durations for respective life cycle phases. Life cycle progress through any given phase depends on a physiological day accumulator as a function of temperature and day length, in many cases. Crops like soybean are sensitive to day length, whereas other crops such as peanut are not. When the physiological day accumulator reaches a value defined by a threshold given in the cultivar file, a new growth stage is triggered. A physiological day can be thought of as equivalent to one calendar day if temperatures are optimum 24 hours per day and day length is below the critical short or long day length requirement, depending on species sensitivity. The species file also contains coefficients that indicate the effect of water or nitrogen deficit on rate of life cycle progress. These coefficients may vary with life cycle phase; for example, water deficit may slow the onset of reproductive growth but accelerate reproductive growth after beginning seed fill. The species file also allows different cardinal temperatures for pre-anthesis development compared to post-anthesis reproductive development. For additional information on phenology in CROPGRO see papers by Boote et al. (1998a,b), Grimm et al. (1993, 1994), Piper et al. (1996a,b), and Mavromatis et al. (2001).

The CROPGRO plant growth model allows crop photosynthesis to be calculated by two options:
(1) daily canopy photosynthesis, similar to radiation use efficiency models, or
(2) hourly hedgerow light interception and leaf-level photosynthesis.

The daily canopy photosynthesis option, modified from the method used in SOYGRO V5.4 (Jones et al., 1989), predicts daily gross photosynthesis as a function of daily irradiance for a full canopy, which is then multiplied by factors 0 to 1 for light interception, temperature, leaf nitrogen status, and water deficit. There are additional adjustments for CO_2 concentration, specific leaf weight, row spacing, and cultivar.

The second method of photosynthesis computation that is available to CROPGRO crops, the hourly hedgerow light interception and leaf level photosynthesis method, is described in Section 4.6, Soil plant atmosphere interface module, because it involves an energy balance at the soil plant atmosphere interface.

Growth of new tissues depends on daily available carbohydrate, partitioning to different tissues, and respiration costs of tissue synthesis. During vegetative growth, the model follows a partitioning pattern dependent on vegetative growth stage, but modified by water deficit and nitrogen deficiency. Partitioning coefficients for leaf, stem, and root are defined in the species crop template file. Beginning at flowering, cohorts of flowers, pods, and seeds are added daily. These cohorts have an explicit assimilate demand per day depending on genetic potential and temperature. Reproductive tissues have first priority for assimilate over vegetative tissues, up to a maximum reproductive partitioning factor. This factor may be less than 1.0 for indeterminate plants (such as peanut and tomato) and 1.0 for determinate plants, indicating that reproductive tissue eventually can utilize 100% of the assimilate.

Leaf area expansion depends on leaf weight growth and specific leaf area, where the latter depends on temperature, light, and water deficit. Leaf expansion during reproductive growth is terminated by decrease of assimilate allocated to leaf growth and by reaching a phase that terminates leaf expansion. During seed fill, nitrogen is mobilized from vegetative tissues. As a result photosynthesis declines and leaf abscission increases. Protein and carbohydrate mobilized from vegetative tissue contribute to seed growth while photosynthesis declines.

Growth respiration and conversion efficiency follow the approach of Penning de Vries and van Laar (1982) where the glucose cost for respiration and for condensation are computed as a function of the composition of each tissue. The species file contains the glucose cost to synthesize protein, lipid, lignin, organic acid, cellulose-carbohydrate, and mineral fractions as well as the approximate composition of each tissue. Maintenance respiration depends on temperature as well as gross photosynthesis and total crop mass minus protein and oil in the seed. Maintenance respiration is subtracted from gross daily photosynthesis to give available carbohydrates for new tissue growth.

Various authors have published details on these relationships and sources of data used in their development (Wilkerson et al., 1983; Boote et al., 1986; Jones et al., 1989; Boote and Pickering, 1994; Boote et al., 1997; Boote et al., 1998a,b; Boote et al., 2002).

4.4. Individual crop models

The individual crop module interface serves the same function as the CROPGRO Crop Template Module in that it has nearly the same interface variables (Table 6), linking plant growth dynamics to the other modules in the DSSAT-CSM. However, it is designed to link modules that describe growth, development and yield for individual crops. This module links in, for example, the CERES models from DSSAT v3.5 after modifications were made to fit the modular structure. Several of the individual models from DSSAT v3.5 have been implemented (maize, sorghum, millet, wheat, barley, and rice) as well as the potato SUBSTOR model (Hoogenboom et al., 1999b; Ritchie et al., 1998; Singh et al., 1998). Additional crops could be added to DSSAT-CSM by adhering to the modular structure and providing the interface variables defined in Table 6. The following synopsis summarizes the simulation of crop growth for three crops (maize, wheat, and barley).

4.4.1. Maize, wheat and barley model descriptions

The CERES-Maize, Wheat and Barley models were modified for integration into the modular DSSAT cropping system model. For these CERES models, the plant life cycle is divided into several phases, which are similar among the crops (Table 7). Rate of development is governed by thermal time, or growing degree-days (GDD), which is computed based on the daily maximum and minimum temperatures. The GDD required to progress from one growth stage to another are either defined as a user input (Table 8), or are computed internally based on user inputs and assumptions about duration of intermediate stages. Cultivar specific inputs for all DSSAT-CSM CERES models are presented in absolute terms for consistency, a convention change from that followed previously for wheat and barley for which relative values were used. The number of GDD occurring on a calendar day is a function of a triangular or trapezoidal function defined by a base temperature, one or two optimum temperatures, and a maximum temperature above which development does not occur. Daylength may affect the total number of leaves formed by altering the duration of the floral induction phase, and thus, floral initiation. Daylength sensitivity is a cultivar-specific user input. Currently, only temperature and, in some cases, daylength, drive the accumulation of growing degree-days (GDD); drought and nutrient stresses currently have no effect. During the vegetative phase, emergence of new leaves is used to limit leaf area development until after a species-dependent number of leaves have appeared. Thereafter, vegetative branching can occur, and leaf area development depends on the availability of assimilates and specific leaf area. Leaf area expansion is modified by daily temperature (GDD), and water and nitrogen stress.

Table 6. Interface for individual plant growth modules

Input Variable	Definition	Input Variable	Definition
CONTROL	Composite variable containing variables related to control and/or timing of simulation. (See **Error! Reference source not found.** for list of composite variables) SOILPROP	SOILPROP	Composite variable containing soil properties including bulk density, drained upper limit, lower limit, pH, saturation water content. (See **Error! Reference source not found.** for list of composite variables)
EOP	Potential plant transpiration rate (mm/d)	SRFTEMP	Soil surface temperature (°C)
FLOODWAT	Composite variable containing information related to bund management. (See **Error! Reference source not found.** for list of composite variables)	ST(L)	Soil temperature in soil layer L (°C)
HARVFRAC	Two-element array containing fractions of (1) yield harvested and (2) by-product harvested (fraction)	SW(L)	Volumetric soil water content in layer L (cm3 [water] / cm3 [soil])
ISWITCH	Composite variable containing switches which control flow of execution for model. (See **Error! Reference source not found.** for list of composite variables)	TRWUP	Potential daily root water uptake over soil profile (cm/d)
NH4(L)	Ammonium N in soil layer L (µg[N] / g[soil])	WEATHER	Constructed variable which contains daily weather data. (See **Error! Reference source not found.** for list of composite variables)
NO3(L)	Nitrate in soil layer L (µg[N] / g[soil])	YREND	Date for end of season (usually harvest date) (YYYYDDD)
SNOW	Snow accumulation (mm)	YRPLT	Planting date (YYYYDDD)
Output Variable	**Definition**	**Output Variable**	**Definition**
CANHT	Canopy height (m)	RLV(L)	Root length density for soil layer L (cm[root] / cm3[soil])
EORATIO	Ratio of increase in EO with increase in LAI (up to LAI=6.0) for use with FAO-56 Penman reference EO.	RWUMX	Maximum water uptake per unit root length, constrained by soil water (cm3[water] / cm [root])
FLOODN	Composite variable which contains flood nitrogen mass and concentrations. (See **Error! Reference source not found.** for list of composite variables) SENESCE	SENESCE	Composite variable containing data about daily senesced plant matter. (See **Error! Reference source not found.** for list of composite variables)
HARVRES	Composite variable containing harvest residue amounts for total dry matter, lignin, and N amounts. (See **Error! Reference source not found.** for list of composite variables)	STGDOY(I)	Day when plant stage I occurred (YYYYDDD)
KSEVAP	Light extinction coefficient used for computation of soil evaporation	UNH4(L)	Rate of root uptake of NH4, computed in NUPTAK (kg [N] / ha - d)
KTRANS	Light extinction coefficient used for computation of plant transpiration	UNO3(L)	Rate of root uptake of NO3, computed in NUPTAK (kg [N] / ha -d)
MDATE	Harvest maturity date (YYYYDDD)	XHLAI	Healthy leaf area index (m2[leaf] / m2[ground])
NSTRES	Nitrogen stress factor (1=no stress, 0=max stress)	XLAI	Leaf area (one side) per unit of ground area (m2[leaf] / m2[ground])
PORMIN	Minimum pore space required for supplying oxygen to roots for optimal growth and function (cm3/cm3)		

Table 7. Growth stages simulated by the DSSAT CERES-maize, wheat and barley models

Maize	Wheat	Barley
Germination	Germination	Germination
Emergence	Emergence	Emergence
End of Juvenile		
Floral Induction	Terminal Spikelet	Maximum Primordia
	End ear growth	End ear growth
75% Silking		
Beginning grain fill	Beginning grain fill	Beginning grain fill
Maturity	Maturity	Maturity
Harvest	Harvest	Harvest

Table 8. Genetic Coefficients for the DSSAT CERES-Maize, Wheat and Barley Models

A. Maize	
P1	Degree days (base 8^{o}C) from emergence to end of juvenile phase
P2	Photoperiod sensitivity coefficient (0-1.0)
P5	Degree days (base 8^{o}C) from silking to physiological maturity
G2	Potential kernel number.
G3	Potential kernel growth rate mg/(kernel d)
PHINT	Degree days required for a leaf tip to emerge (phyllochron interval) (°C d)
B. Wheat and Barley	
P1D	Photoperiod sensitivity coefficient (% reduction/h near threshold)
P1V	Vernalization sensitivity coefficient (%/d of unfulfilled vernalization)
P5	Thermal time from the onset of linear fill to maturity (°C d)
G1	Kernel number per unit stem + spike weight at anthesis (#/g)
G2	Potential kernel growth rate (mg/(kernel.d))
G3	Tiller death coefficient. Standard stem + spike weight when elongation ceases (g)
PHINT	Thermal time between the appearance of leaf tips (°C d)

Daily plant growth is computed by converting daily intercepted photosynthetically active radiation (PAR) into plant dry matter using a crop-specific radiation use efficiency parameter. Light interception is computed as a function of leaf area index, plant population, and row spacing. The amount of new dry matter available for growth each day may also be modified by the most limiting of water or nitrogen stress, and temperature, and is sensitive to atmospheric CO_2 concentration. Above ground biomass has priority for carbohydrate, and at the end of each day, carbohydrate not used for above ground biomass is allocated to roots. Roots must receive, however, a specified stage-dependent minimum of the daily carbohydrate available for growth. Leaf area is converted into new leaf weight using empirical functions.

Kernel numbers per plant are computed during flowering based on the cultivar's genetic potential, canopy weight, average rate of carbohydrate accumulation during flowering, and temperature, water and nitrogen stresses. Potential kernel number is a user-defined input for specific cultivars. Once the beginning of grain fill is reached, the model computes daily grain growth rate based on a user-specified cultivar input (Table 8) defined as the potential kernel growth rate (mg / (kernel d)). Daily growth rate is modified by temperature and assimilate availability. If the daily pool of carbon is insufficient to allow growth at the potential rate, a fraction of carbon can be remobilized from the vegetative to reproductive sinks each day. Kernels are allowed to grow until physiological maturity is reached. If the plant runs out of resources, however, growth is terminated prior to physiological maturity. Likewise, if the grain growth rate is reduced below a threshold value for several days, growth is also terminated. Readers are referred to other papers for additional details on these CERES models (Jones and Kiniry, 1986; Ritchie and Otter, 1985; Ritchie et al., 1998).

4.4.2. Changes to maize, millet and sorghum sub modules

There have been several new features added to the CERES maize, millet and sorghum models in the DSSAT 4.0 release. Some of the major additions are listed below:

1. Species and ecotype files have been created for these CERES maize, millet and sorghum models. Many coefficients that were formerly hard-coded have been moved into external species and ecotype files. This allows the user to have more control over many growth and development processes including temperature and CO_2 response, radiation use efficiency, emergence rate and early maturity due to slow grain filling.
2. Several major pest damage types have been incorporated into these CERES models. The damage types include leaf, stem, root and seed weight, leaf area index, seed numbers, and daily carbon assimilation rate and plant population. The pest damage is entered in file T in the same manner as in the CROPGRO model (see DSSAT 3.5 documentation, Hoogenboom, 1994a).
3. Soil fertility (other than nitrogen) can now be incorporated into a simulation as an empirical reduction in daily crop growth rate. The soil file, normally called soil.sol, contains a data entry, SLPF, which is a generic fertility factor. This factor has been incorporated into these CERES models to directly reduce daily crop growth rate (CARBO). Thus, users can now reduce plant growth based on poor fertility using this new input.
4. When the soil is saturated with water, plant growth and cell expansion are reduced. A water-logging factor has been incorporated to reduce photosynthesis and leaf expansion when the soil is within 2% of saturation for more than 2 days.

<u>Warning</u>: The user should be aware that for some data sets, the maize, millet and sorghum results could vary substantially from those of previous versions of the CERES models if the soil characteristics include soil fertility factors of less than 1.0. This value was ignored in DSSAT v3.5.

4.4.2.1.New Input Files

Species files have been developed for maize, sorghum and millet crops. These files contain parameters that are typically viewed as constant across all cultivars of a given species. Ecotype files have also been created for each crop. These files contain parameters that are constant across groups of cultivars within a species. The Cultivar files remain unchanged from the DSSAT 3.5 release format.

Species file

The Species file for Maize is listed in Figure 2. Generally, these parameters should not be changed without consultation with a model developer.

```
*MAIZE SPECIES COEFFICIENTS - MZCER990 MODEL

*TEMPERATURE EFFECTS
!       TBASE TOP1  TOP2  TMAX
  PRFTC  6.2  16.5  33.0  44.0
  RGFIL  5.5  16.0  39.0  48.5
*PHOTOSYNTHESIS PARAMETERS
  PARSR   0.50
  CO2X      0   220   330   440   550   660   770   880   990  9999
  CO2Y  0.00  0.81  1.00  1.03  1.06  1.10  1.13  1.16  1.18  1.25
*STRESS RESPONSE
  FSLFW   0.050
  FSLFN   0.050
*SEED GROWTH PARAMETERS
  SDSZ   .2750
  RSGR     0.1
  RSGRT    5.0
  CARBOT   7.0
  DSGT    21.0
  DGET   150.0
  SWCG    0.02
*EMERGENCE INITIAL CONDITIONS
  STMWTE  0.20
  RTWTE   0.20
  LFWTE   0.20
  SEEDRVE 0.20
  LEAFNOE 1.0
  PLAE    1.0
*NITROGEN PARAMETERS
  TMNC    0.00450
  TANCE   0.0440
  RCNP    0.01060
  RANCE   0.0220
*ROOT PARAMETERS
  PORM    0.05
  RWMX    0.03
  RLWR    0.98
  RWUEP1  1.50
```

Figure 2. Species file for maize

The first group of parameters in the species file describes the effect of temperature on crop growth rate (PRFTC) and grain filling rate (RGFIL). The variables TBASE, TOP1, TOP2 and TMAX define the minimum base temperature, first and second optimum temperatures, and the maximum temperature above which the rate is reduced to zero. Figure 3 and Figure 4 illustrate the effects of temperature on daily crop growth rate and relative grain filling rate, respectively.

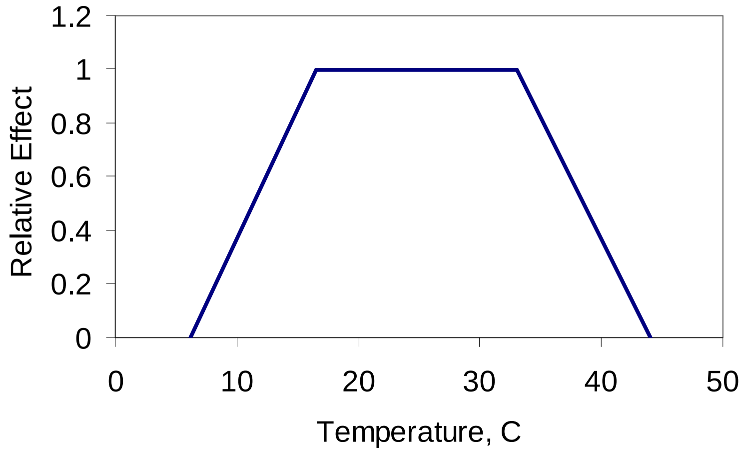

Figure 3. Temperature effect on daily crop growth rate

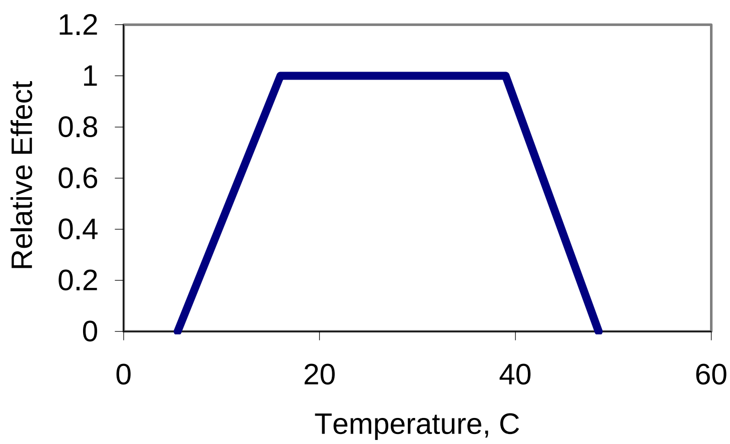

Figure 4. Temperature effect on relative grain filling rate.

The next group of parameters in the species file is related to daily photosynthesis. The parameter PARSR is the conversion of solar radiation to photosynthetically active solar radiation. The CO2X and CO2Y parameters are the x and y coordinates of the CO2 effect on daily crop growth rate.

The remaining parameters in the species file are defined in Table 9.

Table 9. Maize species coefficients

Name	Default Value	Definition	Units
FSLFW	0.05	Daily fraction of leaf area senesced under 100% water stress	1/day
FSLFN	0.05	Daily fraction of leaf area senesced under 100% nitrogen stress	1/day
SDSZ	0.275	Maximum potential seed size	Mg/seed
RSGR	0.1	Relative seed growth rate below which plants may mature early due to water or nitrogen stress or cool temperatures	--
RSGRT	5	Number of consecutive days relative seed growth rate is below RSGR before early maturity occurs	Days
CARBOT	7	Number of consecutive days that daily plant growth rate is below 0.001 g/plant before plant growth is terminated due to stress.	Days
DSGT	21	Maximum days from sowing to germination before seed dies	Days
DGET	150	Growing degree days between germination and emergence after which the seed dies due to drought	GDD
SWCG	0.02	Minimum available soil water required for seed germination	cm3/cm3
STMWTE	0.2	Stem weight at emergence	G/plant
RTWTE	0.2	Root weight at emergence	G/plant
LFWTE	0.2	Leaf weight at emergence	G/plant
SEEDRVE	0.2	Carbohydrate reserve in seed at emergence	G/plant
LEAFNOE	1	Leaf number at emergence	#/plant
PLAE	1	Leaf area at emergence	cm^2/plant
TMNC	0.0045	Plant top minimum N concentration	g N/g dry matter
TANCE	0.044	Nitrogen content in above ground biomass at emergence	g N/g dry matter
RCNP	0.0106	Root critical nitrogen concentration	g N/g dry matter
RANCE	0.022	Root N content at emergence	g N/g root
PORM	0.05	Minimum volume required for supplying oxygen to roots for optimum growth	--
RWMX	0.03	Maximum root water uptake per unit length of root	cm^3 water/cm root
RLWR	0.98	Root length to weight ratio	cm/g
RWUEP1	1.5	Threshold soil water content for reducing leaf expansion	--

Ecotype file

The Ecotype file contains parameters that are assumed to be constant over groups of cultivars. An example for maize is shown below.

```
*MAIZE ECOTYPE COEFFICIENTS CSM19990.EXE MODEL

@ECO#  ECONAME.........  TBASE TOPT  ROPT  P20   DJTI  GDDE  DSGFT  RUE   KCAN
IB0001 GENERIC MIDWEST1    8.0 34.0  34.0  12.5   4.0   6.0   170.  4.2   0.85
```

The ECO# is the code that matches ecotype parameters with cultivar parameters from the cultivar file. The following additional parameters are defined in this file:

- TBASE - base temperature below which no development occurs, C
- TOPT - temperature at which maximum development rate occurs during vegetative stages, C
- ROPT - temperature at which maximum development rate occurs for reproductive stages, C
- P2O - Daylength below which daylength does not affect development rate, hours
- DJTI - Minimum days from end of juvenile stage to tassel initiation if the cultivar is not photoperiod sensitive, days
- GDDE - Growing degree days per cm seed depth required for emergence, GDD/cm
- DSGFT - GDD from silking to effective grain filling period, C
- RUE - Radiation use efficiency, g plant dry matter/MJ PAR
- KCAN - Canopy light extinction coefficient for daily PAR.

4.4.2.2.Pest damage

In the DSSAT 4.0 release, a limited number of pest damage types have been incorporated into the Maize, Sorghum and Millet models. The method for entering pest damage into file T and simulating damage follows the procedures outlined in the DSSAT 3.5 documentation. The pest damage variables that are available for these CERES models are defined in the *.PST file as shown below:

```
*CORN PEST COEFFICIENTS
01 ALMD  Act. leaf mass dest. 1 LMD   1.00000000     0.0000    g/m2/day
02 ALAD  Act. leaf area dest. 1 LAD   1.00000000     0.0000    g/m2/day
03 PLMD  % leaf mass dest.    3 LMD   1.00000000     0.0000    %/day
04 PLAD  % leaf area dest.    3 LAD   1.00000000     0.0000    %/day
05 ASMD  Act. stem mass dest. 1 SMD   1.00000000     0.0000    g/m2/day
06 PSMD  % Stem mass dest.    3 SMD   1.00000000     0.0000    %/day

07 ARTD  Act. root mass dest. 1 RMD   1.00000000     0.0000    g/m2/day
08 PRTD  % root mass dest.    3 RMD   1.00000000     0.0000    %/day
09 ASDD  Act. seed mass dest. 1 SDM   1.00000000     0.0000    g/m2/day
10 PSDD  % seed mass dest.    3 SDM   1.00000000     0.0000    %/day
11 NWPD  #. plants dest.      1 WPDM  1.00000000     0.0000    #/m2/day
12 PWPD  % plants dest.       3 PPLD  1.00000000     0.0000    %/day
13 PASM  Assim. reduct.       3 ASM   1.00000000     0.0000    %/day
```

Further information about which state variables are being reduced in CERES Maize is shown in Table 10. Damage is applied to analogous variables in the Sorghum and Millet models.

Table 10. Maize pest damage coupling points

Pest ID	PNAME	PCTID	PCPID	Internal coupling point	Model damage variable	Model state variable damage is applied to
ALMD	Leaf weight, g/m2/day	1	LMD	TLFMD	WLIDOT, g/m2/d	LFWT, g/plant
ALAD	Leaf area, m2/m2/day	1	LAD	TLFAD	LAIDOT, m2/m2/d	PLA, cm2/plant
PLMD	Leaf weight, %/day	3	LMD	PLFMD	WLIDOT, g/m2/d	LFWT, g/plant
PLAD	Leaf area, %/day	3	LAD	PLFAD	LAIDOT, m2/m2/d	PLA, cm2/plant
ASMD	Stem weight, g/m2/d	1	SMD	WSTMD	WSIDOT, g/m2/d	STMWT, g/plant
PSMD	Stem weight, %/day	3	SMD	PSTMD	WSIDOT, g/m2/d	STMWT, g/plant
ARTD	Root weight, g/m2/d	1	RMD	WRTMD	WRIDOT, g/m2/d	RTWT, g/plant
PRTD	Root weight, %/day	3	RMD	PRTMD	WRIDOT, g/m2/d	RTWT, g/plant
ASDD	Seed weight, g/m2/d	1	SDM	WSDD	SWIDOT, g/m2/d	GRNWT, g/plant EARWT, g/plant GPP, #/plant
PSDD	Seed weight, %/d	3	SDM	PSDD	SWIDOT, g/m2/d	GRNWT, g/plant EARWT, g/plant GPP, #/plant
PWPD	Whole plants, %/d	3	PPLD	Mult.	Mult.	Mult.
PASM	Assimilate reduc. %/day	3	ASM	PPSR	ASMDOT, g/plant	CARBO, g/plant

4.4.2.3. Soil Fertility Factor

A soil fertility factor (SLPF) has been incorporated into the CERES maize, millet and sorghum models to account for the effect of soil nutrients (other than nitrogen) on daily plant growth rate. The SLPF factor is a surface input in the soil file, and is thus, a soil property. This factor reduces daily crop growth rate by multiplying the crop growth rate variable, CARBO by the soil fertility factor, SLPF as shown below:

```
CARBO = PCARB*AMIN1(PRFT,SWFAC,NSTRES,(1.0-SATFAC))*SLPF
```

This factor works the same way for maize, sorghum and millet. Most of the soils in the DSSAT database or in user soil databases have SLPF values set to 0.0 because this was not previously used in the CERES models. If the model reads a SLPF value of 0.0, it automatically sets it to 1.0, which has no effect on daily crop growth. However, if the user wants to simulate reduced growth due to fertility, they need to determine appropriate SLPF values for specific fields and enter them in the soil database.

Warning: The user should be aware that for some data sets, the maize, millet and sorghum results could vary substantially from those of previous versions of the CERES models if the soil characteristics include soil fertility factors of less than 1.0.

4.4.3. Changes to wheat / barley sub module

The CSM wheat and barley model is restructured from Generic Ceres 3.5. It has been cast into a modular structure, which in itself has resulted in some changes in output, and re-organized so that the calculation of rates precedes all updating of state variables. Previously, some variables were updated before the calculation of all rates was complete, such that a change in the sequencing of calculations resulted in some change in outputs, particularly when the supplies of water or nitrogen were short. This was of most significance relative to root growth, calculations for which were previously done between the soil water and soil nitrogen routines, and not along with the other plant growth aspects.

In addition to the structural changes described above, most parameters have been taken out of the code of the model and placed in files (called Ecotype or Species files) as used in the Cropsim and Cropgro models. These files are read using Generic routines that make use of the abbreviations associated with each parameter, which are presented either in a header line, or on the same line as the parameter itself. The tracking of these input parameters has been made easier than in the past by the introduction of an output file (Work.out) in which inputs are mirrored as they are read. This file is also used for messages as the simulation proceeds so that problems that may arise can be identified in an easier manner. A number of additional output files are also produced using the Output routines from the Cropsim model.

For DSSAT-CSM, the science of the DSSAT3.5 wheat/barley models has been changed as little as possible. However, carbon and nitrogen lost from the plant through senescence is now 'exported' from the plant routine for adding to soil organic matter pools in the associated soil routines, and this aspect may result in changes in nitrogen release from the soil and hence in plant growth in some situations. Further, a number of aspects that appeared unjustified or to be in error have been changed. These are listed below.

Roots. The restriction of root length volume to a maximum of 4.0 has been removed.

Introduced variables for root dry weight growth (RTWTG) and respiration (RTRESP) to avoid problem of multiplying by 0.6 in various places. Did not change RLWR so had to divide later by 0.6 to maintain equivalence.

Leaves. Leaf number was originally set to two at emergence. This has been eliminated so that leaf number increments from zero at emergence.

Specific area of new leaves in phase one, which changes as a function of accumulated developmental units, can now only decrease to the value set for phase two. In the earlier version the value could fall below that set for phase two.

Specific leaf area changed so that it relates to lamina instead of lamina plus sheath.

Changes in specific leaf area that used to be seen when leaves were killed by cold, and which resulted because leaf area was reduced but leaf weight not, have been eliminated. When leaves are killed by cold, leaf weight is now reduced in proportion to the reduction in leaf area.

Leaf weight loss through general senescence also used to be calculated in a manner not related to leaf area loss. This has been corrected. However, only a specified fraction of the leaf weight (see species file) is lost from the plant. Also, the algorithms dealing with leaf senescence have been simplified and adjusted such that there is no longer a possibility of the addition of leaf area through senescence, something that could happen in V3.5.

Leaf area growth used to change markedly when tiller number reached 900/m2. This discontinuity has been eliminated.

Potential leaf size changed to increase linearly with leaf number.

Tillers. Removed statement restricting tiller number to maximum of 1000/m2 once beyond phase 1. Caused a crash in tiller number for winter types. Changed method of calculating standard tiller weight. Used total canopy weight and increased standard weight linearly from emergence to maturity, at which stage standard = G3 coefficient. Changed tillering algorithm to use Fibonacci series.

Grains. Keeping kernel wt at a minimum of 20 mg taken out. Number set at anthesis rather than start of fill. Grains grow at half maximum rate until linear.

Reserves. Introduced chaff and reserves weight as subsets of stem weight. Main calculations still based on STWT.

Dead matter. Dead material now retained on plant after specified stage.

Seed. The expressions dealing with the use of seed reserves have been re-framed so that there is no possibility of seed reserves falling below zero, and for the movement of dry matter from the rest of the plant to the seed.

Stress. The various stress factor expressions have been re-cast so that they can be calculated from upper and lower limit parameters. A 'reserves' factor has been introduced to summarize calculations dealing with the impact of changes in minimum stem weight on photosynthesis.

Nitrogen. The nitrogen uptake from any layer of the soil is now restricted to zero, so that the possibility of an (apparent) release of nitrogen to the soil during nitrogen uptake calculations has been eliminated. This could happen in V3.5.

The nitrogen 'exudation' routines that were used to eliminate plant nitrogen when N concentration increased above the upper critical value have been changed. These algorithms used to result in sudden changes in nitrogen concentration late in the life cycle, when senescence was occurring rapidly.

Potential tops and root growth, which were used to calculate N demand, has been replaced by actual tops and root growth. Critical and minimum N concentrations are now calculated from the Xstage rather than the Zadoks stage, which was previously calculated incorrectly.

Nitrogen loss through senescence now subtracted. Not done previously, which resulted in high N concentrations in litter early in season. Growth is reduced under low N conditions with this change.

Vegetative N content split into leaf and stem components. Critical and minima read from species file.

Germination and emergence. Changed algorithms so that gradual moisture effect rather than threshold, and made extension growth after germination sensitive to moisture as well as germination.

Senescence. Senescence functions for phase six (post physiological maturity) have been introduce to ensure that leaf area and photosynthesis are reduced to zero. This aspect is important when a specified harvest date that is several weeks later than physiological maturity is used.

Changed algorithms in phase 2. Old had specific limits and was causing 'see-sawing'. Changed old algorithm which was starting senescence from leaf 2, not leaf 1. Related senescence to coefficients from species file, not embedded algorithm which used sum of thermal time in phase.

Failure. Crop failure is now set with a control flag (CFLFAIL) that triggers termination, rather than by re-setting the growth stage. The number of days with no carbohydrate assimilation required to trigger failure during grain fill has been increase from one to five.

Photosynthesis Reserves effect removed (was during filling only).

Partitioning Changed to give a gradual change in PTF rather than an abrupt change at phase change.

Vernalization Now accumulates from germination, not emergence.

Hardening. The cold hardening algorithms have been simplified, and cold hardening is now permitted from germination, not from emergence as previously.

Temperature Responses. All response functions now read from input data. The grain nitrogen accumulation response set to the same as for dry matter. BUT, root depth growth left a linear function of thermal time =TT*RDGS1/STDDAY.

Developmental units No longer adjusted in phase 1 by ratio of PHINT to standard phint (95 for wheat,75 for barley). NB. THE FOLLOWING IS A SIGNIFICANT CHANGE!!

Vernalization and daylength effects multiplied instead of previous minimum approach. This necessary to handle datasets from the Punjab. Temperature limits on daily thermal time raised to 26 for both vegetative and reproductive.

Growth stages Zadoks stages calculated from different aspects as required according to the Zadoks definition. (ie.Germination and emergence stages, leaf numbers, tiller numbers, and then reprod stages). The way in which internal Xstages are equated with Zadoks stages is still questionable, and this aspect will need examination using good phenology datasets. Zadoks is the growth scale used for writing to Plantgro.out.

Coefficients Cultivar coefficients changed scalars to absolutes. Grain growth rate (G2) replaced by standard grain weight. Grain number coeff (G1) changed to whole canopy basis,not stem wt.. Phase 1 duration (ECO file) changed so that no longer have to adjust developmental units in relation to phyllochron interval. Vernalization coefficient changed to a duration value rather than a sensitivity slope, which now calculated internally.

4.5. Soil module

The soil in the land unit is represented as a one-dimensional profile; it is homogenous horizontally and consists of a number of vertical soil layers. The Soil module integrates information from three sub modules: soil water, soil carbon and nitrogen, and soil dynamics. Table 11 defines the interface variables for this module.

The soil dynamics module is designed to read in soil parameters for the land unit and to modify them based on tillage, long-term changes in soil carbon, or other field operations. Currently, the module reads in soil properties from a file, checks them for validity and makes these soil properties available to other modules.

Descriptions of the other two sub modules called by the Soil module are given below.

4.5.1. Soil carbon and nitrogen balance sub module

The DSSAT cropping system model has two options to simulate the soil organic matter (SOM) and nitrogen balance. The original SOM model in DSSAT v3.5 (Godwin and Jones, 1991; Godwin and Singh, 1998), based on the PAPRAN model of Seligman and van Keulen (1981), was converted into a modular structure and retained in the new DSSAT-CSM. This is the default method for use by DSSAT-CSM.

Additionally, a SOM module developed by Gijsman et al. (2002), based on the CENTURY model (Parton *et al.*, 1988, 1994), is included in DSSAT-CSM. This CENTURY-based module was added to facilitate simulation of soil organic sequestration potential for different crop rotations over long time periods after initializing soil C and other variables only once at the start of the simulation.

Most of the interface input variables to the soil carbon and nitrogen balance modules are soil properties and variables computed in the soil water and soil temperature sub modules. Transport of N through the soil to deeper layers is based on water flux values obtained from the soil water module. The only interface variable from the Plant module is the array of plant mass being senesced and abscised onto the soil surface daily. The output variables sent to other modules are ammonium and nitrate nitrogen in each soil layer (Table 11).

Currently, only the CERES-based module has been linked to simulation of flooded nitrogen processes, and therefore is the only option allowable for lowland rice simulations.

Table 11. Soil module interface

Input Variable	Definition	Input Variable	Definition
CONTROL	Composite variable containing information related to the simulation control. (See **Error! Reference source not found.** for list of composite variables)	SRFTEMP	Temperature of soil surface litter (°C)
EO	Potential evapotranspiration rate (mm/d)	ST(L)	Soil temperature in soil layer L (°C)
ES	Actual soil evaporation rate (mm/d)	SWDELTX(L)	Change in soil water content due to root water uptake in layer L (cm3 [water] / cm3 [soil])
FLOODWAT	Composite variable containing information related to bund management. (See **Error! Reference source not found.** for list of composite variables)	UNH4(L)	Rate of root uptake of NH4, computed in NUPTAK (kg [N] / ha - d)
HARVRES	Composite variable containing harvest residue amounts for total dry matter, lignin, and N amounts. (See **Error! Reference source not found.** for list of composite variables)	UNO3(L)	Rate of root uptake of NO3, computed in NUPTAK (kg [N] / ha -d)
IRRAMT	Irrigation amount for today (mm / d)	WEATHER	Constructed variable which contains daily weather data. (See **Error! Reference source not found.** for list of composite variables)
ISWITCH	Composite variable containing information related to simulation switches and methods. (See **Error! Reference source not found.** for list of composite variables)	XHLAI	Healthy leaf area index (m2[leaf] / m2[ground])
NSTRES	Nitrogen stress factor (1=no stress, 0=max stress)	YREND	Date for end of season (usually harvest date) (YYYYDDD)
SENESCE	Composite variable containing data about daily senesced plant matter. (See **Error! Reference source not found.** for list of composite variables)	YRPLT	Planting date (YYYYDDD)
Output Variable	**Definition**	**Output Variable**	**Definition**
FLOODN	Composite variable which contains flood nitrogen mass and concentrations. (See **Error! Reference source not found.** for list of composite variables)	SW(L)	Soil water content in layer L (cm3 [water] / cm3 [soil])
NH4(L)	Ammonium N in soil layer L (µg[N] / g[soil])	SWDELTS (L)	Change in soil water content due to drainage in layer L (cm3 [water] / cm3 [soil])
NO3(L)	Nitrate in soil layer L (µg[N] / g[soil])	SWDELTU(L)	Change in soil water content due to evaporation and/or upward flow in layer L
SNOW	Snow accumulation (mm)	WINF	Water available for infiltration - rainfall plus net irrigation minus runoff (mm / d)
SOILPROP	Composite variable containing soil properties including bulk density, drained upper limit, lower limit, pH, saturation water content. (See **Error! Reference source not found.** for list of composite variables)		

4.5.1.1. CENTURY-based soil carbon and nitrogen balance sub module

The CENTURY model is more appropriate for use in low input agricultural systems, for example those that use green manure where the surface layer is crucial. Gijsman et al. (2002) showed that this new component greatly improved the accuracy of simulating the long-term changes in soil carbon in the Rothamsted bare fallow experiment. The main differences between the CENTURY-based module and the CERES-based soil N module are:

(i) The CENTURY-based module divides the SOM in more fractions, each of which has a variable C:N ratio and can mineralize or immobilize nutrients,
(ii) it has a residue layer on top of the soil, and
(iii) the decomposition rate is texture dependent.

The CENTURY-based module distinguishes three types of SOM: [1] easily decomposable (microbial) SOM1, [2] recalcitrant SOM2, which contains lignin and cell walls, and [3] an almost inert SOM3. At initialization of the simulation, the fractional ratio of these three pools is set, with SOM1 of only about 2% of total SOM, while SOM2 and SOM3 vary with the management history of the soil (grassland or cultivated) and the degree of depletion. The improved SOM module also allows one to perform more realistic simulations on carbon sequestration, *i.e.* the build up of soil organic C under different management systems.

4.5.1.2. Revisions to the CERES-based soil carbon and nitrogen balance sub module

Because the CERES-based soil carbon and nitrogen balance routines (NTRANS) are well-documented (Godwin, 1991, 1998), only the major changes to the module are described herein. As with the other modules in DSSAT-CSM, NTRANS was reorganized into a modular format. This resulted in a change in the order of calculations, which in some cases can alter computed results.

Flooded N routines. Flooded N processes have been added to the NTRANS routine. Other than reorganization into the CSM modular format, these routines are identical to those in the CERES-Rice model.

Ammonia volatilization. An ammonia volatilization routine was added to NTRANS. This routine was previously used in the DSSAT v3.5 CERES-Rice model.

Nitrification. The previous nitrification routine was replaced with that from the CERES-Rice model based on the work of Gilmour (1984).

Senescence. Senesced plant matter is now added to the soil surface (for leaf, stem and shell) or to the soil layers (root, nodule) on a daily basis.

Error checking. Numerous checks have been added to the code to ensure that both input and computed data are within valid ranges.

4.5.2. Soil water sub-module

The soil water balance model developed for CERES-Wheat by Ritchie and Otter (1985) was adapted for use by all of the DSSAT v3.5 crop models (Jones and Ritchie, 1991; Jones, 1993; Ritchie, 1998). This one-dimensional model computes the daily changes in soil water content by soil layer due to infiltration of rainfall and irrigation, vertical drainage, unsaturated flow, soil evaporation, and root water uptake processes. In the new DSSAT-CSM, soil evaporation, plant transpiration, and root water uptake processes were separated out into a soil-plant-atmosphere module (SPAM) to create more flexibility for expanding and maintaining the model. In addition, paddy management components were added so that lowland flooded fields could be simulated.

Otherwise, the upland water balance model in DSSAT-CSM is the same as in DSSAT v3.5 CROPGRO model. Individual processes are modeled using the same logic and equations. The soil has parameters that describe its surface conditions and layer-by-layer soil water holding and conductivity characteristics. The model uses a "tipping bucket" approach for computing soil water drainage when a layer's water content is above a drained upper limit parameter. Upward unsaturated flow is also computed using a conservative estimate of the soil water diffusivity and differences in volumetric soil water content of adjacent layers (Ritchie, 1998).

Soil water infiltration during a day is computed by subtracting surface runoff from rainfall that occurs on that day. The SCS method (Soil Conservation Service, 1972) is used to partition rainfall into runoff and infiltration, based on a "curve number" that attempts to account for texture, slope, and tillage. The modification to this method that was developed by Williams et al. (1984) is used in the model; it accounts for layered soils and soil water content at the time when rainfall occurs. When irrigation is applied, the amount applied is added to the amount of rainfall for the day to compute infiltration and runoff. Drainage of liquid water through the profile is first calculated based on an overall soil drainage parameter assumed to be constant with depth. The amount of water passing through any layer is then compared with the saturated hydraulic conductivity of that layer, if this parameter is provided. If the saturated hydraulic conductivity of any layer is less than computed vertical drainage through that layer, actual drainage is limited to the conductivity value, and water accumulates above that layer. This feature allows the model to simulate poorly drained soils and perched water tables. For example, a soil may have a layer with very low or no drainage at the bottom of the profile. Vertical drainage from the profile would not occur or it would be very low, limited by the saturated hydraulic conductivity value of the bottom layer.

Evaporation of water from the soil surface and root water uptake (transpiration) from each layer are computed in the Soil-plant-atmosphere interface module and communicated to this soil water balance module. Each day, the soil water content of each layer is updated by adding or subtracting daily flows of water to or from the layer due to each process.

4.6. Soil plant atmosphere interface module

This module computes daily soil evaporation and plant transpiration. The current version was originally developed by Ritchie (1972) and was used in all of the DSSAT v3.5 crop models as part of the soil water balance. This module brings together soil, plant and atmosphere inputs and computes light interception by the canopy, potential evapotranspiration, as well as actual soil evaporation and plant transpiration (Table 12). It also computes the root water uptake of each soil layer. The daily weather values as well as all soil properties and current soil water content, by layer, are required as input. In addition, leaf area index (LAI) and root length density for each layer are needed.

Potential evapotranspiration. The module first computes daily net solar radiation, taking into account the combined soil and plant canopy albedo. It calculates potential evapotranspiration (ET) using one of four current options. The default Priestley-Taylor (1972) method requires only daily solar radiation and temperature, and was described in detail by Ritchie (1972; 1985) and Jones and Ritchie (1991). The Penman-FAO (Doorenbos and Pruit, 1977) method for computing potential evapotranspiration can optionally be used to better account for arid or windy conditions, but weather data files must include wind and humidity data. We have also created options for using the Penman-Monteith (Monteith, 1986) method for daily potential ET calculations and for using hourly energy balance (unpublished).

The potential ET is partitioned into potential soil evaporation and potential plant transpiration.

Soil evaporation. Actual soil evaporation is based on a two-stage process (Ritchie, 1972). After the soil surface is first wetted due to either rainfall or irrigation, evaporation occurs at the potential rate until a cumulative soil evaporation amount since wetting is reached. Then, a soil-limiting daily soil evaporation amount is computed as a square root function of time since stage one ended. Actual soil evaporation is the minimum of the potential and soil-limiting calculations on a daily basis. If evaporation is less than potential soil evaporation, this difference is added back to potential plant transpiration to account for the increased heat load on the canopy when the soil surface is dry (Ritchie, 1972).

Plant transpiration. To determine whether the soil or atmosphere limits plant transpiration, potential root water uptake is computed by calculating a maximum water flow to roots in each layer and summing these values (Ritchie, 1985, 1998; Jones and Ritchie, 1991). These calculations account for root length density in each layer and the soil water content in the layer. The equation that computes potential root water uptake in each layer is an approximation to the radial flow equation, where assumptions are made about soil texture effect on hydraulic conductivity, root diameter, and a maximum water potential difference between roots and the soil. The actual plant transpiration is then computed as the minimum of potential plant transpiration and the potential root water uptake. Thus, the atmosphere can limit transpiration by low solar radiation and cool temperatures, the canopy can limit it by low LAI, and the soil can limit it by low soil water content, low root length density, and their distributions relative to each other.

Table 12. Soil-plant-atmosphere module interface

Input Variable	Definition	Input Variable	Definition
CANHT	Canopy height (m)	RWUMX	Maximum water uptake per unit root length, constrained by soil water (cm3[water] / cm [root])
CONTROL	Composite variable containing variables related to control and/or timing of simulation. (See **Error! Reference source not found.** for list of composite variables) SOILPROP	SOILPROP	Composite variable containing soil properties including bulk density, drained upper limit, lower limit, pH, saturation water content. (See **Error! Reference source not found.** for list of composite variables)
EORATIO	Ratio of increase in EO with increase in LAI (up to LAI=6.0) for use with FAO-56 Penman reference EO.	SW(L)	Volumetric soil water content in layer L (cm3 [water] / cm3 [soil])
FLOODWAT	Composite variable containing information related to bund management. (See **Error! Reference source not found.** for list of composite variables)	SWDELTS(L)	Change in soil water content due to drainage in layer L (cm3 [water] / cm3 [soil])
ISWITCH	Composite variable containing switches which control flow of execution for model. (See **Error! Reference source not found.** for list of composite variables)	SWDELTU(L)	Change in soil water content due to evaporation and/or upward flow in layer L (cm3 [water] / cm3 [soil])
KSEVAP	Light extinction coefficient used for computation of soil evaporation	WEATHER	Constructed variable which contains daily weather data. (See **Error! Reference source not found.** for list of composite variables)
KTRANS	Light extinction coefficient used for computation of plant transpiration	WINF	Water available for infiltration - rainfall minus runoff plus net irrigation (mm / d)
PORMIN	Minimum pore space required for supplying oxygen to roots for optimal growth and function (cm3/cm3)	XHLAI	Healthy leaf area index (m2[leaf] / m2[ground])
RLV(L)	Root length density for soil layer L (cm[root] / cm3[soil])		
Output Variable	**Definition**	**Output Variable**	**Definition**
EO	Potential evapotranspiration rate (mm/d)	ST(L)	Soil temperature in soil layer L (°C)
EOP	Potential plant transpiration rate (mm/d)	SWDELTX(L)	Change in soil water content due to root water uptake in layer L (cm3 [water] / cm3 [soil])
ES	Actual soil evaporation rate (mm/d)	TRWUP	Potential daily root water uptake over soil profile (cm/d)
SRFTEMP	Temperature of soil surface litter (°C)		

This method for computing evapotranspiration has provided an excellent functional approach for determining water stress in the plant without explicitly modeling water status in the plant component. The ratio of actual ET to potential ET, if less than 1.0, indicates that stomatal conductance would have had to be decreased sometimes during the day to prevent plant desiccation. This ratio is typically used in the plant modules to reduce photosynthesis in proportion to relative decreases in transpiration. Similarly, a ratio of potential root water uptake and potential transpiration is used to reduce plant turgor and expansive growth of crops. The rationale for this is that as soil water becomes more limiting, turgor pressure in leaves would decrease and affect leaf expansion before photosynthesis is reduced. In the current plant modules this ratio is set to 1.5.

Hourly hedgerow photosynthesis sub module. An option exists for CROPGRO crops to have photosynthesis computed by the hourly hedgerow photosynthesis light interception approach as described by Boote and Pickering (1994). On an hourly time step during each day, interception and absorption of direct and diffuse light components are computed based upon canopy height and width, leaf area index (LAI), leaf angle, row direction, latitude, day of year, and time of day (Boote and Pickering, 1994). Photosynthesis of sunlit and shaded leaves is computed hourly using the asymptotic exponential response equation, where quantum efficiency and light-saturated photosynthesis rate variables are dependent on CO2 and temperature (Boote and Pickering, 1994). Hourly canopy photosynthesis on a land area basis is computed from the sum of sunlit and shaded leaf contributions by multiplying sunlit and shaded leaf photosynthetic rates by their respective LAIs. Gross photosynthesis is integrated hourly to provide a daily total value for use by other modules.

Currently the CROPGRO model is the only crop growth model of DSSAT-CSM that is linked to the hourly hedgerow photosynthesis model. This routine reads several crop-specific parameters from the species file, which are not currently available for other crops.

Soil Temperature sub module

The soil temperature model is a sub-module of the Soil-Plant-Atmosphere module. It was originally derived from the EPIC model (Williams et al., 1984; Jones et al., 1991) and is the same as the one in the CERES and CROPGRO models in DSSAT v3.5. Soil temperature is computed from air temperature and a deep soil temperature boundary condition that is calculated from the average annual air temperature and the amplitude of monthly mean temperatures. It also includes a simple approach to calculate the impact of solar radiation and albedo on the soil surface temperature. However, it does not consider differences in soil wetness or surface conditions. Soil temperature is used to modify plant processes (emergence) and soil organic matter decomposition. Additional details on this component are in Jones and Kiniry (1986) in the description of the CERES-Maize model.

4.7. Weather module

The main function of the weather module is to read or generate daily weather data. It reads in daily weather values (maximum and minimum air temperatures, solar radiation and precipitation, relative humidity and wind speed when available), from the daily weather file. Hourly weather values are computed for use by some modules that require them. This module generates daily weather data using the WGEN (Richardson, 1981, 1985) or SIMMETEO (Geng et al., 1986, 1988) weather generators. It also can modify daily weather variables for studying climate change or simulating experiments in which solar radiation, rainfall, maximum and minimum temperatures, day length, and/or atmospheric CO_2 concentrations were set at constant values or increased/decreased relative to their read-in values. Based on the inputs provided from the experiment file, the Weather module knows whether to just read in daily values or to generate or modify them (using the Environmental Modification sub module). The variables listed in Table 13 are passed through its interface.

Table 13. Weather module interface

Input Variable	Definition	Input Variable	Definition
CONTROL	Composite variable containing information related to the simulation control. (See **Error! Reference source not found.** for list of composite variables) ISWITCH	ISWITCH	Composite variable containing information related to simulation switches and methods. (See **Error! Reference source not found.** for list of composite variables)
Output Variable	**Definition**	**Output Variable**	**Definition**
WEATHER	Constructed variable which contains daily weather data. (See **Error! Reference source not found.** for list of composite variables)		

4.8. Operations management module

The management module determines when field operations are performed. Currently, these operations are planting, harvesting, applying inorganic fertilizer, irrigating and applying crop residue and organic material. These operations are specified by users in the standard "experiment" input file (Hunt et al., 2001). Users specify whether any or all of the operations are to be automatic or fixed based on input dates or days from planting. Table 14 lists the interface variables for this module. Table 15 summarized the options available for simulating the various management operations.

Automatic planting. Conditions that cause automatic planting within the interval of time are soil water content averaged over a specified depth (i.e., 30 cm) and soil temperature at a specified depth to be between specified limits.

Automatic harvesting. Harvesting can occur on given dates, when the crop is mature, or when soil water conditions in the field are favorable for machine operation.

Irrigation. Irrigation can be applied on specific dates with specified irrigation amount or can be controlled by the plant available water. If plant available water drops below a specified fraction of water holding capacity in an irrigation management depth, an irrigation event is triggered. The irrigation amount applied can be either a fixed amount or it can refill the profile to the management depth.

Fertilizer application. Similarly, fertilizer can be applied on fixed dates in specified amounts, or the applications can optionally be controlled by plant needs for nitrogen via the nitrogen stress variable from the Plant module.

Residue application. Crop residue and organic fertilizer, such as manure, is applied either at the start of simulation, after harvesting the crop or on fixed dates similar to inorganic fertilizer applications.

These management options allow users a great deal of flexibility for simulating experiments that were conducted in the past for model evaluation and improvement and for simulating optional management systems for different applications. The management file also provides scope to define multiple crops and management strategies for crop rotations and sequencing.

Table 14. Operations management module interface

Input Variable	Definition	Input Variable	Definition
CONTROL	Composite variable containing variables related to control and/or timing of simulation. (See **Error! Reference source not found.** for list of composite variables)	ST(L)	Soil temperature in soil layer L (°C)
FLOODWAT	Composite variable containing information related to bund management. (See **Error! Reference source not found.** for list of composite variables)	STGDOY(I)	Day when plant stage I occurred (YYYYDDD)
ISWITCH	Composite variable containing switches which control flow of execution for model. (See **Error! Reference source not found.** for list of composite variables)	SW(L)	Volumetric soil water content in layer L (cm3 [water] / cm3 [soil])
SOILPROP	Composite variable containing soil properties including bulk density, drained upper limit, lower limit, pH, saturation water content. (See **Error! Reference source not found.** for list of composite variables)	WEATHER	Constructed variable which contains daily weather data. (See **Error! Reference source not found.** for list of composite variables)
Output Variable	**Definition**	**Output Variable**	**Definition**
HARVFRAC	Two-element array containing fractions of (1) yield harvested and (2) by-product harvested (fraction)	YREND	Date for end of season (usually harvest date) (YYYYDDD)
IRRAMT	Irrigation amount for today (mm / d)	YRPLT	Planting date (YYYYDDD)
MDATE	Harvest maturity date (YYYYDDD)		

Table 15. Management Simulation Options

Management Options	Variable Name	FILEX Header	Values (default bold)	Description
Planting / Transplanting	IPLTI	PLANT	A	Automatic when conditions satisfactory
			R	On reported date
Irrigation and Water Management	IIRRI	IRRIG	A	Automatic when required
			N	Not irrigated
			F	Automatic with fixed amounts at each irrigation date
			R	On reported dates
			D	As reported, in days after planting
			P	As Reported through last reported day, then automatic C to re-fill profile (as in option A)
			W	As Reported through last reported day, then automatic adding AIRAMT each time
Fertilization	IFERI	FERTI	A	Automatic when required
			N	Not fertilized
			F	Automatic with fixed amounts at each fertilization date
			R	On reported dates
			D	As reported, in days after planting
Residue applications	IRESI	RESID	A	Automatic for multiple years/crop sequences
			N	No applications
			R	On reported dates
			D	As reported, in days after planting
Harvest	IHARI	HARVS	A	Automatic when conditions satisfactory
			G	At reported growth stage(s)
			M	At maturity
			R	On reported date(s)
			D	On reported days after planting

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Volume 1
Chapter 4

User's Guides for Initialization of Soil Properties

User’s Guide
DSSAT v4.5 Soil phosphorus model
Data requirements

C.H. Porter, J.W. Jones, U. Singh, K. Dzotsi

The DSSAT v4.5 soil phosphorus model maintains four inorganic P pools (solution, labile, active and stable) and several organic P pools (microbial and stable humic material and metabolic and structural fresh organic matter). Accurate estimations of the correct initial proportions of P in each pool are critical to modeling the P transformations and predicting the soluble P quantities that are available for uptake by plants. This document summarizes the variables needed to correctly initialize the organic and inorganic soil phosphorus parameters.

As a minimum, the soil phosphorus model requires that the user supply a value of measured extractable soil phosphorus for each soil layer and the method of extraction. The soil pH and total organic carbon (OC) are also very important for accurate initialization, although the model can be run if these data are missing. Missing OC data are estimated based on soil texture and missing pH data are assigned a value of 7.0. For adequate modeling of soil phosphorus processes, the user should supply measured values of both OC and pH, as the default values are likely to result in inaccurate predictions of soil P quantities. All soil P parameters can be estimated from extractable P, OC and pH, but the reliability of the estimates improves if additional measured soil data are available.

Computations of the relative amounts of the inorganic P components and of the transformation rates between components are based on general soil classification categories assigned to each soil layer, and on chemical composition of each layer. The criteria used for this classification are listed in Table 1 for the four general soil classes: andisols, calcareous, slightly weathered, and highly weathered soils. Extractable phosphorus can be measured directly by one of several methods. Equations are used to compute labile and other inorganic P components from the measured extractable phosphorus, and these equations vary with the extraction method and the soil class. The extraction methods used for each soil class are listed in Table 2.

Table 1. Criteria used for assigning soil classifications

Soil Class	**Criteria**
Andisol	Soil description or taxonomy includes the terms ‘ANDOSOL’ or ‘ANDISOL’ or ‘VOLCAN’ or ‘ANDEPT’.
Calcareous	High calcium carbonate content. CaCO3(L) > 0.15%
Slightly weathered	High ratio of cation exchange capacity to clay content. CEC(L)/(CLAY(L)/100.) > 16.
Highly weathered	Low ratio of cation exchange capacity to clay content. CEC(L)/(CLAY(L)/100.) <= 16.
Other or unspecified	Any other soils, or soils which cannot be classified based on available data.

Regression equations, determined from measurements of phosphorus in many different soils (Sharpley, et al., 1984, 1989, Singh, 1985), are used to estimate the labile P content from soil type and measured extractable P. In some cases, additional soil chemical parameters are used in the calculations, if provided. Table 3 lists the data that can be used to determine labile P content and other soil P components for each soil class. Note that some data can be entered in both the soil file and the soil analysis section of the experiment file. The soil profile contains data which are typical of a particular soil type, whereas, the soil analysis section of the experiment file contains data which were analyzed for a specific field, usually at the initiation of an experiment. Data provided in the soil analysis section of the experiment file override the more generic soil file data if both are provided.

Table 2. Phosphorus extraction methods with corresponding method code (input in File X) used in DSSAT v4.5 for soil categories.

Phosphorus extraction method	**Extraction method code (SMPX)**	**Soil class**				
		Calcareous	**Slightly weathered**	**Highly weathered**	**Andisol**	**Other**
Olsen	SA001	X	X	X	X	X
Bray No. 1	SA002	X	X	X	X	X
Mehlich I (double acid, 1:5)	SA004		X	X	X	
Anion exchange resin	SA005	X	X	X	X	X
Truog	SA006		X	X	X	X
Mehlich I (double acid, 1:10)	SA007			X		
Colwell	SA008			X		
Water	SA009	X				
IFDC Pi strip	SA010	X	X	X	X	X
Morgan's solution	SA014		X			

The phosphorus availability index is computed as a measure of the activity level of the P in the soil. This factor is estimated based on calcium carbonate for calcareous soils; base saturation, labile P and pH for slightly weathered soils; clay content for highly weathered soils; and on labile P for all other cases.

Rates of transformation between the various inorganic P pools are computed from labile P and P availability index. The transformation rates in turn determine the equilibrium ratios of the inorganic P components.

Initial quantities of P in the organic matter pools are estimated based on pH, organic C and soil class for each soil layer; or organic phosphorus can be input directly for each soil layer in the soil profile data.

Figure 1 presents a listing of a soil profile used with a phosphorus experiment in Tanzania with required, recommended and optional soil P data highlighted.

The INFO.OUT file, generated during a DSSAT v4.5 simulation, contains details about how inorganic soil P components were initialized for each soil layer and the soil parameters that were used in the calculations. Users are encouraged to open this file, which is found in the data output directory, to review computation methods, input data used and the computed P components. Figure

2 lists a sample of output information from the INFO.OUT file regarding estimation of initial soil P data using the soil profile data listed in Figure 1.

Table 3. Soil parameters used to initialize organic and inorganic P variables. Data requirements vary with soil class.

Soil data used to initialize phosphorus pools	Importance	Soil file header	Soil Analysis header	Soil class which uses this data			
				Calcar-eous	**Slightly weathered**	**Highly weathered**	**Andisol or other**
Extractable phosphorus (mg kg^{-1})	Required	SLPX	SAPX	X	X	X	X
Phosphorus extraction method (see Table 2)	Required	SMPX	SMPX	X	X	X	X
pH	Recommended (default 7.0)	SLHW	SAPHW	X	X	X	X
Total organic carbon , OC (g/100g)	Recommended	SLOC	SAOC	X	X	X	X
Total soil phosphorus (mg kg^{-1})	Optional	SLPT	--	X	X	X	X
Organic P (mg kg^{-1})	Optional	SLPO	--	X	X	X	X
Calcium carbonate CaCO3 (g kg^{-1})	Recommended for calcareous soils	CACO3	--	X			
Exchangeable potassium (cmol kg^{-1})	Recommended for slightly weathered soils	SLKE	SAKE		X		
Method of potassium extraction	Optional	SMKE	SMKE		X		
Base saturation (cmol kg^{-1})	Optional	SLBS	--		X		
Cation exchange capacity CEC (cmol kg^{-1})	Recommended	SCEC	--		X	X	
Clay content (%)	Recommended	SLCL	--		X	X	

```
*SUMO930002  MOROGORO, TZ SALO 100   OXISOL ISOHYPERTHEMIC, ARIDIC  TROPUSTIC

@SITE        COUNTRY            LAT     LOG  SCS FAMILY
 MOROGORO    TANZANIA          -6.5    37.3 REDDISH BROWN SAND LOAM

@ SCOM  SALB  SLUI  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE  SRGP
 2.5YR  0.12   6.0  0.50  84.0  1.00  0.80 IB001 SA005 IB001 IB003

@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC  SADC
    10    Ap 0.091 0.227 0.382 1.000 16.56  1.55  1.13  60.0  20.0  20.0  0.06  4.56   -99  8.97   -99
    20    Ap 0.066 0.202 0.382 0.841 16.56  1.55  1.13  65.0  30.0  15.0  0.06  4.50   -99  8.89   -99
    30     E 0.104 0.240 0.399 0.499 16.16  1.50  0.76  65.0  15.0  30.0  0.05  5.38   -99  5.65   -99
    40    AB 0.125 0.261 0.365 0.338 16.56  1.60  0.76  53.0  13.0  24.0  0.06  5.50   -99  5.31   -99
    50    B1 0.088 0.224 0.382 0.166  6.98  1.55  0.70  65.0  13.0  22.0  0.05  5.69   -99  5.44   -99
    60    B2 0.165 0.301 0.347 0.134  5.98  1.65  0.70  55.0  10.0  35.0  0.04  4.59   -99  3.77   -99
    70    B2 0.053 0.189 0.417 0.019  5.98  1.45  0.40  68.0  15.0  17.0  0.04  4.23   -99  3.31   -99
    80    B2 0.159 0.295 0.417 0.016 16.55  1.45  0.33  40.0  24.0  36.0  0.05  5.14   -99  2.03   -99
    90    B3 0.154 0.290 0.434 0.012  5.99  1.40  0.33  35.0  30.0  35.0  0.05  4.46   -99  1.91   -99
   100    B3 0.089 0.225 0.472 0.003  5.99  1.29  0.30  38.0  22.0  20.0  0.03  4.61   -99  1.94   -99

@  SLB  SLPX  SLPT  SLPO CACO3  SLAL  SLFE  SLMN  SLBS  SLPA  SLPB  SLKE  SLMG  SLNA  SLSU  SLEC   SLCA
    10  5.42   270 120.0  1.77   1.5  3.20   -99   -99   -99   -99   1.6  5.60  0.19   -99   -99   -99
    20  5.03   270 120.0  1.59   1.5  3.20   -99   -99   -99   -99   1.6  5.70  0.19   -99   -99   -99
    30  4.33   242 120.0  1.45   1.4  3.00   -99   -99   -99   -99   1.4  2.80  0.22   -99   -99   -99
    40  4.01   170  80.0  1.31   1.3  2.87   -99   -99   -99   -99   1.4  2.60  0.22   -99   -99   -99
    50  3.31   170  80.0  1.24   1.3  2.86   -99   -99   -99   -99   1.4  2.80  0.22   -99   -99   -99
    60  3.14   170  80.0  1.07   1.3  2.20   -99   -99   -99   -99   0.4  2.30  0.22   -99   -99   -99
    70  2.89   170  80.0  0.61   1.3  2.20   -99   -99   -99   -99   0.4  2.30  0.16   -99   -99   -99
    80  3.33    75  50.0  0.33   1.3  1.29   -99   -99   -99   -99   0.4  1.30  0.16   -99   -99   -99
    90  2.42    75  50.0  0.34   1.3  1.87   -99   -99   -99   -99   0.4  1.20  0.16   -99   -99   -99
   100  2.41    75  50.0  0.34   1.2  1.10   -99   -99   -99   -99   0.4  1.20  0.16   -99   -99   -99
```

Figure 1. Listing of sample soil profile with phosphorus input data used with a phosphorus experiment in Tanzania with highlighted fields for:

- required data (red),
- recommended data (green) and
- optional data (blue)

```
SOILDYN  YEAR DOY = 1994  63
 Soil layer classifications (used for soil P model)
 Layer Depth Soil_Layer_Type   Backup_Data
   1      5  CALCAREOUS        CaCO3:  0.18%
   2     15  CALCAREOUS        CaCO3:  0.17%
   3     30  HIGHLYWEATHERED   CaCO3:  0.15%; CEC:   6.7 cmol/kg; CLAY:  65.0%
   4     45  HIGHLYWEATHERED   CaCO3:  0.13%; CEC:   5.3 cmol/kg; CLAY:  57.0%
   5     60  HIGHLYWEATHERED   CaCO3:  0.11%; CEC:   4.3 cmol/kg; CLAY:  58.3%
   6     80  HIGHLYWEATHERED   CaCO3:  0.05%; CEC:   2.7 cmol/kg; CLAY:  54.0%
   7    100  HIGHLYWEATHERED   CaCO3:  0.03%; CEC:   1.9 cmol/kg; CLAY:  36.5%

SOMINI  YEAR DOY = 1994  63
Soil layer  1
Organic P read from soil file: 120.00 ppm
C:P ratio below acceptable range.
Revised Organic P: 113.26

SPINIT  YEAR DOY = 1994  63
Soil layer:  1
Soil type: CALCAREOUS
P extraction method: SA005
Measured P =    5.40 ppm
Labile P   =    5.40 ppm
Active P   =   27.05 ppm
Stable P   =  108.19 ppm
P Avail Index   =    0.60
Rate PLab->PAct = 0.02455/d
Rate PAct->PLab = 0.00490/d
Rate PAct->PSta = 0.00030/d
Rate PSta->PAct = 0.00010/d
```

Figure 2. Listing of selected output from INFO.OUT file showing P initialization based on soil profile inputs presented in Figure 1.

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DSSAT v4.5 User's Guide
DSSAT-Century soil organic matter module
data requirements and initialization procedures

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The DSSAT-CENTURY soil organic matter model maintains three humic pools (microbial, active and stable) and two fresh organic matter pools (structural and metabolic). Accurate estimations of the correct initial proportions of organic matter in each pool is critical to modeling decomposition of organic matter and the accompanying release or immobilization of inorganic nutrients to the soil. This document summarizes the data requirements for correct initialization of organic matter pools when using the DSSAT-CENTURY model (Gijsman et al., 2002 and Parton, et al., 1992).

First, the minimum requirements for initializing the various pools of organic matter are presented. Then, a more complex methodology is presented that can be used to more precisely initialize organic matter pools using an antecedent simulation of soil conditions for a long period of time ending at the start of the experiment. This more complex methodology should be adopted when the contribution of decomposing organic matter is critical to the prediction of soil fertility.

The terms organic carbon and organic matter are sometimes used interchangeably, but in the DSSAT-CENTURY model, they are maintained separately. Static conversion factors are used when converting organic matter to organic carbon and vice versa within the model. The conversions used by the DSSAT-CENTURY model for fresh organic matter (FOM) and soil organic matter (SOM) are:

- 0.400 kg[C]/kg[FOM]
- 0.526 kg[C]/kg[SOM]

Minimum data

As a minimum, the DSSAT-CENTURY model must have values of total soil organic carbon and soil texture to initialize all organic matter pools. These values are read from the soil profile data as shown in Figure 1. If organic carbon has been measured in a particular field for an experiment, those data should be entered in the soil analysis section of the experiment file, as shown in Figure 2. The soil analysis values, if provided, override the more generic values in the soil file. Total soil organic carbon amounts from either source are assumed to include the carbon from both FOM and SOM. These are partitioned into the various pools of organic matter as discussed in the sections below.

The model will assume default values for organic carbon and for clay and silt content if these data are missing. However, simulation of organic matter processes will not be accurate if these default values are used. If the release of nutrients due to decomposition of organic matter is an important factor in the fertility of the soil, it is very important to have accurate measurements of these data.

```
*SUMO930002  MOROGORO, TZ SALO 100   OXISOL ISOHYPERTHEMIC, ARIDIC  TROPUSTIC

@SITE        COUNTRY           LAT     LOG  SCS FAMILY
 MOROGORO    TANZANIA         -6.5    37.3 REDDISH BROWN SAND LOAM

@ SCOM  SALB  SLUI  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE  SRGP
 2.5YR  0.12   6.0  0.50  84.0  1.00  0.80 IB001 SA005 IB001 IB003

@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC  SADC
    10    Ap 0.091 0.227 0.382 1.000 16.56  1.55  1.13  60.0  20.0  20.0  0.06  4.56   -99  8.97   -99
    20    Ap 0.066 0.202 0.382 0.841 16.56  1.55  1.13  65.0  30.0  15.0  0.06  4.50   -99  8.89   -99
    30     E 0.104 0.240 0.399 0.499 16.16  1.50  0.76  65.0  15.0  30.0  0.05  5.38   -99  5.65   -99
    40    AB 0.125 0.261 0.365 0.338 16.56  1.60  0.76  53.0  13.0  24.0  0.06  5.50   -99  5.31   -99
    50    B1 0.088 0.224 0.382 0.166  6.98  1.55  0.70  65.0  13.0  22.0  0.05  5.69   -99  5.44   -99
    60    B2 0.165 0.301 0.347 0.134  5.98  1.65  0.70  55.0  10.0  35.0  0.04  4.59   -99  3.77   -99
    70    B2 0.053 0.189 0.417 0.019  5.98  1.45  0.40  68.0  15.0  17.0  0.04  4.23   -99  3.31   -99
    80    B2 0.159 0.295 0.417 0.016 16.55  1.45  0.33  40.0  24.0  36.0  0.05  5.14   -99  2.03   -99
    90    B3 0.154 0.290 0.434 0.012  5.99  1.40  0.33  35.0  30.0  35.0  0.05  4.46   -99  1.91   -99
   100    B3 0.089 0.225 0.472 0.003  5.99  1.29  0.30  38.0  22.0  20.0  0.03  4.61   -99  1.94   -99
```

Figure 1. Listing of sample soil profile showing total soil organic carbon (SLOC, g[C]/100g[soil]), clay content (SLCL, %) and silt content (SLSI, %)

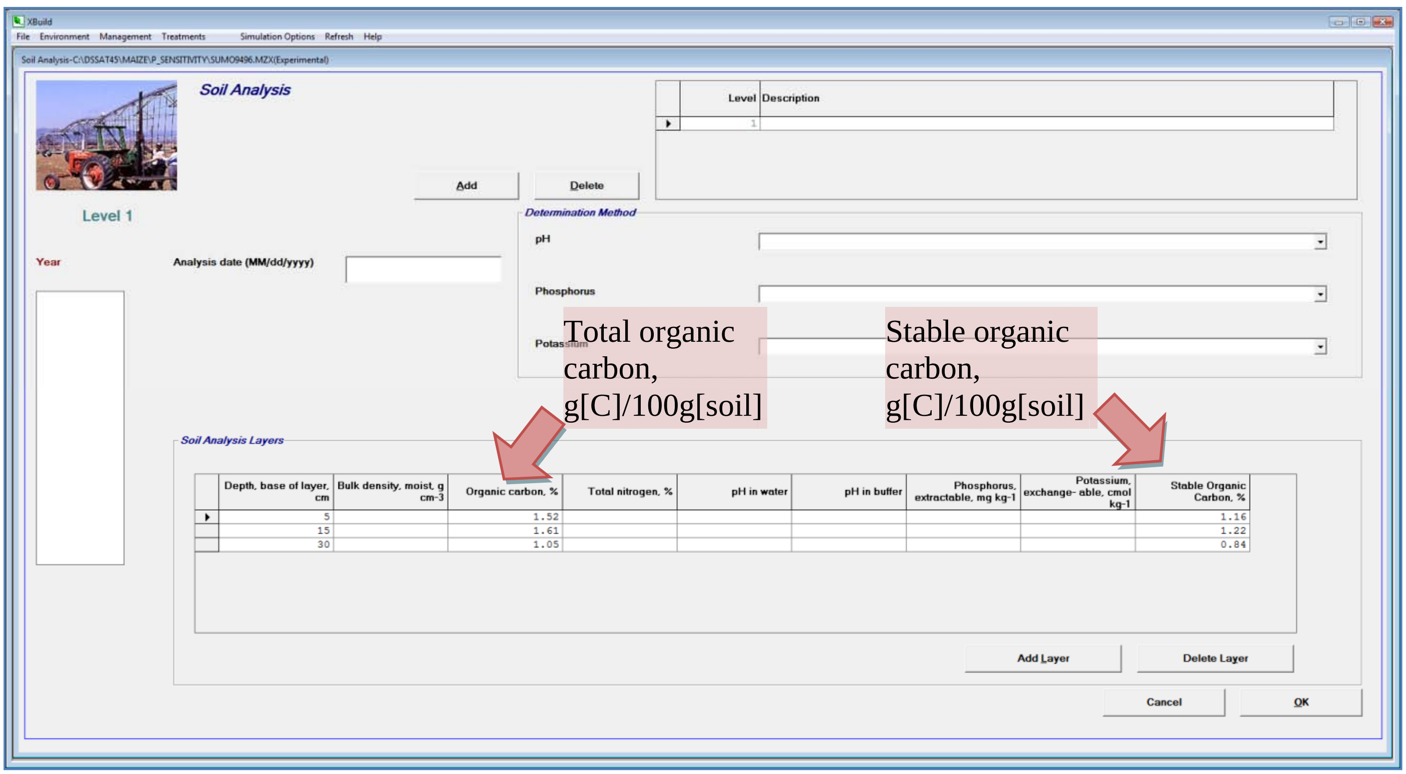

Figure 2. Sample entry in Soil Analysis section of experiment file showing measured total and stable organic carbon in g[C]/100g[soil] to a depth of 30 cm. This screen shot shows the data entry location within the Crop Management Data tool (XBuild). In this example, soil organic carbon data were measured within the top 30 cm.

Initialization of Fresh Organic Matter

FOM is initialized based on user-input values for crop residues left in the field from a previous crop. The data listed in Table 1 are specified in the "Initial Conditions" section of the experiment file. It is assumed that these initial fresh organic matter values were measured or estimated prior to any application of organic matter to the soil and that the measurements represent only residues left in the field from a previous crop. If additional organic amendments were applied to the field, those amounts should be entered in the "Residues and organic fertilizer" section of the experiment file.

Table 1. Input data for initialization of fresh organic matter in the "Initial Conditions" section of the experiment file

Input data	**Units**
Previous crop	--
Root residue weight	kg [dry matter] ha^{-1}
Nodule residue weight	kg [dry matter] ha^{-1}
Surface residue weight	kg [dry matter] ha^{-1}
N content of surface residue	%
P content of surface residue	%
Incorporation percentage of surface residue	%
Incorporation depth of surface residue	cm

If the initial root, nodule or surface residues are not specified, values of zero are assigned. The N and P contents of the residue, if not specified in the initial conditions, are read from an external file (RESCH045.SDA, see Appendix A, this document). This file lists physical and chemical characteristics crop residues and organic fertilizers, such as lignin content and water holding capacity.

The lignin fraction, obtained from the RESCH045.SDA file, is an important parameter for partitioning fresh organic matter into the easily decomposed metabolic portion and the more recalcitrant structural portion. The lignin content can have a significant impact on decomposition rates and release of N and P to the soil. Partitioning of nitrogen and phosphorus to the fresh organic matter pools also depends on the carbon partitioning and the lignin fraction.

Most users do not need to modify the RESCH045.SDA file, although if data are available on lignin content, or other characteristics, of residue in a particular field, then the file can be edited as described in Appendix A.

Initialization of Soil Organic Matter

The initial total soil organic carbon is computed as the difference between total organic carbon and the carbon in the specified initial amounts of FOM. SOM is partitioned by the DSSAT-CENTURY model into three pools, SOM1 (microbial), SOM2 (active), and SOM3 (stable). Three methods are available to compute the initial proportions of the SOM pools and the method used for each soil layer depends on the quality of input data provided. The three methods, in order of preference, are:

1. Measured, or previously estimated, stable organic carbon (specified in g[C]/100g[soil]).
2. Field management history.

3. Regression equation based on soil texture data.

All three methods first estimate the proportion of stable organic matter, SOM3, as a fraction of the total SOM. Then the proportions of SOM1 and SOM2 are assumed to be 5% and 95%, respectively, of the remaining, SOM1+SOM2, portion.

Method 1. Measured or previously estimated stable organic matter. Direct measurement of stable organic matter is the most reliable method of partitioning organic matter. If available, these measured data are entered in the "Soil Analysis" section of the experiment file with units of g[C]/100g[soil] as shown in Figure 2. However, this measurement is seldom done due to the high cost of the analysis.

It is possible to estimate the stable organic fractions by a pre-simulation process which is described below. A user may choose to perform this "spin-up" simulation one time and then enter the computed "initial" stable carbon amount in the "Soil Analysis" section as if it were a measured value.

Method 2. Field management history. If stable organic C measurements are not available, then initial partitioning of SOM can be estimated using information about the field management history. In the Fields section of the experiment file, a Field history code and Field history duration can be entered as shown in Figure 3. The field history code represents a combination of the level of management (irrigation, fertilizer, residue left in field) as well as the condition of the soil at the beginning of this management regime. The field history duration represents the number of years that this management scenario has been in effect. These two values, plus the soil texture classification of each soil layer, are used to look up the stable organic matter, or SOM3, amount, expressed as a fraction of total SOM. The lookup file, SOMFR045.SDA, is located in the StandardData directory in DSSAT45 and currently contains information for five management scenarios:

- FH101 – Cultivated, good management, initial default SOM
- FH102 – Cultivated, poor management, initial default SOM
- FH201 – Cultivated, good management, initial grass or forest
- FH202 – Cultivated, poor management, initial grass or forest
- FH301 – Cultivated, good management, initial degraded land

The data in the SOMFR045.SDA file were derived from many long-term simulations using different management regimes, soil types and beginning soil carbon conditions. A listing of this file is provided in Appendix B of this document.

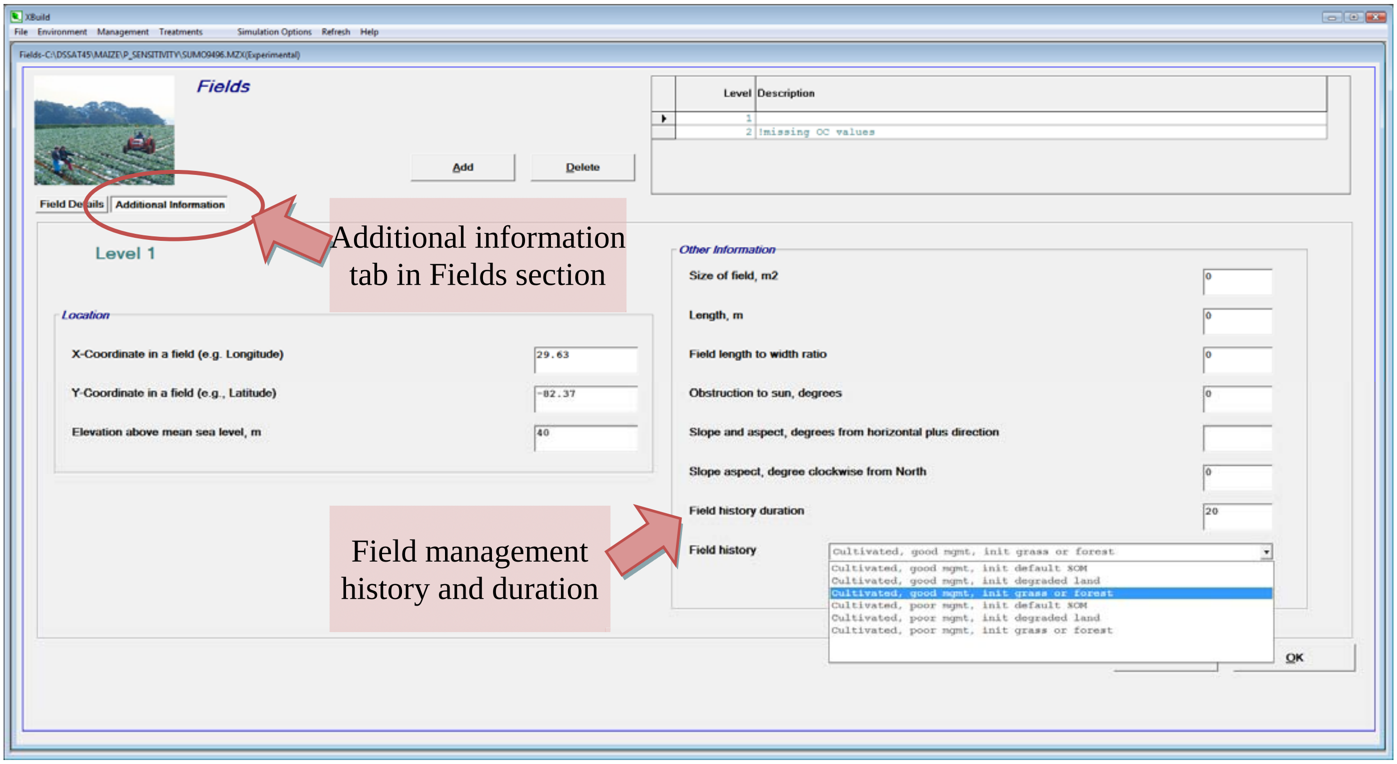

Figure 3. Sample of data entry in Fields section of experiment file showing location of entries for field management history and field history duration. This screen shot shows the data entry location within the Crop Management Data tool (XBuild).

Method 3. Regression equation. If only soil texture data are available for an experiment, then the soil texture is used to estimate the carbon in stable organic matter based on a relationship developed by Samuel Adiku (Porter et al., 2009).

$$StableC = 0.15 * (Clay + Silt) + 0.69$$

Where StableC = stable organic C in g/kg
Clay = soil clay content in %
Silt = soil silt content in %

These values represent the physically protected soil carbon and may underestimate stable soil carbon for some clay soil types which also contain significant portions of biochemically protected soil carbon. The estimate should be more reliable for sandy soils where the biochemically protected C is negligible.

Table 2 summarizes input data used for initialization of SOM pools.

Table 2. Summary of input data used for initialization of soil organic matter

Input data requirements	Data location File	 Data section
All methods:		
Total organic C, g[C]/100g[soil]	Soil file, or	Soil layer data
	Experiment file	Soil analysis, profile data
Method 1: measured stable C input		
Stable organic C, g[C]/100g[soil]	Experiment file	Soil analysis, profile data
Method 2: Field history		
Field history	Experiment file	Field
Field history duration, years	Experiment file	Field
Method 3: Regression equation		
Clay content, %	Soil file	Soil layer data
Silt content, %	Soil file	Soil layer data

The INFO.OUT file, generated during a DSSAT v4.5 simulation, contains details about how soil organic matter pools were initialized for each soil layer and the methods that were used in the calculations. Users are encouraged to open this file, found in the data directory (e.g., C:\DSSAT45\Maize), to review computation methods, input data used and the computed organic matter components. Figure 4 lists a sample of output information from the INFO.OUT file regarding estimation of initial soil organic matter data.

```
SOMINI  YEAR DOY = 1994  63
 Initial SOM fractions (fraction of total soil organic matter):
                      SAND   TOC  FOMC  SOMC  SOM1  SOM2  SOM3
  Lyr Dep Texture       %     %     %     %   frac  frac  frac Method
   1   5 Clay         20.0 1.520 0.004 1.516 0.012 0.223 0.765 Measured data
   2  15 Clay         12.5 1.610 0.003 1.607 0.012 0.229 0.759 Measured data
   3  30 Clay         15.0 1.050 0.002 1.048 0.010 0.188 0.802 Measured data
   4  45 Clay         30.0 0.740 0.001 0.739 0.001 0.019 0.980 Regression eqn
   5  60 Clay         30.7 0.700 0.001 0.699 0.001 0.019 0.980 Regression eqn
   6  80 Clay         26.5 0.365 0.001 0.364 0.001 0.019 0.980 Regression eqn
   7 100 ClayLoam     37.5 0.315 0.000 0.315 0.001 0.019 0.980 Regression eqn
```

Figure 4. Partial listing of INFO.OUT file showing initialization data for soil organic carbon pools

Antecedent simulation of estimating initial carbon pool partitioning

A method has been developed which can more precisely estimate the proportions of carbon in each organic matter pool in a way which provides information specific to a particular site and experiment. The method involves iterative simulations of crop rotations and soil processes for a period of from 5 to 20 years leading up to the start of the experiment. Figure 4 shows the procedure as a flowchart.

At the beginning of the antecedent simulation, initial total soil carbon and fresh organic matter are estimated. The proportions of SOM pools are estimated using the regression method which uses soil texture information. Management and crop rotations for the antecedent simulation should represent typical management scenarios for the field for the simulated antecedent time period. If weather data are not available for the entire antecedent simulation period, the method can still be applied by repeating data for the weather years that are available at that site. Even repeating a single year of weather data for the 20 years can result in an adequate estimation of soil organic matter processes over the long period of time.

With each iteration, the estimate of initial total soil carbon at the start of the antecedent simulation is refined until the measured value of soil carbon at the start of the experiment (i.e., the end of antecedent simulation) is adequately predicted. At this point, the stable organic C can be noted and used as input in the "Soil Analysis" section of the experiment file, as if it were a measured value.

The fresh organic matter that was assumed at the beginning of the simulation has a relatively short time constant and will not affect organic matter values much at the end of the simulation. Therefore, only initial total organic carbon need be modified in the iterations to generate reasonable estimates of the SOM proportions at the beginning of the simulation.

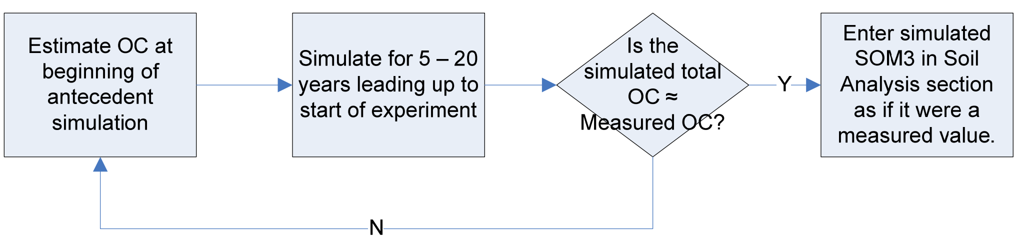

Figure 4. Iterative procedure to estimate SOM3 fraction for an experiment with measured total organic C, using an antecedent "spin-up" simulation.

References

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Appendix A. Listing of the RESCH045.SDA file:

The previous crop code, in the FIELDS section of the experiment file, is used to look up residue characteristics for initial conditions. Similarly, the residue type code is used to look up characteristics of applied organic matter.

```
*Organic Matter Application PARAMETER FILE - DSCSM045 Model 12/01/2009

@VERSION
 4.5.0.0

! Model parameter file which externalizes many of the
! coefficients needed for simulating the composition
! of soil organic matter.
!RETYP  Residue type code
!CR     Crop type (if applicable)
!AM     Area covered per unit dry weight of residue (cm2/g = ha/kg*10^5)
!WATFAC Saturation water content of surface mulch (kg[H2O]/kg[DM] = mm-ha/kg * 10^4)
!EXTFAC Mulch layer light extinction coefficient
!PSLIG  Proportion of lignin in surface residue (fraction)
!SCN    N content of initial surface (shoots) residue (%)
!SCP    P content of initial surface (shoots) residue (%)
!PRLIG  Proportion of lignin in subsurface residue (fraction)
!RCN    N content of initial subsurface (roots) residue (%)
!RCP    P content of initial subsurface (roots) residue (%)

*CHARACTERISTICS
!Res Crop |---------------- Surface ----------------| |-- Sub-surface --|
!Type  ID   Cover  Satur.  Evapor  Lignin  Nitr  Phos  Lignin  Nitr  Phos
@RETYP CR      AM  WATFAC  EXTFAC   PSLIG   SCN   SCP   PRLIG   RCN   RCP Description
!Generic Crops
 RE001 --      37     3.8    0.80    0.10  1.10  0.20    0.15  0.90  0.09 Generic crop residue
 RE101 --      32     3.8    0.50    0.12  1.20  0.25    0.18  0.75  0.06 Generic legume residue
 RE201 --      37     3.5    0.85    0.08  1.10  0.32    0.10  0.90  0.16 Generic cereal crop
residue
 RE301 --      40     3.5    0.80    0.07  1.10  0.13    0.11  0.90  0.06 Generic grass
 RE999 DC      32     3.8    0.80    0.20  0.40  0.04    0.30  0.25  0.02 Decomposed crop residue

!Manure/compost
!RETYP CR      AM  WATFAC  EXTFAC   PSLIG   SCN   SCP   PRLIG   RCN   RCP Description
 RE002 --      70     3.8    0.50    0.08  4.00  0.25     -99   -99   -99 Green manure
 RE003 --      10     3.8    0.80    0.07  4.80  0.67     -99   -99   -99 Barnyard manure
 RE004 --     140     3.8    0.50    0.02  5.00  1.60     -99   -99   -99 Liquid manure
 RE005 --      32     3.8    0.80    0.10  1.00  0.17     -99   -99   -99 Compost
 RE006 --       4     1.0    0.94    0.20  0.40  0.04     -99   -99   -99 Bark

!Legumes
!RETYP CR      AM  WATFAC  EXTFAC   PSLIG   SCN   SCP   PRLIG   RCN   RCP Description
 RE102 CP      32     3.8    0.50    0.12  1.20  0.27    0.18  0.75  0.06 Cowpea residue
 RE103 MC      32     3.8    0.50    0.08  3.00  0.70    0.12  2.00  0.18 Mucuna residue
 RE104 PN      32     3.8    0.50    0.12  1.20  0.25    0.18  0.75  0.06 Peanut residue
 RE105 PP      32     3.8    0.50    0.16  3.60  0.25    0.25  2.00  0.18 Pigeon Pea residue
 RE106 SB      32     3.8    0.50    0.13  1.20  0.70    0.21  0.75  0.18 Soybean residue
 RE107 AL      32     3.8    0.50    0.08  3.60  0.21    0.10  2.40  0.06 Alfalfa residue
 RE108 CH      32     3.8    0.50    0.12  1.20  0.25    0.18  0.75  0.06 chickpea forage
 RE109 FB      32     3.8    0.50    0.10  1.90  0.40    0.15  1.20  0.09 Faba bean
 RE110 PE      32     3.8    0.50    0.09  1.90  0.40    0.13  1.20  0.09 Pea residue
 RE111 --      69     3.8    0.50    0.08  3.20  0.60    0.12  2.00  0.14 Hairy vetch

!Cereals
!RETYP CR      AM  WATFAC  EXTFAC   PSLIG   SCN   SCP   PRLIG   RCN   RCP Description
 RE202 ML      30     3.5    0.85    0.09  1.10  0.32    0.10  0.90  0.16 Pearl millet residue
 RE203 MZ      30     3.5    0.86    0.10  1.10  0.32    0.10  0.90  0.16 Maize residue
 RE204 SG      30     3.5    0.85    0.06  1.10  0.20    0.10  0.90  0.10 Sorghum residue
 RE205 WH      45     5.0    0.85    0.06  0.59  0.16    0.10  0.50  0.08 Wheat residue
 RE206 BA      40     3.8    0.85    0.03  1.90  0.54    0.06  1.50  0.27 Barley
 RE207 RI      40     3.8    0.85    0.04  0.75  0.10    0.07  0.60  0.10 rice
 RE208 --      42     3.8    0.81    0.03  2.00  0.55    0.06  1.50  0.27 rye

!Grasses
```

```
!RETYP CR       AM  WATFAC  EXTFAC   PSLIG   SCN   SCP   PRLIG   RCN   RCP Description
 RE302 BH       40     3.5    0.80    0.07  1.10  0.13    0.11  0.90  0.06 Bahiagrass
 RE303 BG       40     3.5    0.80    0.07  1.10  0.13    0.11  0.90  0.06 Bermudagrass
 RE304 SI       40     3.5    0.80    0.10  1.10  0.13    0.16  0.90  0.06 Switchgrass
 RE305 BR       40     3.5    0.80    0.05  1.10  0.13    0.08  0.90  0.06 brachiaria
 RE306 --       40     3.5    0.80    0.10  1.10  0.13    0.16  0.90  0.06 forage grasses

!Other
!RETYP CR       AM  WATFAC  EXTFAC   PSLIG   SCN   SCP   PRLIG   RCN   RCP Description
 RE401 BF       40     3.5    0.80    0.16  1.10  0.19    0.24  0.90  0.09 Bush fallow residue
 RE402 SC       40     3.5    0.80    0.07  0.34  0.03    0.11  0.30  0.01 Sugarcane
 RE403 PI       30     3.5    0.80    0.10  0.88  0.08    0.15  0.90  0.04 Pineapple
```

How to modify residue characteristics or add a new residue type:

The RESCH045.SDA file is editable by the user if measurements of a particular crop residue are available or if additional residue types must be added. The file is located in the StandardData directory of DSSAT45. If an additional residue type is added, the name and residue type code must also be entered in the "Residues and Organic Fertilizer" section of the Detail.CDE file in the DSSAT45 directory. After changes are made to these files, the database in XBuild (the DSSAT Crop Management Data tool) must be refreshed before the new entries can be used by that tool.

Appendix B. Listing of the SOMFR045.SDA file

```
*SOMFR045.SDA Stable SOM fractions - DSCSM045 Model 12/01/2009

!========================================================================================================
! Initial SOM fractions are based on previous land use / management,
!   soil type, number of years under this management and on initial
!   carbon composition.
!
! Values in these tables represent the fraction of total organic C (OC)
!   that is stable (SOM3). Intermediate (SOM2) and microbial (SOM1) SOM
!   are estimated in the DSSAT-CENTURY model based on these stable SOM
!   fractions as follows:
!      SOM1 = 0.05 * (1.0 - SOM3).
!      SOM2 = 1.0 - SOM3 - SOM1
!========================================================================================================

@FH101 Cultivated with good management practices, initially cultivated land
!100 yr continuous simulation approach, irrigated, high N application rate
!Initial conditions: 44% stable C
!Years this mgmt ->|---0 yrs----|----5 yrs----|---10 yrs----|---20 yrs----|---60 yrs----|-Steady State|
!Soil depth (cm) ->| 0-20  20-40|  0-20  20-40|  0-20  20-40|  0-20  20-40|  0-20  20-40|  0-20  20-40|
@ L  TEXTURE        S3_T0  S3_D0  S3_T5  S3_D5 S3_T10 S3_D10 S3_T20 S3_D20 S3_T60 S3_D60 S3_TSS S3_DSS
  1  Sand            0.44   0.44   0.49   0.60   0.48   0.69   0.41   0.75   0.31   0.78   0.29   0.78
  2  LoamySand       0.44   0.44   0.55   0.63   0.60   0.75   0.62   0.84   0.60   0.88   0.60   0.88
  3  SandyLoam       0.44   0.44   0.50   0.60   0.52   0.70   0.50   0.78   0.44   0.82   0.43   0.82
  4  SiltyLoam       0.44   0.44   0.49   0.57   0.49   0.64   0.47   0.72   0.44   0.79   0.43   0.79
  5  Silt            0.44   0.44   0.49   0.56   0.48   0.64   0.46   0.71   0.43   0.77   0.43   0.77
  6  Loam            0.44   0.44   0.52   0.59   0.56   0.70   0.57   0.79   0.56   0.85   0.55   0.85
  7  SandClayLoam    0.44   0.44   0.57   0.60   0.65   0.72   0.72   0.83   0.75   0.91   0.75   0.91
  8  SiltClayLoam    0.44   0.44   0.52   0.56   0.55   0.65   0.58   0.74   0.60   0.83   0.60   0.83
  9  ClayLoam        0.44   0.44   0.54   0.58   0.59   0.67   0.64   0.78   0.68   0.87   0.68   0.87
 10  SandyClay       0.44   0.44   0.56   0.60   0.64   0.71   0.70   0.82   0.74   0.90   0.74   0.90
 11  SiltyClay       0.44   0.44   0.51   0.56   0.54   0.64   0.56   0.72   0.57   0.81   0.57   0.82
 12  Clay            0.44   0.44   0.53   0.57   0.59   0.66   0.63   0.76   0.67   0.85   0.67   0.86


@FH102 Cultivated with poor management practices, initially cultivated land
!100 yr continuous simulation approach, non-irrigated, non-fertilized
!Initial conditions: 44% stable C
!Years this mgmt ->|---0 yrs----|----5 yrs----|---10 yrs----|---20 yrs----|---60 yrs----|-Steady State|
!Soil depth (cm) ->| 0-20  20-40|  0-20  20-40|  0-20  20-40|  0-20  20-40|  0-20  20-40|  0-20  20-40|
@ L  TEXTURE        S3_T0  S3_D0  S3_T5  S3_D5 S3_T10 S3_D10 S3_T20 S3_D20 S3_T60 S3_D60 S3_TSS S3_DSS
  1  Sand            0.44   0.44   0.54   0.68   0.58   0.83   0.69   0.95   0.89   0.98   0.93   0.98
  2  LoamySand       0.44   0.44   0.56   0.66   0.59   0.81   0.62   0.93   0.86   0.98   0.94   0.98
  3  SandyLoam       0.44   0.44   0.53   0.64   0.54   0.78   0.54   0.91   0.76   0.98   0.89   0.98
  4  SiltyLoam       0.44   0.44   0.52   0.60   0.53   0.72   0.53   0.85   0.65   0.95   0.74   0.97
  5  Silt            0.44   0.44   0.51   0.60   0.52   0.72   0.52   0.84   0.64   0.95   0.73   0.96
  6  Loam            0.44   0.44   0.53   0.62   0.55   0.76   0.56   0.88   0.70   0.97   0.80   0.98
  7  SandClayLoam    0.44   0.44   0.56   0.62   0.62   0.75   0.67   0.88   0.81   0.97   0.85   0.98
```

```
  8  SiltClayLoam    0.44   0.44   0.53   0.59   0.56   0.70   0.59   0.83   0.71   0.95   0.77   0.96
  9  ClayLoam        0.44   0.44   0.54   0.60   0.58   0.72   0.62   0.85   0.73   0.96   0.79   0.96
 10  SandyClay       0.44   0.44   0.55   0.61   0.60   0.74   0.65   0.87   0.79   0.97   0.83   0.97
 11  SiltyClay       0.44   0.44   0.52   0.59   0.55   0.69   0.57   0.82   0.66   0.94   0.73   0.95
 12  Clay            0.44   0.44   0.54   0.59   0.58   0.71   0.63   0.84   0.75   0.95   0.80   0.96

@FH201 Cultivated with good management practices, initially grassland/forest
!100 yr continuous simulation approach, irrigated, high N application rate
!Initial conditions: 34% stable C
!Years this mgmt ->|---0 yrs----|----5 yrs----|---10 yrs----|---20 yrs----|---60 yrs----|-Steady State|
!Soil depth (cm) ->| 0-20  20-40|  0-20  20-40|  0-20  20-40|  0-20  20-40|  0-20  20-40|  0-20  20-40|
@ L  TEXTURE        S3_T0  S3_D0  S3_T5  S3_D5 S3_T10 S3_D10 S3_T20 S3_D20 S3_T60 S3_D60 S3_TSS S3_DSS
  1  Sand            0.34   0.34   0.43   0.55   0.43   0.66   0.39   0.74   0.31   0.78   0.29   0.78
  2  LoamySand       0.34   0.34   0.49   0.58   0.56   0.72   0.60   0.83   0.60   0.88   0.60   0.88
  3  SandyLoam       0.34   0.34   0.44   0.54   0.48   0.67   0.48   0.77   0.44   0.82   0.43   0.82
  4  SiltyLoam       0.34   0.34   0.42   0.50   0.45   0.60   0.45   0.71   0.44   0.79   0.43   0.79
  5  Silt            0.34   0.34   0.42   0.49   0.44   0.59   0.44   0.69   0.43   0.77   0.43   0.77
  6  Loam            0.34   0.34   0.46   0.53   0.52   0.66   0.55   0.78   0.56   0.85   0.56   0.85
  7  SandClayLoam    0.34   0.34   0.50   0.54   0.61   0.68   0.70   0.82   0.75   0.91   0.75   0.91
  8  SiltClayLoam    0.34   0.34   0.45   0.49   0.51   0.60   0.56   0.72   0.60   0.83   0.60   0.83
  9  ClayLoam        0.34   0.34   0.47   0.51   0.55   0.63   0.62   0.76   0.68   0.87   0.68   0.87
 10  SandyClay       0.34   0.34   0.50   0.53   0.59   0.67   0.69   0.81   0.74   0.90   0.74   0.90
 11  SiltyClay       0.34   0.34   0.45   0.49   0.49   0.59   0.53   0.70   0.57   0.81   0.57   0.82
 12  Clay            0.34   0.34   0.47   0.50   0.54   0.62   0.61   0.74   0.67   0.85   0.67   0.86

@FH202 Cultivated with poor management practices, initially grassland/forest
!100 yr continuous simulation approach, non-irrigated, non-fertilzed
!Initial conditions: 34% stable C
!Years this mgmt ->|---0 yrs----|----5 yrs----|---10 yrs----|---20 yrs----|---60 yrs----|-Steady State|
!Soil depth (cm) ->| 0-20  20-40|  0-20  20-40|  0-20  20-40|  0-20  20-40|  0-20  20-40|  0-20  20-40|
@ L  TEXTURE        S3_T0  S3_D0  S3_T5  S3_D5 S3_T10 S3_D10 S3_T20 S3_D20 S3_T60 S3_D60 S3_TSS S3_DSS
  1  Sand            0.34   0.34   0.46   0.62   0.51   0.80   0.62   0.94   0.87   0.98   0.93   0.98
  2  LoamySand       0.34   0.34   0.49   0.61   0.54   0.78   0.58   0.92   0.85   0.98   0.94   0.98
  3  SandyLoam       0.34   0.34   0.46   0.58   0.48   0.75   0.50   0.89   0.75   0.98   0.89   0.98
  4  SiltyLoam       0.34   0.34   0.45   0.54   0.47   0.68   0.49   0.83   0.65   0.96   0.76   0.97
  5  Silt            0.34   0.34   0.44   0.53   0.47   0.67   0.49   0.82   0.64   0.95   0.75   0.96
  6  Loam            0.34   0.34   0.46   0.56   0.50   0.72   0.53   0.87   0.70   0.97   0.82   0.98
  7  SandClayLoam    0.34   0.34   0.49   0.55   0.57   0.71   0.65   0.86   0.81   0.97   0.87   0.98
  8  SiltClayLoam    0.34   0.34   0.46   0.52   0.51   0.65   0.56   0.81   0.70   0.95   0.78   0.96
  9  ClayLoam        0.34   0.34   0.47   0.53   0.53   0.67   0.59   0.82   0.73   0.96   0.80   0.96
 10  SandyClay       0.34   0.34   0.48   0.54   0.56   0.70   0.63   0.85   0.79   0.97   0.85   0.97
 11  SiltyClay       0.34   0.34   0.45   0.51   0.49   0.64   0.54   0.79   0.66   0.94   0.74   0.95
 12  Clay            0.34   0.34   0.47   0.52   0.53   0.66   0.60   0.82   0.75   0.95   0.82   0.96


@FH301 Cultivated with good management practices, initially degraded
!100 yr continuous simulation approach, irrigated, high N application rate
!Initial conditions: Stable C from 100 year continuous simulations for FH102
!Initial conditions: previously degraded land, use initial SOM from transient simulation scenarios
!Years this mgmt ->|---0 yrs----|----5 yrs----|---10 yrs----|---20 yrs----|---60 yrs----|-Steady State|
!Soil depth (cm) ->| 0-20  20-40|  0-20  20-40|  0-20  20-40|  0-20  20-40|  0-20  20-40|  0-20  20-40|
```

@ L	TEXTURE	S3_T0	S3_D0	S3_T5	S3_D5	S3_T10	S3_D10	S3_T20	S3_D20	S3_T60	S3_D60	S3_TSS	S3_DSS
1	Sand	0.93	0.98	0.82	0.91	0.69	0.85	0.51	0.80	0.32	0.78	0.29	0.78
2	LoamySand	0.94	0.98	0.89	0.94	0.82	0.91	0.72	0.88	0.62	0.88	0.60	0.88
3	SandyLoam	0.89	0.98	0.84	0.92	0.74	0.88	0.60	0.83	0.45	0.82	0.43	0.82
4	SiltyLoam	0.74	0.97	0.78	0.90	0.68	0.85	0.56	0.81	0.45	0.79	0.43	0.79
5	Silt	0.73	0.96	0.77	0.89	0.67	0.85	0.54	0.80	0.43	0.77	0.43	0.77
6	Loam	0.80	0.98	0.83	0.92	0.75	0.89	0.66	0.86	0.56	0.85	0.56	0.85
7	SandClayLoam	0.85	0.98	0.88	0.95	0.84	0.93	0.79	0.92	0.76	0.91	0.75	0.91
8	SiltClayLoam	0.77	0.96	0.82	0.91	0.75	0.88	0.67	0.85	0.61	0.83	0.60	0.83
9	ClayLoam	0.79	0.96	0.84	0.93	0.79	0.90	0.73	0.88	0.68	0.87	0.68	0.87
10	SandyClay	0.83	0.97	0.87	0.94	0.83	0.93	0.78	0.91	0.74	0.90	0.74	0.90
11	SiltyClay	0.73	0.95	0.80	0.91	0.73	0.88	0.65	0.84	0.57	0.82	0.57	0.82
12	Clay	0.80	0.96	0.84	0.92	0.78	0.90	0.72	0.87	0.67	0.86	0.67	0.86