CERES-Maize

A Simulation Model of Maize Growth and Development

Edited by

C. A. JONES and J. R. KINIRY

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With contributions by
P. T. Dyke, D. B. Farmer, D. C. Godwin,
S. H. Parker, J. T. Ritchie, and D. A. Spanel

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Contents

Preface

During the last 20 years rapid progress has been made in the simulation of agricultural processes. A number of models are now available to simulate processes such as weather, hydrology, nutrient cycling and movement, tillage, soil erosion, soil temperature, and crop growth and development. Many of these models are quite restricted in purpose, simulating only discrete processes such as denitrification, leaching of NO_3, soil temperature, or the movement of water in the soil. Others integrate several of these processes. During the last few years more comprehensive agricultural simulation models have begun to appear. These models simulate a number of processes and predict their interacting effects on crop growth and yield. As more and more processes are simulated, model development and testing require the expertise of an increased number of scientific disciplines and more teamwork and organization. Modeling comprehensive agricultural systems is rapidly becoming a team effort involving scientists around the world and demanding well-integrated networks to exchange both experimental data and software.

This book provides the documentation, testing, and software of CERES-Maize, a quite comprehensive model of maize (Zea mays L.) growth and development. Two versions of the model are provided. The standard version considers the independent and interacting effects of genotype, weather, and hydrology. The nitrogen version considers those factors as well as nitrogen nutrition. The development of the Crop-Environment Resource Synthesis (CERES) Maize model was coordinated by Dr. J. T. Ritchie at the Grassland, Soil and Water Research Laboratory of the United States Department of Agriculture, Agricultural Research Service (USDA-ARS). Dr. Ritchie was responsible for the conceptual development of the model as well as many of the subroutines and much of the detailed FORTRAN code. However, he was aided by a large, informal network of experimental scientists and modelers from throughout the world. These cooperators are acknowledged in the text, but it is appropriate to point out here that their ideas, data, and constructive suggestions were indispensable.

Shortly before completion and final testing of the CERES-Maize model, Dr. Ritchie left ARS for a position at Michigan State University. Final modifications and testing were completed by the editors.

We would like to thank the following individuals for their invaluable assistance in the final testing, modification, and documentation of the model: Kitty Myers for editorial assistance, Norman Erskine for preparation of the figures, Dan Taylor and Wes Fuchs for selection and preparation of typical soil pedons, Sandi Hill for making many model runs and modifications, Jeff Arnold for help in adapting a soil temperature model, Diane Farmer and Sarah Parker for converting the Amdahl versions of the model to PC versions.

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CERES-Maize

1. The CERES-Maize Model

J. T. Ritchie

CERES-Maize, like the similar model CERES-Wheat, is a user-oriented, daily-incrementing simulation model of maize growth, development, and yield. It is available in two versions. The standard version simulates the effects of genotype, weather, and soil properties on maize growth and yield. The nitrogen version also simulates soil and plant nitrogen dynamics and their effects on the crop. CERES-Maize was developed by the United States Department of Agriculture, Agricultural Research Service (USDA-ARS), Crop Systems Evaluation Unit located at Grassland, Soil and Water Research Laboratory, Temple, TX. Important collaborators included (in alphabetical order): D. K. Cassel, North Carolina State University, Raleigh; P. T. Dyke, USDA-Economic Research Service, Temple, TX; W. W. Fuchs, USDA-Soil Conservation Service, Temple, TX; D. C. Godwin, International Fertilizer Development Center, Muscle Shoals, AL; W. C. Iwig, USDA-Statistical Reporting Service, Washington, DC; D. P. Knievel, Penn State University, University Park, PA; H. A. Nix, CSIRO, Canberra, Australia; L. F. Ratliff, USDA-Soil Conservation Service, Fort Worth, TX; and D. R. Upchurch, USDA-ARS, Lubbock, TX.

CERES-Maize is a multipurpose simulation model that can be used for

—within-year crop management decisions;

—multi-year risk analysis for strategic planning;

—yield forecasting for large areas;

—definition of research needs.

These purposes require that the model have the following characteristics:

—use readily available weather, soil, and genetic inputs;

—be written in a familiar and widely used computer language;

—require minimal computation time;

—be adapted to use on both mainframe and microcomputers.

As a result of these constraints, most input data are available from or can be readily estimated from routinely collected daily weather data, standard soil characterization data, and data provided in the model documentation. The computer program is written in the familiar scientific language, FORTRAN, and diskettes of both versions of the model are enclosed. The model has been successfully run on the IBM-compatible personal microcomputers listed in Table 1.1.[1] These systems require 256K memory and Microsoft DOS 2.0 or higher. A step-by-step description of how to run the model on microcomputers is given in Chapter 6. Flow charts of the two versions of the model are given in Chapter 4.

In order to accurately simulate maize growth, development, and yield, the model takes into account the following processes:

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[1]Mention of a trademark name or proprietary product does not constitute a guarantee or warranty by the USDA-ARS and does not imply its approval over other products that also may be suitable.

Table 1.1 Computers tested and found to be compatible.

AT&T 6300 PC	IBM PC JR
CENTURION PC	IBM XT
COLUMBIA DESKTOP	KAYPRO 16
COMPAQ DESKPRO	KAYPRO 286I
COMPAQ DESKPRO 286	NCR PC-4
COMPAQ PORTABLE	PANASONIC SR. PARTNER
COMPAQ PORTABLE +	SANYO MBC 550-2
COMPAQ PORTABLE 286	TELEX
CORONA PPC 400	TI PORTABLE PROFESSIONAL COMPUTER
DATA GENERAL ONE	TI PROFESSIONAL COMPUTER
EAGLE PC PORTABLE	TRS 1000
EAGLE PC	XEROX PERSONAL COMPUTER
EAGLE PC TURBO	ZENITH Z150
ESPRIT 6310	ZENITH Z160
IBM AT	
IBM PC	

—phenological development, especially as it is affected by genetics and weather;
—extension growth of leaves, stems, and roots;
—biomass accumulation and partitioning, especially as phenological development affects the development and growth of vegetative and reproductive organs;
—soil water balance and water use by the crop;
—soil nitrogen transformations, uptake by the crop, and partitioning among plant parts.

Both standard and nitrogen versions of the model are available. The standard version assumes that nitrogen fertility is adequate. It requires fewer soil inputs and has a shorter execution time than the nitrogen version. For applications in which water is nonlimiting or only phenological predictions are required, the standard version can be run with the water balance switched off to further reduce execution time. Components of both the standard and nitrogen versions of CERES-Maize have been described briefly (Godwin et al., 1984; Jones et al., 1984).

The CERES-Maize model is designed to simulate the effects of cultivar, planting density, weather, soil water, and nitrogen on crop growth, development, and yield. The effects of weeds, insects, diseases, other nutrient deficiencies and toxicities, and catastrophic weather events such as hurricanes or wind damage are not considered.

> **This documentation is designed to aid users of both the standard and nitrogen versions. The nitrogen version includes all components of the standard version; however, users of the standard version may wish to ignore parts of the documentation related to nitrogen. Therefore, sections of the documentation that refer only to the nitrogen version are printed in bold type and are indented and single spaced.**

2. File Structure

D. B. Farmer, S. H. Parker,[1] and D. A. Spanel[2]

The CERES-Maize model uses two data input files, the parameter input file and the daily weather input file. Each treatment, or unique set of conditions to be simulated, should have a separate parameter input file named by the user. Each set of daily weather data is stored in an input file with a unique, user-specified name.

Upon execution, the standard version of the model writes data to three output files. The output file OYLD.DAT contains general growth, development, yield, and soil data needed by most users. OBIO.DAT contains detailed plant growth data, and OWAT.DAT contains detailed information on the water balance.

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[1]The Texas Agricultural Experiment Station, Texas A&M University System, Blackland Research Center, Temple, Texas. All programs and information of the Texas Agricultural Experiment Station are available to everyone without regard to race, color, religion, sex, age, handicap, or national origin.

[2]Authors are listed in alphabetical order.

The nitrogen version of the model uses three additional output files: a soil nitrogen file (ONIS.DAT), a nitrogen mineralization file (OMIN.DAT), and a nitrogen uptake file (ONIP.DAT).

All input and output files are configured in the MAIN program. Tables 2.1 and 2.2 give the subroutines and their related input and output files for the standard and nitrogen versions of the model, respectively.

Table 2.1. Model subroutines and their related output files in the STANDARD version.

Subroutines	Input Files	Output Files
MAIN program	Weather	
PROGRI	Parameter	OYLD.DAT
SOILRI	Parameter	OYLD.DAT
WATBAL		
PHENOL		OYLD.DAT
PHASEI		OYLD.DAT
GROSUB		OYLD.DAT
WRITE		
OUTWA		OWAT.DAT
OUTGR		OBIO.DAT
CALDAT		

Table 2.2. Model subroutines and their related output files in the NITROGEN version.

Subroutines	Input Files	Output Files
MAIN program	Weather	
PROGRI	Parameter	OYLD.DAT
SOILRI	Parameter	OYLD.DAT
WATBAL		
PHENOL		OYLD.DAT
PHASEI		
GROSUB		OYLD.DAT
WRITE		
OUTWA		OWAT.DAT
OUTGR		OBIO.DAT
CALDAT		
SOILNI	Parameter	OYLD.DAT OMIN.DAT
MINIMO		
NUPTAK		
NFLUX		
NFACTO		
DNIT		
NITRIF		
SOLT		
NWRITE		
NBAL		OMIN.DAT
OUTMN		ONIS.DAT
OUTNU		ONIP.DAT

PARAMETER INPUT FILE

The parameter file is used to assign values to variables that control the input, execution, and output of the model. Each treatment or set of conditions to be simulated is represented by a unique parameter file. The user defines the file name for each treatment, e.g., STDSP.DAT, and the data are read in subroutine PROGRI.

The size, format, location, and definition of each variable in the parameter file are given in Tables 2.3 and 2.4 at the end of this chapter.

Lines 1-5.

Five types of variables are found in the first five lines of the parameter file: switches, output control numbers, management inputs, initial conditions, and measured values. Switches determine whether certain sections and subroutines of the model are accessed during the program run. Output control numbers define the frequency of output for the output file. Management inputs initialize variables such as sowing date, initial plant population, irrigation dates and amounts, etc. Initial conditions include initial soil water contents of the soil layers. Measured values can be provided by the user for comparison with values predicted by the model.

The first line of the parameter file is the title (TITLE) or name of the treatment specified by the user. The second line contains variables specifying details of management, input, and output. The third line contains genetic information for the cultivar. The fourth line contains measured values such as silking date, grain yield, etc., that are compared with simulated values in the output file OYLD.DAT. The fifth line contains general soil information for the whole profile.

Soil layer information.

Information concerning individual soil layers begins on line 6 of the parameter file. One line is used to initialize each soil layer. The information required is the thickness of the layer (DLAYR), the lower limit of plant-extractable water (LL), the drained upper limit (DUL), water content at saturation (SAT), a weighting factor for rooting (WR), and initial soil water content (SW) (Table 2.3). Initialization of these variables is described in Chapter 3. After the last line of soil information is entered, a line with DLAYR set equal to zero is necessary to signal the end of soil information input. No more than ten layers of soil information can be entered.

The variable INSOIL in line 2 of the parameter file affects the specification of initial soil water (SW). If INSOIL is 0.0 or 1.0, initial SW is set to the lower limit (LL) or to the drained upper limit (DUL), respectively. These limits are discussed in detail in Chapter 3. If INSOIL is between 0.0 and 1.0, initial SW is automatically set to a value between LL and DUL (see Chapter 4). If INSOIL is greater than 1.0, the user must input the initial SW content of each layer.

> In the nitrogen version, organic carbon concentration (OC), moist bulk density (BD), pH (PH), and initial soil ammonium (NH4) and nitrate (NO3) concentrations are read from the same lines as those used to initialize soil layer information in the standard version (Table 2.4).

Irrigation information.

IIRR is a switch in line 2 of the parameter file that describes irrigation. If IIRR is zero, no irrigation is used. Otherwise, IIRR is set to 1 and irrigation dates and amounts are read from the parameter file below the soil layer information (Table 2.3). The information required is the day of the year (JDAY) and the amount of each irrigation (AIRR). One line in the parameter file is used for each irrigation event. The model stops reading irrigation values when it encounters a zero value in the columns specifying the day of irrigation. No distinction is made between irrigation and rainfall when calculating runoff; therefore, some runoff may occur from irrigation application.

In the nitrogen version, IIRR is also a switch. It should be set to zero if no irrigation is used, to 1 if irrigation dates and amounts are specified, or to the number of mm (2-99) of water to be applied if the model is to automatically apply irrigation (Table 2.4).

Fertilizer inputs.

Fertilizer application in the nitrogen version is specified below irrigation, or below the soil information if irrigation is not specified. Each line contains the day of the year (JFDAY), amount of elemental nitrogen applied (AFERT), depth of incorporation (DFERT), and type of fertilizer nitrogen applied (IFTYPE) (Table 2.4). One line is used for each application of nitrogen fertilizer. After the last line of fertilizer information is entered, a line with JFDAY set equal to zero is necessary to signal the end of fertilizer data. If no fertilizer is used, zeros are entered for the day of the year as a signal to the model.

Examples.

Below are three examples of parameter files for the standard version. In the first, the eighth number on the second line is INSOIL. In this example, INSOIL is 1.0. Therefore, initial soil water contents are automatically set to the drained upper limit of plant-extractable water; and columns 26-29 of the lines describing soil layers, which are normally used to specify initial soil water, are zero. The seventh number on the second line is IIRR. It is set to 1, indicating that dates and amounts of irrigations are supplied by the user in the lines below the soil layer information. In this case, 32 mm of water is applied on JDAY 187. The values of LL, DUL, and SAT are identical for all soil layers and soil depth is only 94 cm because this data set represents an artificially mixed pedon over a plastic barrier.

```
MISSOURI, 1979  SW=UL, IRR
150 05.70 05.00 39.00 07 07 01 1.00 01
B73 X MO17        220. .520 880. 730.0 10.00
207 271 014291 .341 00000 0621 03.1 002119
.14 06.0 0.30 60.0
15.0 .160 .315 .370 0.93 .000
15.0 .160 .315 .370 0.70 .000
20.0 .160 .315 .370 0.32 .000
20.0 .160 .315 .370 0.10 .000
24.0 .160 .315 .370 0.05 .000
0000
187 32.00
000
```

In the second example, INSOIL is set to zero; therefore, initial soil water is automatically set to the lower limit of plant-extractable water. IIRR is set to zero, indicating that no irrigation is to be used. Measured values in line 4 are set to zero because this is a hypothetical treatment that was never actually conducted.

```
MISSOURI, 1979  SW=LL, NO IRR
150 05.70 05.00 39.00 07 07 00 0.00 01
B73 X MO17        220. .520 880. 730.0 10.00
000 000 000000 0000 00000 0000 0000 000000
.14 06.0 0.30 60.0
15.0 .160 .315 .370 0.93 .000
15.0 .160 .315 .370 0.70 .000
20.0 .160 .315 .370 0.32 .000
20.0 .160 .315 .370 0.10 .000
24.0 .160 .315 .370 0.05 .000
0000
```

In the third example IIRR is again set to 1, and the line of irrigation data is the same as the first example. However, INSOIL is now greater than 1.0, indicating that initial water content of each layer is read from columns 26-29, beginning on line 6 of the parameter file.

```
MISSOURI, 1979  SW=SPECIFIED, IRR
150 05.70 05.00 39.00 07 07 01 1.10 01
B73 X MO17         220. .520 880. 730.0 10.00
000 000 000000 0000 00000 0000 0000 000000
.14 06.0 0.30 60.0
15.0 .160 .315 .370 0.93 .190
15.0 .160 .315 .370 0.70 .250
20.0 .160 .315 .370 0.32 .280
20.0 .160 .315 .370 0.10 .315
24.0 .160 .315 .370 0.05 .315
0000
187 32.00
000
```

Following are two examples of parameter files for the nitrogen version. In the first, the last number in the second line is INSOIL. In this example INSOIL is zero, indicating that initial soil water is set to the lower limit of plant-extractable water. Therefore, no data for initial water content appear in columns 26-29. However, initial organic carbon, bulk density, pH, and ammonium and nitrate concentrations of the seven soil layers appear in columns 31-54.

IIRR is the eleventh value on the second line. In this case, IIRR is zero, indicating that no irrigation is applied. Thus, no irrigation dates or amounts appear in columns 1-9 below the soil layer information. However, fertilizer was applied three times. The days of application (JFDAY), the amounts of elemental nitrogen applied (AFERT), the depths of application (DFERT), and the code numbers for the nitrogen source (IFTYPE) are specified in columns 1-16.

```
FLO,SC 81  SW=LL, NO IRR, FERT
097 07.10 04.00 34.00 0001 07 14 05 07 07 0000 0.00
PIO 3382         200. .700 800. 650.0 08.50
000 000 000000 0000 00000 0000 0000 000000 000000 0000 0000 0000
.14 5.00 0.60 60.0 16.8 20.0 060 00500 10.0 80.0 00200 45.0
10.0 .075 .210 .250 1.00 .000 0.30 1.55 6.00 02.0 05.0
10.0 .075 .210 .250 1.00 .000 0.30 1.55 6.00 02.0 05.0
21.0 .100 .240 .290 0.80 .000 0.17 1.67 6.20 02.0 05.0
30.0 .210 .310 .350 0.40 .000 0.01 1.54 6.50 02.0 05.0
30.0 .210 .320 .360 0.10 .000 0.01 1.54 6.70 01.0 02.0
25.0 .180 .280 .320 0.10 .000 0.01 1.68 6.80 01.0 02.0
25.0 .180 .280 .320 0.10 .000 0.01 1.74 6.80 01.0 02.0
0000
090 66.70 10. 03
139 66.70 10. 03
153 66.70 10. 03
000
```

In the second example, INSOIL is set to 1.1, indicating that initial water contents of all layers are specified beginning on line 6 of the parameter file. IIRR is set to 1 indicating that irrigation dates and amounts are specified by the user.

Fertilizer dates and amounts are identical to those in the previous example, but fertilizer type is now urea (IFTYPE=1) rather than anhydrous ammonia (IFTYPE=3). Measured values are given in line 4 because this treatment was conducted in an actual field experiment.

```
FLD,SC 81  SW=SPEC, IRR, FERT
097 07.10 04.00 34.00 0001 07 14 05 07 07 01.0 1.10
PIO 3382            200. .700 800. 650.0 08.50
156 210 011550 .276 418.5 0000 04.2 23800. 010954 1.62 0248 0158
.14 5.00 0.60 60.0 16.8 20.0 060 00500 10.0 80.0 00200 45.0
10.0 .075 .210 .250 1.00 .189 0.30 1.55 6.00 02.0 05.0
10.0 .075 .210 .250 1.00 .189 0.30 1.55 6.00 02.0 05.0
21.0 .100 .240 .290 0.80 .228 0.17 1.67 6.20 02.0 05.0
30.0 .210 .310 .350 0.40 .310 0.01 1.54 6.50 02.0 05.0
30.0 .210 .320 .360 0.10 .320 0.01 1.54 6.70 01.0 02.0
25.0 .180 .280 .320 0.10 .280 0.01 1.68 6.80 01.0 02.0
25.0 .180 .280 .320 0.10 .280 0.01 1.74 6.80 01.0 02.0
0000
121 013.7
133 004.3
139 014.0
146 014.2
153 005.6
160 011.2
162 027.2
168 027.2
170 027.4
174 026.4
177 025.9
201 027.7
205 027.4
000
090 66.70 10. 01
139 66.70 10. 01
153 66.70 10. 01
000
```

WEATHER INPUT FILE

The name of the weather input file is specified by the user. It contains the daily weather data for the treatment to be simulated. Weather data are read by the MAIN program, with one line of data for each day. The first seven columns of each line are used as an identification field or comment field and are not read. The year (IYR), day of year (JDATE), solar radiation (SOLRAD), maximum air temperature (TEMPMX), minimum air temperature (TEMPMN), and precipitation (RAIN) are read with the format (7X,I2,1X,I3,3X,F4.0,3F6.1). Below is a sample of four lines of weather data.

```
MO 79   150   466.  28.9  13.3   0.3
MO 79   151   466.  28.9  13.3   0.3
MO 79   152   617.  26.1  11.7   0.0
MO 79   153   705.  26.1  15.0   0.5
```

GENERAL OUTPUT FILE

The general output file (OYLD.DAT) contains the title of the experiment, the day of year on which the program begins (weather data begins), the cultivar name, the plant population, and the cultivar's genetic coefficients. This information is followed by soil characteristics including: soil albedo (SALB), upper limit of stage 1 soil evaporation (U), soil water conductivity (SWCON), and runoff curve number (CN2). The following information is then printed for each soil layer (and for the total profile when appropriate); lower and upper boundaries of the layer, lower limit of plant-extractable water (LL), drained upper limit (DUL), the soil water content at saturation (SAT), plant-extractable soil water (ESW), initial soil water content (SW), and the rooting preference factor (WR). All water contents are volumetric fractions.

In addition, the nitrogen version prints initial elemental nitrogen concentrations as ammonium (NH_4) and nitrate (NO_3) of each layer and of the whole profile.

Next, the day of the year and amount of each irrigation (mm) are printed by both model versions.

The nitrogen version of the model then prints the day of the year, and amount (kg elemental N/ha) and source of fertilizer nitrogen applied.

Both model versions next print a variety of information at the end of each growth stage. These data include the date, day of year, and description of each phenological event. The above-ground biomass (g/m^2), leaf area index (m^2 leaf area/m^2 ground area), cumulative evapotranspiration (ET, mm), plant transpiration (EP, mm), precipitation (PREC, mm), irrigation (IRRIG, mm), and plant-extractable soil water in the soil profile (PESW, cm) are then printed.

Next, the standard version prints simulated and measured days of silking and physiological maturity, grain yield (kg/ha at 15.5% water content), dry single kernel weight (g/kernel), grain number (grains/m^2 and grains/ear), maximum leaf area index, final above-ground biomass (kg/ha), and the water stress indices CSD1 and CSD2 for growth stages 1-5.

The nitrogen version also prints stover weight (kg/ha), grain nitrogen concentration (%), total plant nitrogen content (kg N/ha), grain nitrogen content (kg N/ha), and the nitrogen stress indices CNSD1 and CNSD2 for growth stages 1-5.

Examples of the printed general output files of the standard and nitrogen versions follow.

CERES MAIZE OUTPUT SUMMARY

MISSOURI, 1979 SW=UL, IRR PROGRAM BEGINS DAY 150

CULTIVAR B73 X MO17 POPULATION (PLANTS/M2) 5.70

GENETIC CONSTANTS

P1 220.00 P2 .52 P5 880.00 G2 730.00 G3 10.000

SALB .14 U 6.0 SWCON .30 CN2 60.0

DEPTH-CM	LL	DUL	SAT	ESW	SW	WR
0.- 15.	.160	.315	.370	.155	.315	.930
15.- 30.	.160	.315	.370	.155	.315	.700
30.- 50.	.160	.315	.370	.155	.315	.320
50.- 70.	.160	.315	.370	.155	.315	.100
70.- 94.	.160	.315	.370	.155	.315	.050
TOT PROF	15.0	29.6	34.8	14.6	29.6	

IRRIGATION (MM)

	1
DAY	187
AMOUNT	32.

WATER BALANCE COMPONENTS CUMULATIVE AFTER GERMINATION

DATE	DAY		BIOMASS	LAI	ET	ES	EP	PREC	PESW
5/30/79	150	SOWING							
5/31/79	151	GERMIN.			8.2	8.2	.0	.9	14.
6/ 5/79	156	EMERG.			7.0	7.0	.0	1.9	13.
6/20/79	171	END JUV.	14.	.31	36.9	29.1	7.8	39.5	12.
6/26/79	177	TAS.INIT.	37.	.66	52.6	32.6	20.0	42.1	11.
7/27/79	208	75% SILK	683.	3.64	193.9	65.9	128.0	131.9	3.
8/ 6/79	218	BEG.GR.F.	959.	3.30	244.1	77.5	166.6	289.7	5.
9/26/79	269	END GR.F.	1810.	.85	396.1	133.3	262.8	483.5	0.
9/28/79	271	PHYS.MAT.	1810.	.85	397.3	134.4	262.8	483.5	0.

	PREDICTED VALUES	MEASURED VALUES
SILKING DAY	208	207
MATURITY DAY	271	271
GRAIN KG/HA 15%	12030.	14291.
KERN WT G DRY	.3076	.3410
FINAL GPSM	3305.	0.
GRAINS/EAR	580.	621.
LAI AT SILKING	3.64	3.10
BIOMASS KG/HA	18098.	21190.

GROWTH STAGE	CSD1	CSD2
1	.00	.00
2	.00	.00
3	.00	.00
4	.00	.00
5	.45	.50

CERES-MAIZE OUTPUT SUMMARY NITROGEN VERSION
FLO,SC 81 SW=SPEC, IRR, FERT PROGRAM BEGINS DAY 60

CULTIVAR PIO 3382 POPULATION (PLANTS/M2) 7.10

GENETIC CONSTANTS
P1 200.00 P2 .70 P5 800.00 G2 650.00 G3 8.500

SALB .14 U 5.0 SWCON .60 CN2 60.0

DEPTH-CM	LL	DUL	SAT	ESW	SW	WR	NH4	NO3
0.- 10.	.075	.210	.250	.135	.189	1.000	2.00	5.00
10.- 20.	.075	.210	.250	.135	.189	1.000	2.00	5.00
20.- 41.	.100	.240	.290	.140	.228	.800	2.00	5.00
41.- 71.	.210	.310	.350	.100	.310	.400	2.00	5.00
71.- 101.	.210	.320	.360	.110	.320	.100	1.00	2.00
101.- 126.	.180	.280	.320	.100	.280	.100	1.00	2.00
126.- 151.	.180	.280	.320	.100	.280	.100	1.00	2.00
TOT PROF	25.2	42.1	48.4	16.9	41.5		43.	82.

IRRIGATION (MM)

	1	2	3	4	5	6	7	8	9	10	11	12
DAY	121	133	139	146	153	160	162	168	170	174	177	201
AMOUNT	14.	4.	14.	14.	6.	11.	27.	27.	27.	26.	26.	28.

	13
DAY	205
AMOUNT	27.

FERTILIZER NITROGEN (KG/HA)

	1	2	3
DAY	90	139	153
AMOUNT	66.7	66.7	66.7
SOURCE	CO(NH2)2	CO(NH2)2	CO(NH2)2

WATER BALANCE COMPONENTS CUMULATIVE AFTER GERMINATION

DATE	DAY		BIOMASS	LAI	N %	ET	EP	PREC	IRRIG	PESW
4/ 7/81	97	SOWING								
4/ 8/81	98	GERMIN.				61.	0.	63.	0.	16.
4/12/81	102	EMERG.				3.	0.	0.	0.	15.
4/29/81	119	END JUV.	16.	.33	2.55	35.	8.	26.	0.	14.
5/ 5/81	125	TAS.INIT.	37.	.67	3.40	59.	22.	26.	14.	13.
6/ 9/81	160	75% SILK	757.	3.94	2.16	211.	125.	156.	63.	15.
6/17/81	168	BEG.GR.F	1077.	3.59	2.23	260.	164.	172.	117.	16.
7/20/81	201	END GR.F	1992.	.88	1.31	442.	296.	328.	225.	14.
7/22/81	203	PHYS.MAT.	1992.	.88	1.31	447.	296.	328.	225.	13.

	PREDICTED	MEASURED
SILKING DAY	160	156
MATURITY DAY	203	210
GRAIN KG/HA 15%	11051.	11550.
KERN WT G DRY	.2618	.2760
FINAL GPSM	3567.	419.
GRAINS/EAR	502.	0.
LAI AT SILKING	3.94	4.20
BIOMASS KG/HA	19916.	23800.

	PREDICTED	MEASURED
STOVER KG/HA	10578.1	10954.0
GRAIN N%	1.72	1.62
TOTAL N KG/HA	221.0	248.0
GRAIN N KG/HA	161.0	158.0

GROWTH STAGE	CSD1	CSD2	CNSD1	CNSD2
1	.00	.00	.01	.08
2	.00	.00	.05	.19
3	.00	.00	.00	.01
4	.00	.00	.00	.00
5	.00	.00	.00	.03

BIOMASS OUTPUT FILE

The biomass output file (OBIO.DAT) is written in subroutine OUTGRO of both model versions. The output control number KOUTGR in the parameter file defines the interval at which output is written to OBIO.DAT. The following information is written to the file: day of year, the number of leaves that the plant has produced, leaf area index (m^2 leaf area/m^2 ground area), root weight (g/plant), stem weight (g/plant), grain weight (g/plant), leaf weight (g/plant), root depth (cm), and root length density (cm root/cm^3 soil) in the top five soil layers.

An example of the printed output from OBIO.DAT follows.

MISSOURI, 1979 SW=UL, IRR

DAY	LEAF	LAI	----- ORGAN WEIGHT ------				ROOT	--- ROOT LENGTH ---				
	NO.		ROOT	STEM	EAR	LEAF	DPTH	L1	L2	L3	L4	L5
		M2/M2	-------- G/PLANT --------				CM	----- CM/CM3 ------				
162	4	.04	.4	.0	.0	.2	30.	.1	.0	.0	.0	.0
169	7	.26	1.8	.0	.0	2.0	53.	.5	.3	.1	.0	.0
176	10	.66	6.8	.0	.0	6.5	77.	1.6	1.1	.4	.1	.0
183	12	1.36	14.3	.5	.0	15.7	94.	3.6	2.6	.9	.2	.1
190	15	2.18	22.2	4.3	.0	28.3	94.	5.0	4.1	1.4	.4	.1
197	18	3.10	29.9	26.7	.0	43.6	94.	5.0	5.0	2.0	.6	.2
204	21	3.47	39.2	52.7	.0	50.3	94.	4.9	5.0	3.8	1.2	.5
211	22	3.41	41.8	61.4	.0	53.2	94.	5.0	5.0	3.8	1.4	.5
218	22	3.27	50.0	69.2	5.5	53.2	94.	5.0	5.0	4.3	1.5	.6
225	22	3.14	53.5	69.2	40.9	53.2	94.	5.0	5.0	4.7	1.7	.7
232	22	2.55	51.6	58.3	64.5	53.2	94.	5.0	5.0	4.7	1.7	.7
239	22	2.06	50.9	51.4	89.8	53.2	94.	5.0	5.0	4.7	1.7	.7
246	22	1.97	49.7	46.0	125.5	52.7	94.	5.0	5.0	4.6	1.7	.7
253	22	1.95	49.9	49.8	159.7	52.7	94.	5.0	5.0	4.5	1.6	.7
260	22	1.40	48.2	44.3	172.0	51.1	94.	5.0	5.0	4.5	1.6	.7
267	22	.95	46.5	44.3	178.2	49.4	94.	5.0	5.0	4.5	1.6	.7

SOIL WATER OUTPUT FILE

The soil water output file (OWAT.DAT) is called in subroutine OUTWA if the switch ISWSWB in the parameter file is set to 1. This switch is not available in the nitrogen version. The output control number KOUTWA in the parameter file defines the interval at which ouput is written to OWAT.DAT. The following information is written to the file: day of the year, plant transpiration (EP, mm), evapotranspiration (ET, mm), potential ET (E0, mm), solar radiation (SR, cal/cm^2), maximum and minimum temperatures (TMAX and TMIN, °C) (average daily amounts for the interval), and total precipitation (PRECIP, mm) for the interval. In addition, the volumetric soil water content in each of the top five soil layers (L1-L5) and the total plant-extractable soil water in the soil profile (PESW, cm) are printed for the day of the output.

An example of the printed output is given below.

MISSOURI, 1979 SW=UL, IRR

DAY	EP (AVERAGE, MM)	ET (AVERAGE, MM)	EO (AVERAGE, MM)	SR (AVERAGE, LY)	TMAX (AVERAGE, C)	TMIN (AVERAGE, C)	PERIOD PRECIP MM	L1 (VOLUMET SOIL WATER, CM/CM)	L2	L3	L4	L5	TOTAL PESW CM
156	.0	2.2	5.2	524.	27.5	14.0	1.40	.28	.29	.30	.31	.31	13.2
163	.1	2.0	4.9	485.	28.4	15.3	14.00	.29	.30	.30	.30	.30	13.2
170	.8	1.9	6.0	571.	29.5	18.0	4.80	.27	.28	.29	.30	.30	12.3
177	2.0	2.6	5.2	525.	28.5	15.7	1.30	.23	.26	.28	.29	.29	10.6
184	2.7	4.3	4.5	454.	27.9	18.3	18.00	.20	.24	.27	.28	.29	9.4
191	2.5	4.0	4.0	420.	26.3	16.3	3.70	.24	.26	.27	.28	.28	10.2
198	4.7	5.7	5.7	560.	31.7	20.2	.00	.17	.19	.21	.26	.27	6.2
205	4.2	4.7	4.7	487.	30.1	17.8	.00	.15	.17	.18	.20	.23	2.9
212	3.1	3.8	3.8	382.	31.2	20.3	75.20	.34	.32	.19	.19	.21	7.8
219	4.4	5.8	5.8	575.	30.2	19.7	10.90	.21	.23	.21	.20	.21	4.8
226	4.0	4.9	5.3	512.	27.1	16.0	.00	.15	.16	.17	.18	.20	1.3
233	1.1	1.4	5.2	489.	28.7	18.0	.00	.14	.16	.16	.17	.18	.4
240	1.5	3.2	5.2	506.	28.2	16.4	20.00	.14	.16	.16	.16	.18	.1
247	2.5	4.3	4.3	410.	29.1	17.8	65.00	.26	.26	.17	.16	.18	3.6
254	3.2	4.5	5.0	499.	27.3	13.2	.00	.16	.17	.16	.16	.17	.4
261	.3	.9	4.7	506.	24.7	9.6	.00	.13	.16	.16	.16	.17	-.2
268	.5	1.3	4.8	504.	25.2	11.0	11.90	.15	.16	.16	.16	.17	.0

SOIL NITROGEN OUTPUT FILE

The soil nitrogen output file (ONIS.DAT) is written in subroutine OUTMN of the nitrogen version of the model. Data are printed at the interval specified by the output control number KOUTNB in the parameter file. If KOUTNB is set to zero, no output is produced.

The following data are printed: day of the year, total immobilization of mineral nitrogen, mineralization of nitrogen from the fresh organic N pool, and mineralization of nitrogen from the humus N pool (average daily amounts for the period). In addition, the concentrations of elemental nitrogen (g/Mg) as nitrate and ammonium are written for the top five soil layers.

An example of the printed output is given below.

FLO,SC 81 SW=SPEC, IRR, FERT

DAY	-- ORGANIC N -			------- NITRATE ------					------ AMMONIUM ------				
	IMOB	MIN	MINH	L1	L2	L3	L4	L5	L1	L2	L3	L4	L5
	- KG/HA	DAY -		-------- G/MG --------					-------- G/MG --------				
64	.8	.2	.0	3.9	5.4	5.2	4.9	2.1	.6	1.9	2.0	2.0	1.0
69	.1	.0	.0	3.9	5.2	5.1	4.8	2.3	.6	1.9	2.0	2.0	1.0
74	.1	.0	.0	4.0	5.1	5.1	4.7	2.4	.6	1.9	2.0	2.0	1.0
79	.1	.0	.0	3.8	5.2	5.1	4.6	2.4	.6	1.9	2.0	2.0	1.0
84	.0	.0	.0	2.5	5.2	5.6	4.5	2.5	.6	1.9	2.0	2.0	1.0
89	.1	.1	.0	2.3	5.4	5.5	4.4	2.7	.6	1.9	2.0	2.0	1.0
94	.2	.1	.0	16.9	5.4	5.7	4.3	2.8	34.6	1.8	2.0	2.0	1.0
99	.1	.1	.0	34.4	5.3	5.7	4.2	2.9	13.2	1.8	2.0	2.0	1.0
104	.1	.1	.0	41.5	5.1	5.7	4.2	2.9	3.9	1.8	2.0	2.0	1.0
109	.1	.1	.0	42.4	4.9	5.7	4.1	2.9	3.2	1.9	2.0	2.0	1.0
114	.1	.1	.0	29.4	14.3	6.9	4.0	3.0	3.0	1.9	2.0	2.0	1.0
119	.1	.1	.0	29.3	12.6	6.7	3.9	3.0	2.9	1.9	2.0	2.0	1.0
124	.1	.1	.0	24.3	12.9	6.5	4.0	3.3	2.5	1.9	2.0	2.0	1.0
129	.1	.1	.0	11.5	14.6	8.9	3.8	3.3	2.3	2.0	2.0	2.0	1.0
134	.1	.1	.0	8.9	11.4	8.1	3.7	3.3	2.2	2.0	2.0	2.0	1.0
139	.0	.1	.0	8.8	8.2	5.8	2.9	3.4	44.7	2.0	2.0	2.0	1.0
144	.1	.1	.0	23.0	6.9	6.2	3.0	3.7	14.6	2.0	2.0	2.0	1.0
149	.1	.1	.0	5.7	7.0	8.1	3.9	3.9	2.2	2.0	2.0	2.0	1.0
154	.1	.1	.0	3.0	2.8	4.1	2.9	3.8	40.5	2.0	2.0	2.0	1.0

NITROGEN MINERALIZATION OUTPUT FILE

The nitrogen mineralization output file (OMIN.DAT) is written in subroutines SOILNI and NBAL of the nitrogen version of CERES-Maize. Data are printed at the interval specified by the output control number, KOUTMN, in the parameter file. If KOUTMN is set to zero, no output is produced.

First, initial ammonium, nitrate, bulk density, and pH are written for each soil layer. Second, initial organic carbon, humus, and humic nitrogen contents are written for each layer. Third, the total surface residue, depth of residue incorporation, residue C:N ratio, residue nitrogen content, total root residue, root residue C:N ratio, and nitrogen content of root residue are written. Fourth, the rate constants used for decomposition of the carbohydrate, cellulose, lignin, and humus fractions of residue and soil organic matter are written.

Next, detailed information concerning nitrogen transformations in each layer is written at the interval specified by the output control number KOUTMN. The data written include: gross nitrogen immobilization in the profile, gross release of nitrogen from mineralization of fresh organic matter, and gross release of nitrogen from mineralization of soil humus (for the last day of the interval). Fresh organic nitrogen content (FON, kg/ha) and elemental nitrogen as nitrate (SNO3, kg/ha) and ammonium (SNH4, kg/ha) are written for each soil layer. Finally, total nitrification (NITRIF, kg/ha), leaching of NO_3 (LEACH, kg/ha), upward movement of NO_3 (UPFLUX, kg/ha), and plant nitrogen uptake (UPTK, kg/ha) for each soil layer during the specified interval are written.

An example of the printed output follows.

FLO,SC 81 SW=SPEC, IRR, FERT

INITIAL MINERAL N IN LAYERS

LAYER	DEPTH CM	--- AMMONIUM -- G/MG	KG/HA	--- NITRATE -- G/MG	KG/HA	BULK DEN.	PH
1	0. - 10.	2.0	3.1	5.0	7.8	1.55	6.0
2	10. - 20.	2.0	3.1	5.0	7.8	1.55	6.0
3	20. - 41.	2.0	7.0	5.0	17.5	1.67	6.2
4	41. - 71.	2.0	9.2	5.0	23.1	1.54	6.5
5	71. - 101.	1.0	4.6	2.0	9.2	1.54	6.7
6	101. - 126.	1.0	4.2	2.0	8.4	1.68	6.8
7	126. - 151.	1.0	4.3	2.0	8.7	1.74	6.8

INITIAL ORGANIC MATTER IN LAYERS

LAYER	DEPTH CM	ORGANIC CARBON %	HUMUS KG/HA	HUMIC N KG/HA
1	0. - 10.	.30	11625.0	465.0
2	10. - 20.	.30	11625.0	465.0
3	20. - 41.	.17	14904.8	596.2
4	41. - 71.	.01	1155.0	46.2
5	71. - 101.	.01	1155.0	46.2
6	101. - 126.	.01	1050.0	42.0
7	126. - 151.	.01	1087.5	43.5

FRESH ORGANIC MATTER

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TOTAL SURFACE RESIDUE(STRAW)      =  500.0  KG/HA
DEPTH OF INCORPORATION            =   10.0  CM
C:N RATIO OF STRAW                =   80.0
N IN STRAW                        =    2.5  KG N/HA

TOTAL ROOT RESIDUE                =  200.0  KG/HA
DISTRIBUTED ACCORDING TO F=EXP(-3*DEPTH/DEPMAX)
C:N RATIO OF ROOT RESIDUE         =   45.0
N IN ROOT RESIDUE                 =    1.8  KG N/HA
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MAXIMUM DECAY RATES OF OM FRACTIONS:
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                                         CARBOHYDRATE :    .800000
                                         CELLULOSE    :    .050000
                                         LIGNIN       :    .009500
                                         HUMUS        :    .000001


                         DAY  =  70

GROSS N IMMOBILIZATION IN PROFILE =      .07 KG N/HA DAY
GROSS N RELEASE FROM FRESH OM MINERALIZATION =      .04 KG N/HA DAY
N RELEASED FROM HUMUS =      .00 KG N/HA DAY
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LAYER	FON	SNO3	SNH4	NITRIF	LEACH	UPFLX	UPTK
1	5.4	6.1	1.0	.000	1.630	1.168	.000
2	.7	8.0	2.9	.000	.602	.010	.000
3	.4	17.9	6.9	.000	.000	-.868	.000
4	.2	22.2	9.2	.000	1.272	.159	.000
5	.1	10.8	4.6	.000	.288	-.075	.000
6	.1	8.2	4.2	.000	.403	-.002	.000
7	.0	8.6	4.3	.000	.351	.000	.000

PLANT NITROGEN OUTPUT FILE

The plant nitrogen output file (ONIP.DAT) is written in subroutine OUTNU of the nitrogen version of the model. Data are printed at the interval specified by the output control number KOUTNU in the parameter file. If KOUTNU is set to zero, no output is produced.

The following data are printed: actual and critical shoot nitrogen concentrations (%), the grain nitrogen content (%), the nitrogen demand of the crop (kg/ha), the nitrogen content of the total shoot and the nongrain portion of the shoot, and the plant extractable nitrogen as nitrate (NO_3, kg/ha) and ammonium (NH_4, kg/ha).

An example of the printed output follows.

FLO,SC 81 SW=SPEC, IRR, FERT

DAY	TOPS NITROGEN ACT	TOPS NITROGEN CRIT	GRAIN N	NITROGEN DEMAND	-- N UPTAKE -- TOTAL	-- N UPTAKE -- VEG TOP	PLANT EXTR N NO3	PLANT EXTR N NH4
	%			KG/HA				
108	7.62	4.43	.00	-.47	.02	1.28	73.39	7.81
115	3.86	4.16	.00	.22	2.50	2.78	90.57	14.34
122	3.30	3.90	.00	1.58	12.40	9.40	82.53	13.77
129	3.60	3.58	.00	1.94	24.92	18.98	89.23	22.76
136	3.35	3.31	.00	3.49	49.36	34.67	65.62	22.50
143	3.04	3.05	.00	5.47	83.74	61.68	90.45	54.83
150	2.78	2.77	.00	7.44	134.91	110.21	76.38	31.35
157	2.46	2.47	.00	6.12	177.74	152.22	86.28	57.58
164	2.35	2.15	.00	-5.54	199.17	173.05	86.79	35.90
171	2.17	1.85	1.79	-20.43	199.17	152.98	87.11	36.20
178	1.72	1.58	1.77	-5.18	202.60	116.88	82.86	36.36
185	1.40	1.40	1.74	2.33	219.64	100.09	66.10	35.87
192	1.21	1.23	1.75	3.40	243.27	87.26	41.93	35.71
199	.97	1.05	1.73	7.03	253.98	63.54	31.76	35.70

Table 2.3. Variables in the parameter file of the STANDARD version.

Variable	Columns	Format	Description
			LINE 1
TITLE	1-36	9A4	Title of treatment to be simulated
			LINE 2
ISOW	1-3	I3	Sowing date (day of year)
PLANTS	5-9	F5.2	Plant population (plants/m^2)
SDEPTH	11-15	F5.2	Sowing depth (cm)
LAT	17-21	F5.2	Latitude of location (degrees, negative for south)
KOUTWA	23-24	I2	Frequency in days of water balance output
KOUTGR	26-27	I2	Frequency in days of growth output
IIRR	29-30	I2	Switch or device number describing irrigation 0: No irrigation applied 1: Irrigation applied as specified by user
INSOIL	32-35	F4.2	Indicator for initial soil water 0.0: Set to lower limit (LL) 1.0: Set to drained upper limit (DUL) 0.0 < INSOIL<1.0: Set to LL + INSOIL*(DUL-LL) 1.0 < INSOIL: Initial soil water input by user
ISWSWB	37-38	I2	Switch for water balance 0: Water balance not used 1: Water balance used

Table 2.3. (cont.)

Variable	Columns	Format	Description
			LINE 3
NAME	1-16	4A4	Cultivar name
P1	18-21	F4.0	Growing degree days (base 8 C) from seedling emergence to the end of the juvenile phase (d °C)
P2	23-26	F4.3	Photoperiod sensitivity coefficient (1/hr)
P5	28-31	F4.0	Growing degree days (base 8 C) from silking to physiological maturity (d °C)
G2	33-37	F5.1	Potential kernel number (kernels/plant)
G3	39-43	F5.2	Potential kernel growth rate (mg/kernel d)
			LINE 4
ISLKJD	1-3	I3	Measured 50% silking date (day of year)
MATJD	5-7	I3	Measured physiological maturity date (day of year)
XYIELD	9-14	F6.0	Measured grain yield (kg/ha at 15.5% moisture)
XGRWT	16-19	F4.3	Measured kernel dry weight at maturity (g/kernel)
XGPSM	21-25	F5.0	Measured grain number at maturity (grains/m^2)
XGPE	27-30	F4.0	Measured grain number at maturity (grains/ear)
XLAI	32-35	F4.1	Measured maximum leaf area index (m^2/m^2)

Table 2.3. (cont.)

Variable	Columns	Format	Description
XBIOM	37–42	F6.0	Maximum above-ground biomass at maturity (kg/ha)
			LINE 5
SALB	1–3	F3.2	Soil albedo (unitless)
U	5–8	F4.1	Stage 1 soil evaporation coefficient (mm)
SWCON	10–13	F4.2	Whole-profile drainage rate coefficient
CN2	15–18	F4.1	Runoff curve number
			SOIL LAYER INFORMATION (one line per layer)
DLAYR	1–4	F4.1	Layer thickness (cm)
LL	6–9	F4.3	Lower limit of plant-extractable water (cm/cm)
DUL	11–14	F4.3	Drained upper limit (cm/cm)
SAT	16–19	F4.3	Water content at saturation (cm/cm)
WR	21–24	F4.2	Weighting factor for root distribution (unitless)
SW	26–29	F4.3	Initial water content (cm/cm)
			IRRIGATION INFORMATION (one line per irrigation)
JDAY	1–3	I3	Irrigation date (day of year)
AIRR	5–9	F5.1	Irrigation amount (mm)

Table 2.4. Variables in the parameter file of the NITROGEN version.

Variable	Columns	Format	Description
			LINE 1
TITLE	1-36	9A4	Title of treatment to be simulated
			LINE 2
ISOW	1-3	I3	Sowing date (day of year)
PLANTS	5-9	F5.2	Plant population (plants/m^2)
SDEPTH	11-15	F5.2	Sowing depth (cm)
LAT	17-21	F5.2	Latitude of location (degrees, negative for south)
DMOD	23-26	F4.2	Weighting factor to adjust the rate of humus mineralization for soils in which organic matter is chemically or physically protected, e.g., Oxisols and Ultisols - 0.6; Dystrandepts - 0.2; Other soils - 1.0
KOUTGR	28-29	I2	Frequency in days of growth output
KOUTMN	31-32	I2	Frequency in days of N mineralization output
KOUTNB	34-35	I2	Frequency in days of detailed N balance output
KOUTNU	37-38	I2	Frequency in days of plant N output
KOUTWA	40-41	I2	Frequency in days of water balance output

Table 2.4. (cont.)

Variable	Columns	Format	Description
IIRR	43-44	F4.0	Switch describing irrigation 0: No irrigation applied 1: Irrigation applied as specified by user 2-99: Automatic irrigation in the specified amount (mm)
INSOIL	46-49	F4.2	Indicator for initial soil water 0.0: Set to lower limit (LL 1.0: Set to drained upper limit (DUL) 0.0 <INSOIL < 1.0: Set to LL + INSOIL* (DUL-LL) 1.0 < INSOIL: Initial soil water input by user
			LINE 3
NAME	1-16	4A4	Cultivar name
P1	18-21	F4.0	Growing degree days (base 8 C) from seedling emergence to the end of the juvenile phase (d °C)
P2	23-26	F4.3	Photoperiod sensitivity coefficient (1/hr)
P5	28-31	F4.0	Growing degree days (base 8 C) from silking to physiological maturity (d °C)
G2	33-37	F5.1	Potential kernel number (kernels/plant)
G3	39-43	F5.2	Potential kernel growth rate (mg/kernel d)

Table 2.4. (cont.)

Variable	Columns	Format	Description
			LINE 4
ISLKJD	1-3	I3	Measured 50 % silking date (day of year)
MATJD	5-7	I3	Measured physiological maturity date (day of year)
XYIELD	9-14	F6.0	Measured grain yield (kg/ha at 15.5 % moisture)
XGRWT	16-19	F4.3	Measured kernel dry weight at maturity (g/kernel)
XGPSM	21-25	F5.0	Measured grain number at maturity (grains/m^2)
XGPE	27-30	F4.0	Measured grain number at maturity (grains/ear)
XLAI	32-35	F4.1	Measured maximum leaf area index (m^2/m^2)
XBIOM	37-42	F6.0	Measured above-ground dry biomass at maturity (kg/ha)
XSTRAW	44-49	F6.0	Measured stover dry weight at maturity (kg/ha)
GRPCTN	51-54	F4.2	Measured grain N concentration at maturity (%)
XTOTNP	56-59	F4.0	Measured crop N content at maturity (kg/ha)
XGNUP	61-64	F4.0	Measured grain N content at maturity (kg/ha)
			LINE 5
SALB	1-3	F3.2	Soil albedo (unitless)
U	5-8	F4.1	Stage 1 soil evaporation coefficient (mm)

Table 2.4. (cont.)

Variable	Columns	Format	Description
SWCON	10-13	F4.2	Whole-profile drainage rate coefficient
CN2	15-18	F4.1	Runoff curve number
TAV	20-23	F4.1	Mean annual air temperature (°C)
AMP	25-28	F4.1	Difference between highest and lowest mean monthly air temperatures (°C)
JDATE	30-32	I3	Day of year of the first day of weather data (day of year)
STRAW	34-38	F5.0	Residue weight (kg/ha)
SDEP	40-43	F4.1	Depth of residue incorporation (cm)
SCN	45-48	F4.1	Residue C:N ratio (kg C/kg N)
ROOT	50-54	F5.0	Root dry weight of previous crop (kg/ha)
RCN	56-59	F4.1	Root C:N ratio (kg C/kg N)
			SOIL LAYER INFORMATION (one line per layer)
DLAYR	1-4	F4.1	Layer thickness (cm)
LL	6-9	F4.3	Lower limit of plant-extractable water (cm/cm)
DUL	11-14	F4.3	Drained upper limit (cm/cm)
SAT	16-19	F4.3	Water content at saturation (cm/cm)
WR	21-24	F4.2	Weighting factor for root distribution (unitless)
SW	26-29	F4.3	Initial water content (cm/cm)

Table 2.4. (cont.)

Variable	Columns	Format	Description
OC	31-34	F4.2	Organic carbon concentration (%)
BD	36-39	F4.2	Moist bulk density (g dry soil/cm^3 moist volume of soil)
PH	41-44	F4.2	Soil pH in 1:1 soil:water slurry
NH4	46-49	F4.1	Initial soil ammonium concentration (mg elemental N as NH_4/kg dry soil)
NO3	51-54	F4.1	Initial soil nitrate concentration (mg elemental N as NO_3/kg dry soil)
		IRRIGATION INFORMATION (one line per application)	
JDAY	1-3	I3	Irrigation date (day of year)
AIRR	5-9	F5.1	Irrigation amount (mm)
		FERTILIZER INFORMATION (one line per application)	
JFDAY	1-3	I3	Fertilization date (day of year)
AFERT	5-9	F5.1	Fertilization amount (kg elemental N/ha)
DFERT	11-13	F3.0	Fertilization depth (cm)
IFTYPE	15-16	I2	Fertilizer type code 0 or 1: urea 2: ammonium nitrate 3: anhydrous ammonia 4: calcium ammonium nitrate 5: other nitrate salts

3. Model Inputs

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and P. T. Dyke

The CERES-Maize model is designed to use readily available or easily calculated inputs, which were briefly described in Chapter 2. This chapter gives simple methods for measuring or estimating a number of important soil and genetic variables.

SOIL WATER INPUTS

Certain variables used to simulate the soil water balance may be unfamiliar to many users. Procedures used to estimate these variables are given below. For comparison, typical values are given in the Appendix for 20 important agricultural soils in the United States.

Soil Albedo

Soil reflectivity or albedo (SALB) ranges from about 0.10 for dry, dark soils with high organic matter to about 0.30 for light desert sands, and it decreases slightly when the soil surface is wet (Monteith, 1973). The albedo of most agricultural soils can be estimated from Table 3.1. For all soils with less than 2% OM, multiply the albedo estimated from Table 3.1 by 0.9 if the soil is

Table 3.1. Estimation of soil albedo.

Organic Matter Content (OM)	Textures	Albedo
%		
OM > 10	all	0.08
10 > OM > 5	all	0.11
5 > OM > 2	all	0.13
2 > OM	sc, sicl, sic, c	0.12
"	sl, l, cl, scl, lcos, cos, s	0.13
"	sil, si	0.14
"	fsl	0.15
"	ls, cosl	0.16
"	vfsl	0.17
"	lfs, lvfs	0.18
"	fs, vfs	0.19

in the frigid or mesic temperature zones. Multiply the reported albedo by 1.1 if the soil is in the thermic or hyperthermic temperature zones.

Stage 1 Soil Evaporation Coefficient

The coefficient for the upper limit of stage 1 soil evaporation (U) varies from about 6 mm in sands and heavy shrinking clays to about 9 mm in loams and 12 mm in clay loams (Ritchie, 1972). The user can estimate an appropriate value based on the textural class of the top layer of soil.

Drainage Coefficient

The whole-profile drainage rate coefficient (SWCON) is used to estimate drainage from the profile. SWCON is first calculated for each soil layer (L) from the porosity (PO(L)) and drained upper limit (DUL(L)) of each layer:

$$PO(L) = 1.-BD(L)/2.65,$$
$$SWCON(L) = (PO(L)-DUL(L))/PO(L),$$

where BD(L) is the moist bulk density of the layer, and 2.65 is the approximate particle density. The whole profile SWCON is the minimum value of SWCON for all the layers.

Runoff Curve Number

The CERES-Maize model uses the "curve number" method for estimating runoff. This method (USDA, Soil Conservation Service, 1972) describes four hydrologic soil groups (Table 3.2) and assigns curve numbers to each group (Table 3.3). The user should choose the most appropriate value from these tables for the runoff curve number (CN2).

Soil Layer Thickness

Up to 10 soil layers may be identified. Users may wish to use horizons described in soil characterization data. However, three rules should be observed to insure an accurate soil water balance. First, the total pedon depth should be approximately 2.0 m unless bedrock or other impermeable layers occur at a shallower depth. Second, within the surface 30 cm, no soil layer should be thicker than 15 cm. Third, below the surface 30 cm, no soil layer should be thicker than 30 cm. These constraints are needed for accurate simulation of water infiltration and water extraction.

Table 3.2. Soil groups used to estimate the runoff curve number (CN2) (USDA, Soil Conservation Service, 1972).

Soil Group	Description
A	Lowest Runoff Potential. Includes deep sands with very little silt and clay, also deep, rapidly permeable loess.
B	Moderately Low Runoff Potential. Mostly sandy soils less deep than A, and loess less deep or less aggregated than A, but the group as a whole has above-average infiltration after thorough wetting.
C	Moderately High Runoff Potential. Comprises shallow soils and soils containing considerable clay and colloids, though less than those of group D. The group has below-average infiltration after presaturation.
D	Highest Runoff Potential. Includes mostly clays of high swelling percent, but the group also includes some shallow soils with nearly impermeable subhorizons near the surface.

Table 3.3. Runoff curve numbers (CN2) for hydrologic soil-cover complexes (for antecedent rainfall condition II, and $I_a = 0.2S$) (USDA, Soil Conservation Service, 1972).

Land Use or Cover	Treatment or Practice	Hydrologic Condition	Hydrolic Soil Group A	B	C	D
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Terraced	Poor	66	74	80	82
	Terraced	Good	62	71	78	81

Soil Water Contents

In the event that you do not want to use one of the representative soils provided in the Appendix, you can measure or calculate volumetric soil water content at saturation (SAT), at the drained upper limit (DUL), and at the lower limit (LL) of plant-extractable water. Ideally, these values would be obtained by allowing a well-developed maize crop to extract water from a plastic-covered plot (to prevent soil evaporation) until it is at the point of death due to drought stress. Volumetric soil water content (LL) is then determined for each soil layer to a depth of at least 2.0 m, or until an impermeable layer (bedrock) is reached. The plot is then irrigated until the entire profile is saturated, and SAT is measured for each soil layer. All plants are then removed, and the plot is recovered with plastic. The soil is allowed to drain for several days until a nearly stable volumetric water content (DUL) is reached.

If this procedure is not possible, the following algorithm can be used to estimate DUL and LL in each layer. The algorithm requires sand (SAN), silt (SIL), and clay (CLA) contents, bulk density (BD), and organic carbon (OC) content of each soil layer (I). The algorithm is not appropriate for organic soils or for highly weathered soils with large amounts of well aggregated 1:1 clays.

First, the porosity of each layer (PO) is calculated from bulk density (BD) measured at approximately -33 kPa using the equation:

PO(I) = 1.-BD(I)/2.65,

where 2.65 is mineral particle density. Next, a correction factor (XZ) for the lower density of organic matter is calculated:

XZ = OC(I)*0.0172,

where OC is the organic carbon concentration (%) of the layer. The maximum bulk density to which the layer could be compacted (BDM) is then calculated:

BDM(I) = (1.-XZ)/(1./BD(I)-XZ/0.224),

where BDM(I) is not allowed to exceed 2.5.

The effects of soil texture on LL(I) and DUL(I) are estimated with the variables W1 and W2, respectively. When sand content is greater than 75%:

```
W1 = 0.19-0.0017*SAN(I),
W2 = 0.429-0.00388*SAN(I).
```

When silt content is greater than 70%:

```
W1 = 0.16,
W2 = 0.1079+0.000504*SIL(I).
```

In other soils:

```
W1 = 0.0542+0.00409*CLA(I),
W2 = 0.1079+0.000504*SIL(I).
```

LL(I) and DUL(I) are then calculated.

```
LL(I) = W1*(1.-XZ)*(1.+BDM(I)-BD(I))+0.23*XZ
DUL(I) = LL(I)+W2*(1.-XZ)-(BDM(I)-BD(I))*0.2+0.55*XZ
```

SAT(I) can then be estimated with the following equation:

```
SAT(I) = K(PO(I)-DUL(I))+DUL(I),
```

where K = 0.5 for sandy and coarse loamy soils and 0.4 for other soils.

It is important to note that these algorithms were developed with data from mineral soils from temperate and subtropical regions. They may produce inaccurate estimates when applied to organic soils or to tropical soils with large amounts of low-activity clays.

Root Distribution Weighting Factor

The root distribution weighting factor (WR) is used to estimate the relative root growth in all soil layers in which roots actually occur. In deep, well-drained soils with no chemical or physical barriers to root growth, the following equation can be used to estimate WR for any soil layer:

WR(I) = EXP(-4.*Z(I)/200.),

where Z(I) is the depth (cm) to the center of layer I. In the top soil layer WR can be set to 1.0.

The user should reduce WR(I) to reflect physical or chemical constraints on root growth in certain soil layers. For example, WR(I) could be reduced to half the value estimated from the preceding equation when soil strength or aluminum toxicity produces moderate reductions in root growth. When these constraints are severe, calculated values of WR(I) can be reduced by 80% to 90%.

INITIAL SOIL NITROGEN INPUTS

The nitrogen version of the CERES-Maize models requires initial KCl-extractable ammonium (NH4, mg elemental N/kg dry soil), KCl-extractable nitrate (NO3, mg elemental N/kg dry soil), moist bulk density (BD, g/cm^3), soil organic carbon content (OC, %), and soil pH (PH, in 1:1 soil:water slurry). These initial values should be measured for the soil layers specified by the soil water file. Methods of sampling and analysis are given in Page et al. (1982).

The dry weight of crop residue on the soil surface (STRAW, kg/ha) and its C:N ratio (SCN, kg C/kg N) are also required. C:N ratios for maize stover normally range from approximately 30 to 100. In most cases the dry weight of root residue (ROOT) can be assumed to be 5% to 10% of the previous crop's final biomass. Root

C:N ratios (RCN) of maize and grain sorghum range from approximately 30 to 60 (Jones, 1983).[1]

GENETIC INPUTS

The CERES-Maize genetic inputs consist of the variables P1, P2, P5, G2, and G5, which are defined in Chapter 2.

P1 (growing degree days base 8°C (GDD_8) from seedling emergence to the end of the juvenile phase) ranges from about 110 to 355 and has been measured for a number of cultivars grown in controlled environments (Kiniry et al., 1983a, b) (Table 3.4). For other cultivars, P1 can be estimated. In the northern United States and Canada, P1 is approximately equal to the GDD_8 from seedling emergence (SE) to 4 days prior to tassel initiation (TI). In the United States Corn Belt, P1 is approximately the GDD_8 from SE to 5 days prior to TI. In the southern US, P1 is approximately the GDD_8 from SE to 6 days prior to TI. Typical values of P1 are 125 for southern Canada, 150 for the northern USA, 200 for the northern US Corn Belt, 210 for the central US Corn Belt, 220 for the southern US Corn Belt, 260 to 350 for the southern USA and tropical regions.

P2 (photoperiod sensitivity coefficient) ranges from zero to 0.8 (Table 3.4). Typical values are zero for cultivars grown in the northern United States and southern Canada, 0.3 to 0.4 for those in the northern and central US Corn Belt, 0.5 to 0.6 for the southern US Corn Belt, 0.75 for the southern United States, and 0.5 for the tropics. P2 is normally determined in controlled-environment studies, but the mean values given in Table 3.4 are adequate for most applications.

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[1] Sections of documentation that refer only to the nitrogen version are printed in bold type and are indented and single spaced.

P5 (GDD_8 from silking to physiological maturity) is approximately 685 for most cultivars that have been tested. However, it appears to be greater in a few cultivars from the southern United States and the tropics (Table 3.4). In the field, P5 can be calculated by summing daily values of GDD_8 between silking and physiological maturity.

G2 (potential kernel number) varies from about 560 to 834 kernels per plant (Table 3.4). In the field, G2 can be estimated from final kernel number on plants grown at low population densities with no water or nutrient stresses when mean daily temperatures are 20° to 30°C.

G5 (potential kernel growth rate) varies from approximately 6 to 11 mg/(kernel d) (Table 3.4). It can be estimated on plants grown at low population densities with no water or nutrient stresses. Mean temperatures during grain filling should be from 20° to 30°C. Kernel growth rates can be estimated by excising kernels from the middle portion of the ear at least three times, beginning approximately 10 days after silking and continuing until just prior to physiological maturity (Duncan and Hatfield, 1964).

Table 3.4. Genetic coefficients by cultivar and region.

Cultivar	P1	P2	P5	G2	G3
	SOUTHERN CANADA				
L281	110	0.30	—	—	6.60
CP170	120	0.00	—	—	—
F7 X F2	125	0.00	—	—	—
LG11	125	0.00	—	—	—
PI0 3995	130	0.30	—	—	8.60
	NORTHERN UNITED STATES				
INRA	135	0.00	—	—	—
EDO	135	0.30	—	—	—
A654 X F2	135	0.00	—	—	—
DEKALB XL71	140	0.30	—	—	—
F478 X W705A	140	0.00	—	—	—
DEKALB XL45	150	0.40	685	—	10.15
B59 X OH43	162	0.80	685	784	6.90
F16 X F19	165	0.00	—	—	—
B60 X R71	172	0.80	685	710	7.70
B59 X C103	172	0.80	685	825	10.15
R1 X (N32 X B14)	172	0.80	685	825	10.15
	NORTHERN NEBRASKA, IOWA, ILLINOIS, INDIANA				
B14 X C131A	180	0.50	685	—	10.15
B14 X C103	180	0.50	685	—	10.15
PI0 3720	180	0.80	685	825	10.00
A632 X W117	187	0.00	—	—	—
PI0 3382	200	0.70	800	650	8.50
PIO 3901	215	0.76	600	560	9.00
PI0 3780	200	0.76	685	600	9.60
C281	202	0.30	685	—	5.80

Table 3.4. (cont.)

Cultivar	P1	P2	P5	G2	G3
S. NEBRASKA, S. IOWA, S. ILLINOIS, S. INDIANA					
PI0 511A	220	0.30	685	645	10.50
PI0 3183	260	0.50	750	600	8.50
W69A X F546	240	0.30	—	—	—
A632 X VA26	240	0.30	—	—	—
W64A X W117	245	0.00	685	825	8.00
B14 X OH43	265	0.80	665	780	6.90
B8 X 153R	218	0.30	760	595	8.80
NEB 611	260	0.30	720	—	7.00
CENTRAL MISSOURI AND KANSAS TO NORTH CAROLINA AND SOUTHWARD					
PI0 3147	255	0.76	685	834	10.00
WF9 X B37	260	0.80	710	—	6.50
PV82S	260	0.50	750	600	8.50
PV76S	260	0.50	750	600	8.50
B73 X MO17	220	0.52	880	730	10.00
NC+59	280	0.30	750	—	10.00
B56 X C131A	318	0.50	700	805	6.40
MCCURDY 67-14	265	0.30	825	825	9.80
TROPICAL HYBRIDS					
H610	340	0.52	900	520	6.50
PIO X 304C	360	0.52	900	550	5.60

4. Subroutine Structure

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The CERES-Maize model is divided into a MAIN program and subroutines. The standard version consists of the MAIN program; two input/initialization subroutines (PROGRI and SOILRI); four process subroutines that simulate the soil water balance (WATBAL), phasic development (PHENOL and PHASEI), and growth (GROSUB); and four output subroutines (OUTWA, OUTGR, WRITE, and CALDAT).

> **The nitrogen version of the model has all the subroutines listed above as well as another input/initialization subroutine (SOILNI); seven more process subroutines that simulate mineralization-immobilization (MINIMO), nitrogen uptake (NUPTAK), nitrogen leaching and upward movement (NFLUX), plant nitrogen deficiency (NFACTO), denitrification (DNIT), nitrification (NITRIF), and soil temperature (SOLT); and four additional output subroutines (NWRITE, NBAL, OUTMN, and OUTNU).[1]**

[1] Sections of documentation that refer only to the nitrogen version are printed with bold type and are indented and single spaced.

In this section, subroutines are described in the order in which they occur in the model. In addition, equations are described in the same form (FORTRAN statements) and in approximately the same order in which they occur. This facilitates comparison of the text and the FORTRAN code.

MAIN PROGRAM

The CERES-Maize MAIN program opens input and output files and then calls subroutine PROGRI, which reads the program title and the first five lines of the parameter file. PROGRI also initializes numerous variables. Subroutine SOILRI is then called to read soil layer and irrigation information and to initialize soil variables (if the switch ISWSWB is not equal to zero).

The MAIN program now enters a daily loop that first reads the year (IYR), the day of the year (JDATE), solar radiation (SOLRAD), maximum air temperature (TEMPMX), minimum air temperature (TEMPMN), and precipitation (RAIN) from the weather file. On the first day of weather data (JDATEX = 367), subroutine CALDAT is called to calculate the month and day of the year from JDATE. Subroutine WATBAL is called to simulate the soil water balance if ISWSWB is not equal to zero. Subroutine PHENOL is called to calculate the rate of plant development if the crop has been planted but has not matured. The crop growth subroutine GROSUB is then called if the crop is growing (crop growth stage (ISTAGE) is less than 6).

Subroutine WRITE is now called to write daily climate, soil water, and crop growth data. The model then returns to the beginning of the daily loop.

In the nitrogen version, subroutine SOILNI is called to initialize soil nitrogen variables before the model enters the daily loop. Within the daily loop, subroutine MINIMO is called to simulate nitrogen mineralization and subroutine NWRITE is called to produce nitrogen-related output.

SUBROUTINE PROGRI

Subroutine PROGRI is called by the MAIN program on the first day of a simulation. Its primary purposes are to read the first five lines of the parameter file, read irrigation data, produce headings for the output file OYLD.DAT, and initialize a large number of variables.

The subroutine also calculates the eight 3-hourly correction factors for air temperature (TMFAC(I)) used in subroutines PHENOL and GROSUB.

TMFAC(I) = 0.931+0.114*I-0.0703*I**2+0.0053*I**3,

where I = 1, 8. It then returns to the MAIN program.

SUBROUTINE SOILRI

Subroutine SOILRI is called by the MAIN program on the first day of the simulation if the soil water balance switch (ISWSWB) is not equal to zero.

The following information is then read from the parameter file for any number of soil layers (NLAYR) up to 10: the thickness of the layer (DLAYR), the lower limit of plant-extractable soil water (LL), the drained upper limit (DUL), the soil water content at saturation (SAT), a root growth weighting factor (WR), and initial soil water content (SW). If INSOIL is greater than 1.0, SW(NLAYR) is read from the parameter file. If INSOIL is less than or equal to 1.0, initial soil water contents are calculated as follows:

SW(NLAYR) = LL(NLAYR)+(DUL(NLAYR)-LL(NLAYR))*INSOIL.

For layers at depths below 110 cm, initial SW may be set higher than that given by the previous equation because crops rarely extract all plant-available water below 110 cm.

Irrigation dates (JDAY(J)) and amounts (AIRR(J), mm) are read if the irrigation switch (IIRR) is not equal to zero.

The relative amount of plant-extractable soil water (SWR) is calculated for soil layer 1:

SWR = (SW(1)-LL(1))/(DUL(1)-LL(1)).

SWR is used to initialize SUMES2, the cumulative stage 2 soil evaporation. If SWR is less than 0.9,

SUMES2 = 25.-27.8*SWR.

SUMES1, the cumulative stage 1 soil evaporation, is set equal to U, the upper limit of stage 1 evaporation, and the time after the beginning of stage 2 evaporation (T) is calculated.

T = (SUMES2/3.5)**2

However, if SWR is not less than 0.9, SUMES2 and T are set to 0 and:

SUMES1 = 100.-100.*SWR.

The subroutine calculates initial values for the upper (DL1) and lower (DL2) depth limits of the soil layers and the plant-extractable soil water (ESW(L)) for each layer, where:

ESW(L) = DUL(L)-LL(L).

The subroutine then writes DL1, DL2, LL(L), DUL(L), SAT(L), ESW(L), SW(L), and WR(L) to the output file OYLD.DAT.

The cumulative depth of the profile (CUMDEP), total soil water in the profile (TSW), total plant-extractable soil water in the profile (TPESW), total soil water in the profile at the lower limit of plant-extractable water (TLL), total soil water in the profile at the drained upper limit (TDUL), and total soil water in the profile at saturation (TSAT) are calculated.

The weighting factor (WF(L)) used to determine run-off is calculated:

```
WX = 1.016*(1.-EXP(-4.16*CUMDEP/DEPMAX)),
WF(L) = WX-XX,
```

where XX is equal to zero in the surface soil layer and in other layers is equal to the value of WX in the layer above.

The depth of rooting (RTDEP) is set equal to DEPMAX, and the following total values for the profile are written to the output file OYLD.DAT: RTDEP, TLL, TDUL, TSAT, TPESW, and TSW.

CN1 and SMX, intermediate variables used to calculate runoff, are calculated from the curve number CN2.

```
CN1 = -16.91+1.348*CN2-0.01379*CN2**2+0.0001172*CN2**3
SMX = 254.*(100./CN1-1.)
```

SWEF, the minimum fraction of LL(1) to which soil evaporation can reduce SW(1), is calculated.

```
SWEF = 0.9-0.00038*(DLAYR(1)-30.)**2
```

Cumulative values of evapotranspiration (CET), soil evaporation (CES), transpiration (CEP), and precipitation (CRAIN) are set to zero. The soil water deficit factors SWDF1 and SWDF2 are set to 1.0, and the maximum root water uptake coefficient RWUMX is set to 0.03 cm^3/cm root.

The program now returns to the MAIN program.

SUBROUTINE WATBAL

Subroutine WATBAL is called daily by the MAIN program if the soil water switch (ISWSWB) is not equal to zero. Its two principal functions are to calculate the redistribution of water due to irrigation, precipitation, and drainage and to calculate potential evapotranspiration, soil evaporation and plant evaporation (transpiration).

> The nitrogen version must use subroutine WATBAL; therefore, it does not have switch ISWSWB.
>
> The nitrogen version has an automatic irrigation option. If IIRR in the parameter file is greater than 1., the model applies IIRR mm of irrigation water whenever the profile water content is more than IIRR mm drier than the profile drained upper limit.

If irrigation and/or precipitation occur on a day, the amount of irrigation (AIRR(J) or TIRR) and rainfall (RAIN) are summed in the PRECIP. The variables DRAIN (drainage from a layer), PINF (precipitation that infiltrates), RUNOFF (runoff), and WINF (water that infiltrates) are then set to zero. Runoff is calculated by the U.S. Soil Conservation Service (SCS) curve number method (USDA, Soil Conservation Service, 1972). A weighted sum (SUM) (weighted for soil depth by the factor WF(L) from subroutine SOILRI) of the relative amount of plant-extractable soil water in the profile is calculated. The SCS curve number soil profile water retention parameter (R2) is then calculated from SUM and the maximum value of R2 (SMX) from subroutine SOILRI.

R2 = SMX*(1.-SUM)

SMX is calculated in subroutine SOILRI. The minimum value of R2 allowed is 2.54 mm.

No runoff occurs if a temporary variable (PB) is less than zero, where:

PB = PRECIP-0.2*R2.

That is, no runoff occurs if precipitation is less than 0.2*R2. If runoff occurs, it is calculated as follows:

RUNOFF = PB*PB/(PRECIP+.8*R2).

Potential infiltration into the soil layer (PINF) is calculated.

PINF = PRECIP-RUNOFF

Drainage and soil water redistribution are calculated next. Note that the units used in the runoff calculations are mm while those used in the drainage and potential evaporation calculations are cm. A loop is used to move water downward through successive soil layers. The amount of water moving downward into a layer is PINF.

In the nitrogen version FLUX(L) is used instead of PINF for water infiltrating or draining into a layer.

FLUX(L) is needed for each soil layer in subroutine NFLUX to estimate leaching of nitrate.

If infiltration occurs, the amount of water that the layer can hold (HOLD) between the current volumetric water content (SW(L)) and saturation (SAT(L)) is calculated.

HOLD = (SAT(L)-SW(L))*DLAYR (L)

If PINF is less than or equal to HOLD, a new value of SW(L) prior to drainage is calculated.

SW(L) = SW(L)+PINF/DLAYR(L)

If this new SW(L) is less than the drained upper limit of volumetric soil water in the layer (DUL(L)) plus 0.003, no drainage occurs. If the new SW(L) is greater than (DUL(L)+0.003), drainage by nonsaturated flow (DRAIN) from the layer is calculated from SW(L), DUL(L), DLAYR(L), and SWCON (the whole-profile drainage rate constant).

DRAIN = (SW(L)-DUL(L))*SWCON*DLAYR(L)

A post-drainage value of SW(L) is now calculated:

SW(L) = SW(L)-DRAIN/DLAYR(L),

and a new value of PINF (representing water moving into the layer below) is set equal to DRAIN.

If the initial value of PINF is greater than HOLD, the water in excess of HOLD (PINF-HOLD) is passed directly to the layer below (by saturated flow), and DRAIN (unsaturated flow) is calculated as follows:

DRAIN = SWCON*(SAT(L)-DUL(L))*DLAYR(L).

Thus, the new value of PINF (representing water moving into the layer below that in question) is the sum of movement from the layer by both saturated and unsaturated flows.

After movement through all soil layers has been calculated, any drainage from the bottom layer of the profile is set equal to PINF. For convenience, this value (times 10.0 to convert it to mm) is set equal to DRAIN, which then represents total saturated and unsaturated flow out of the lowest layer of the soil profile.

In the nitrogen version, subroutines NFLUX and DNIT are called if drainage occurs from any soil layer.

Subroutine WATBAL also contains calculations of potential soil evaporation and potential evapotranspiration. The units of all evaporation calculations are mm. The first calculation estimates the mean temperature during the daylight hours (TD), when both soil and plant evaporation are greatest. TD is a weighted mean of daily maximum (TEMPMX) and minimum (TEMPMN) air temperatures.

TD = 0.60*TEMPMX+0.40*TEMPMN

The integrated crop and soil albedo (ALBEDO) is then calculated from bare soil albedo (SALB) and LAI. If the crop is not growing, ALBEDO is equal to SALB. If the crop is growing,

ALBEDO = 0.23-(0.23-SALB)*EXP(-0.75*LAI).

The equilibrium evaporation rate (EEQ) is then calculated from solar radiation (SOLRAD), ALBEDO, and TD.

EEQ = SOLRAD*(2.04E-4-1.83E-4*ALBEDO)*(TD+29.)

Potential evapotranspiration (EO) is then estimated as a function of TEMPMX. If TEMPMX is between 5.0° and 35.0°C,

EO = EEQ*1.1.

However, if TEMPMX is greater than 35.0°,

EO = EEQ*((TEMPMX-35.)*0.05+1.1),

and if TEMPMX is less than 5.0°,

EO = EEQ*0.01*EXP(0.18*(TEMPMX+20.)).

These equations increase the coefficient relating EEQ to EO to 1.35 when TEMPMX is 40.0°C, and they reduce the coefficient to 0.5 when TEMPMX is 2.0°C.

The potential rate of soil evaporation (EOS) is the following when LAI is less than 1.0:

EOS = EO*(1.-0.43*LAI).

If LAI is greater than 1.0,

EOS = EO/1.1*EXP(-0.4*LAI).

Actual soil evaporation is now calculated according to the method of Ritchie (1972), which is based on two stages of soil evaporation. During stage 1, actual soil evaporation (ES) is limited by energy available for evaporation at the soil surface. This stage continues until a soil-dependent upper limit of stage 1 evaporation

(U) is reached. Soil evaporation then enters stage 2, in which ES is a declining function of time since the beginning of stage 2. The variables SUMES1 and SUMES2 are the sums of ES in stages 1 and 2, respectively, and they are used to determine which stage of soil evaporation is occurring on a day.

If rainfall and/or irrigation occurs on a day and infiltration into the upper layer (WINF) is greater than or equal to SUMES1, SUMES1 is set back to zero. If WINF is less than SUMES1, SUMES1 is updated as follows:

SUMES1 = SUMES1-WINF.

Whenever SUMES1 is less than U, SUMES1 is updated daily according to the following equation:

SUMES1 = SUMES1+EOS.

If the new value of SUMES1 is less than or equal to U,

ES = EOS.

If the new value of SUMES1 exceeds U,

ES = EOS-0.4*(SUMES1-U),

where SUMES1 is the new value of SUMES1.

When this occurs, SUMES2 is calculated as follows:

SUMES2 = 0.6*(SUMES1-U),

and the time after stage 2 evaporation begins (T) is calculated.

T = (SUMES2/3.5)**2.

As the soil continues to dry during stage 2 evaporation, T increases by 1. each day, and ES is calculated as follows.

ES = 3.5*T**0.5-SUMES2

Of course, if ES calculated in this manner is greater than EOS, ES is set equal to EOS.

If rainfall and/or irrigation wet the soil surface slightly but WINF is less than SUMES2, ES is the minimum of the following: EOS, (0.8*WINF), or (ES+WINF).

If during stage 2 evaporation, rainfall and/or irrigation wet the soil surface slightly more and WINF exceeds SUMES2, the model resets T to zero and recalculates SUMES1:

SUMES1 = U+SUMES2-WINF.

The model then calculates stage 1 evaporation as described earlier.

After ES has been determined, it is converted to volumetric water content and subtracted from the volumetric water content of soil layer 1 (SW(1)). However, ES is not allowed to reduce SW(1) below LL(1)*SWEF, where SWEF is the minimum soil water content of layer 1 calculated in subroutine SOILR1.

Upward or downward flow of water due to unsaturated flow at soil water contents between the lower limit and the drained upper limit is now calculated. The variables THET1 and THET2 represent the amount of volumetric soil water above the lower limit in layers L and (L+1), respectively. Water movement (FLOW) is calculated with the following equations.

DBAR = 0.88*EXP(35.4*(THET1+THET2)*0.5)

FLOW = DBAR*(THET2-THET1)/((DLAYR(L)+DLAYR(M))*0.5)

If THET1 is greater than THET2, FLOW is a negative number, and water moves downward. If THET1 is less than THET2, FLOW is positive, and water moves upward. Volumetric soil water in layers L and (L+1) are then increased and decreased, respectively, by the amount of FLOW.

In the nitrogen version, FLOW(L) is calculated for each layer, and it is used in subroutine NFLUX, which is called at this point.

Transpiration by the crop (EP) is calculated (if the crop is growing). If LAI is less than or equal to 3.0,

EP=EO*(1.-EXP(-LAI)).

If LAI is greater than 3.0,

EP = EO.

However, if EP+ES is greater than EO,

EP = EO-ES.

Root growth and water uptake are now calculated for each soil layer in order to update volumetric soil water. The first calculation is the conversion of the daily growth of the root system (GRORT, g/plant) to root length (RLNEW, cm root/cm^2 soil surface area).

RLNEW = GRORT*0.80*PLANTS,

where PLANTS is plant population (plants/m^2).

A loop is used to calculate a zero-to-unity root length density factor for root growth in each layer (RLDF(L)). It is calculated from the soil water deficit factor for root growth in that layer (SWDF) and a root growth weighting factor (WR(L)) for soil depth (read in the parameter file).

RLDF(L) = SWDF*WR(L)

For a layer, SWDF is 1.0 unless the volumetric soil water (SW(L)) declines below 0.25 of plant-extractable soil water for that layer (ESW(L)). In that case,

SWDF = 4.*(SW(L)-LL(L))/ESW(L).

In the nitrogen version, RLDF(L) is calculated as follows:

RLDF(L) = AMIN1(SWDF,RNFAC(L))*WR(L),

where RNFAC is a zero-to-unity root growth factor dependent on mineral N availability (from subroutine NUPTAK).

Rooting depth (RTDEP) is also updated daily in this loop.

RTDEP = RTDEP+DTT*0.22*AMIN1((SWDF1*2.0),SWDF),

where DTT is daily accumulation of growing degree days, and SWDF1 is the soil water deficit factor for photosynthesis and transpiration, and SWDF refers to the deepest layer in which roots are growing. This equation allows air temperature, soil profile water content, and soil water in the deepest layer in which roots are growing to affect the daily increase in rooting depth. A maximum rooting depth (DEPMAX) equal to the depth of the soil profile read in subroutine SOILRI also constrains RTDEP.

RLDF(L) of the deepest layer in which roots are growing is adjusted for the fraction of that layer that has been explored:

RLDF(L) = RLDF(L)*(1.-(CUMDEP-RTDEP)/DLAYR(L)),

where CUMDEP is the cumulative depth of all layers in which roots occur.

A total root length density factor (TRLDF) for root growth is calculated by summing RLDF(L) for each layer in which roots occur.

TRLDF = TRLDF+RLDF(L)

When a layer deeper than the rooting depth is reached, the loop is exited.

A factor used to distribute newly formed root length throughout the soil profile (RNLF) is calculated from the amount of new root length per unit area of soil and TRLDF.

RNLF = RLNEW/TRLDF

Root length density in each layer (RLV(L)) is updated by adding new root length (RLDF(L)*RNLF/DLAYR(L)) and subtracting root senescence (0.005*RLV(L)).

RLV(L) = RLV(L)+RLDF(L)*RNLF/DLAYR(L)-0.005*RLV(L)

Root length density in any layer is constrained between 0.0 and 5.0 cm root/cm^3 soil.

> In the nitrogen version, the ammonium pool of each layer (SNH4(L)) is updated for the NH_4 released because of root death.
>
> SNH4(L) = SNH4(L)+RNLOSS(L)*PLANTS*10.,
>
> where RNLOSS(L) is the amount of nitrogen lost in a layer by each plant, which is calculated in subroutine NUPTAK.

Subroutine WATBAL now calculates water uptake from each soil layer. The amount of water removed from the profile is the minimum of: (1) the total potential root water uptake for all layers (RWU(L)) or (2) the potential transpiration (EP1). Since the units of soil water uptake are cm and those of transpiration are mm, the value of transpiration (EP1) used for water extraction is calculated.

EP1 = EP*0.1

The maximum rate of water uptake per unit root length (RWUMX) was defined in subroutine SOILRI as 0.03 cm^3/cm root. However, potential root water uptake per unit root length may be limited by soil water content.

RWU(L) = 2.67E-3*EXP(62.*(SW(L)-LL(L)))/(6.68-ALOG(RLV(L)))

If RWU(L) is greater than RWUMX, RWU(L) is set equal to RWUMX. RWU(L) is then converted to units of cm uptake/layer.

RWU(L) = RWU(L)*DLAYR(L)*RLV(L)

Finally, potential root water uptake from the profile (TRWU) is calculated by summing RWU(L) for all soil layers.

If transpiration (EP1) is less than or equal to TRWU, the zero-to-unity water use factor (WUF) is calculated.

WUF = EP1/TRWU

WUF is then used to reduce RWU(L) throughout the soil profile to the rate of transpiration.

RWU(L) = RWU(L)*WUF

This system allows either EP1 or the summation of all RWU(L) to limit transpiration. Actual soil water in each layer after the day's transpiration (SW(L)) is updated.

SW(L) = SW(L)-RWU(L)/DLAYR(L)

The total soil water in the profile (TSW) is calculated by summing (SW(L)*DLAYR(L)) for all soil layers.

Total plant-extractable soil water (PESW) for the profile is the difference between TSW and the amount of water in the profile when all layers are at the lower limit of plant-extractable water (TLL).

Two zero-to-unity soil water deficit factors used in subroutine GROSUB are calculated. The less sensitive (SWDF1) is used to affect photosynthesis.

SWDF1 = TRWU/EP1

The more sensitive factor (SWDF2) affects plant cell expansion and is less than 1.0 whenever TRWU/EP1 is less than 1.5.

SWDF2 = 0.67*TRWU/EP1

Whenever EP1 is greater than TRWU, plant evaporation (expressed in mm) is set equal to TRWU, and total evapotranspiration (ET) is recalculated.

ET = ES+EP

Finally, stress-day factors used to evaluate stress during the various growth stages are calculated.

CSD1 = CSD1+1.0-SWDF1
CSD2 = CSD2+1.0-SWDF2

The model then returns to the MAIN program.

SUBROUTINE PHENOL

This subroutine is first called by the MAIN program on the day of sowing (JDATE.EQ.ISOW) and thereafter until the crop is mature. It uses temperature, photoperiod, and genetic characteristics to determine the date the crop begins a new growth stage. It calls subroutine PHASEI to update development-related variables whenever the crop begins a new growth stage. PHASEI also writes the date and summary information on crop production during the previous growth stage.

First, the mean temperature (TEMPM) experienced by the plant is calculated from the maximum (TEMPMX) and minimum (TEMPMN) screen air temperatures.

TEMPM = (TEMPMX+TEMPMN)/2.

Growing degree day (DTT) accumulation is then calculated from TEMPM and a base temperature specified in subroutine PHASEI. This base temperature is 10°C from germination to emergence, and it is 8°C thereafter. If both TEMPMN and TEMPMX are between the base temperature and 34°C, DTT is calculated.

DTT = TEMPM-TBASE

If TEMPMN is less than TBASE or if TEMPMX is above 34°C, eight interpolations of air temperature (TTMP) are calculated using the three-hour temperature correction factor (TMFAC(I)) from subroutine PROGRI.

TTMP = TEMPMN+TMFAC(I)*(TEMPMX-TEMPMN)

For each value of TTMP, a three-hour value of DTT is calculated. If TTMP is between the base temperature and 34°C, DTT is calculated as follows:

DTT = TTMP - TBASE.

DTT is zero when TTMP is less than the base temperature or is greater than 44.0. When TTMP is between 34.0 and 44.0, DTT is calculated as follows:

DTT = (34.-TBASE)*(1.-(TTMP-34.)/10.).

The eight three-hour estimates of DTT are then averaged to obtain the daily value of DTT.

Two variables (SUMDTT and CUMDTT) are used to accumulate DTT. CUMDTT is cumulative daily DTT after seedling emergence. SUMDTT is also cumulative daily DTT, but it is reset to zero at seedling emergence, tassel initiation, and silking. SUMDTT is used to determine the duration of growth stages. CUMDTT is used only in output to indicate the total DTT that has accumulated since seedling emergence.

Subroutine PHENOL is divided into nine parts (ISTAGE) representing the different growth stages of the crop as well as the presowing period.

ISTAGE = 7 (Presowing)

The subroutine is first called by the MAIN program on the sowing date. It then writes the sowing date and other information, calls subroutine PHASEI to update development-related variables, sets a day counter (NDAS) to zero, and determines the soil layer (L0) in which the seed is sown.

ISTAGE = 8 (Sowing to Germination)

If ISTAGE is equal to 8, the subroutine determines whether soil water content is sufficient to allow germination. For germination to occur, one of two conditions must be met. Either the soil water content of the layer where the seed is sown (layer L0) must be greater than the lower limit (SW(L0).GT.LL(L0)) or a weighted average of the water content in layers L0 and L0 + 1 must be adequate for germination. To determine whether the latter is true, the variable SWSD is calculated.

$$SWSD = (SW(L0)-LL(L0))*0.65+(SW(L0+1)-LL(L0+1))*0.35$$

Germination occurs if SWSD is greater than or equal to 0.02.

If the soil is too dry for germination to occur, the day counter NDAS is used to calculate days since sowing. If NDAS reaches 40 before germination occurs, a crop failure is assumed and the message "crop failure because of lack of germination within 40 days of sowing" is written.

When germination occurs, the date and associated information are written, and subroutine PHASEI is called to update the appropriate development-related variables.

ISTAGE = 9 (Germination to Emergence)

Prior to seedling emergence, root depth (RTDEP, cm) increases daily as a function of DTT.

RTDEP = RTDEP+0.15*DTT

Seedling emergence occurs when the growing degree days summation variable SUMDTT reaches P9, whose value is determined from planting depth in subroutine PHASEI. When germination occurs, the date and associated information are written, and subroutine PHASEI is called to update the appropriate development-related variables.

ISTAGE = 1 (Emergence to End of Juvenile Stage)

At emergence ISTAGE is set to 1 in subroutine PHASEI. P1 is the number of growing degree days from emergence to the end of the juvenile stage. It is a genotype-specific coefficient that is read in subroutine PROGRI from the parameter file. The end of the juvenile stage occurs when SUMDTT equals or exceeds P1.

> In the nitrogen version, XSTAGE, the growth stage of the crop used to calculate crop nitrogen demand (Hanway, 1963), is calculated. XSTAGE is zero at emergence and 1.0 at the end of the juvenile stage:
>
> XSTAGE = SUMDTT/P1.

At the end of the juvenile stage, the date and associated information are written, and subroutine PHASEI is called to update the appropriate development-related variables.

ISTAGE = 2 (End of Juvenile Stage to Tassel Initiation)

At the end of the juvenile stage, ISTAGE is set to 2 in subroutine PHASEI.

> In the nitrogen version, XSTAGE, the growth stage of the crop used to calculate nitrogen demand, is 1.0 at the beginning of ISTAGE 2 and is 1.5 at the end. It is calculated from the temporary variable SIND, which is discussed later in this section.
>
> XSTAGE = 1.0+0.5*SIND

Photoperiod in hours (HRLT) is calculated from the day of the year (JDATE) with a series of three equations:

DEC = 0.4093*SIN(0.0172*(JDATE-82.2)),
DLV = (-S1*SIN(DEC)-0.1047)/(C1*COS(DEC)),
HRLT = 7.639*ACOS(DLV),

where DEC is solar declination (radians). The variables S1 and C1, which are calculated in subroutine PROGRI, are the SIN and COS of the latitude (LAT).

The rate of floral induction (RATEIN) is then calculated from HRLT and the genotype-specific constant P2 (read from the parameter file).

RATEIN = 1./(4.+P2*(HRLT-12.5))

For purposes of this calculation, HRLT is not allowed to be less than 12.5 h.

RATEIN is summed daily with the temporary variable SIND. When SIND reaches 1.0, ISTAGE 2 ends. The date and associated information are written, and subroutine PHASEI is called to update the appropriate development-related variables.

ISTAGE = 3 (Tassel Initiation to End of Leaf Growth and Silking)

After tassel initiation, ISTAGE is set to 3 in subroutine PHASEI.

> In the nitrogen version, XSTAGE is calculated from P3 (from subroutine PHASEI) and SUMDTT, the cumulative growing degree days (DTT) since the beginning of ISTAGE 3.
>
> XSTAGE = 1.5+3.0*SUMDTT/P3
>
> Thus, XSTAGE varies from 1.5 at the beginning of ISTAGE 3 to 4.5 at its end.

When SUMDTT equals or exceeds P3, ISTAGE 3 ends. The date of silking (ISDATE) and the maximum leaf area index (MAXLAI) are set equal to the values of JDATE and LAI, respectively, on that day. The date and associated information are written and subroutine PHASEI is called to update the appropriate development-related variables.

ISTAGE = 4 (Silking to Beginning of Effective Grain Filling Period)

After silking, ISTAGE is set to 4 in subroutine PHASEI.

> In the nitrogen version, XSTAGE is calculated from the genotype-specific constant P5 and SUMDTT for ISTAGES 4 and 5. P5 is the number of GDD_8 from silking until physiological maturity from the parameter file. SUMDTT is the cumulative DTT since silking.
>
> XSTAGE = 4.5+5.5*SUMDTT/P5

ISTAGE 4 ends when SUMDTT equals or exceeds 170.0. When this occurs, the number of grains/plant (GPP) and the number of ears/m^2 (EARS) are calculated. GPP is calculated from a genotype-specific constant for potential kernel number (G2) (read from the genetics file) and the average rate of photosynthesis (PSKER) during ISTAGE 4.

```
PSKER = SUMP*1000./IDURP*3.4/5.0,
```

where SUMP is cumulative photosynthesis during ISTAGE 4 and IDURP is the duration of ISTAGE 4 (both calculated in subroutine GROSUB). The function used to predict GPP is derived from Edmeades and Daynard (1979).

```
GPP = G2*(PSKER-195.0)/(1213.2+PSKER-195.0)
```

Grain numbers are sensitive to nitrogen deficiency occurring after silking. In subroutine GROSUB of the nitrogen version, GPP may be further reduced by postsilking nitrogen deficiency.

Barrenness can occur when stresses severely reduce grain numbers. In this model, when GPP is at least 55% of the potential (0.55*G2), there is no barrenness. When GPP is less than 55%, the number of ears/m^2 is reduced below the number of plants/m^2.

```
EARS = PLANTS*((GPP-50.)/(G2-50))**0.33
```

If GPP is less than 50, total barrenness is assumed. The number of grains/m^2 (GPSM) is then calculated.

```
GPSM = GPP*EARS
```

Finally, the date and associated information are written, and subroutine PHASEI is called to update the appropriate development-related variables.

ISTAGE = 5 (Effective Grain Filling Period)

At the beginning of the effective grain filling period ISTAGE is set to 5 in subroutine PHASEI. ISTAGE 5 ends when SUMDTT equals or exceeds (P5*0.95). On that day, the date and associated information are written, and subroutine PHASEI is called to update the appropriate development-related variables.

ISTAGE = 6 (End of Effective Grain Filling Period to Physiological Maturity)

Physiological maturity occurs when SUMDTT equals or exceeds P5 or when daily growing degree day accumulation (DTT) during ISTAGE 6 is less than 2.0 for one day. The latter option allows physiological maturity to occur even when low temperatures during ISTAGE 6 prevent accumulation of sufficient DTT.

When physiological maturity occurs, the date and final yield information are calculated and written. Grain yield is reported at 15.5% moisture both in kg/ha (YIELD) and in bushels/acre (YIELDB). The protein concentration in the grain (XPTN) is assumed to be 6.25 times the grain N concentration (XGNP). Subroutine PHASEI is then called to update appropriate development-related variables.

SUBROUTINE PHASEI

Subroutine PHASEI is called by subroutine PHENOL whenever the crop completes a growth stage (ISTAGE). Subroutine PHASEI then initializes variables that are used in the following growth stage. For example, ISTAGE is updated each time subroutine PHASEI is called.

Several important variables are initialized or calculated in this subroutine. For example, when ISTAGE 9 (germination to emergence) begins, the base temperature (TBASE) is set to 10°C, and the minimum growing degree day (DTT) requirement for emergence (P9) is calculated from sowing depth (SDEPTH, cm).

P9 = 15.+6.*SDEPTH.

At the beginning of ISTAGE 1 (emergence to end of juvenile stage), the base temperature is set to 8°C. This base temperature is used for all succeeding growth stages.

When ISTAGE 3 begins (at tassel initiation), the total number of leaves that will eventually emerge (TLNO) is calculated:

TLNO = IFIX(SUMDTT/21.+6.0),

where SUMDTT is cumulative DTT since emergence and IFIX is the FORTRAN function that converts real values to integers by rounding down to the next integer. This equation implies that six leaf primordia are present at seedling emergence, and one leaf primordium is initiated each 21 growing degree days (Kiniry and Ritchie, 1981; Warrington and Kannemasu, 1983). Cumulative DTT required to complete ISTAGE 3 (P3) is calculated from the DTT required for the collars of all leaves to appear.

P3 = (TLNO–2.)*38.9+96.–SUMDTT

SUMDTT is cumulative DTT since emergence. This equation implies that 38.9 DTT are required for the emergence of each leaf tip except the first two (Kiniry and Ritchie, 1981; Tollenaar et al., 1979). The second leaf emerges 20 DTT after emergence, and the collar of the last leaf appears 76 DTT after its tip. Silking is assumed to occur when the last leaf collars.

When ISTAGE 4 begins, initial ear weight (EARWT) and minimum stem weight (SWMIN) are calculated from stem weight (STMWT).

```
EARWT = 0.167*STMWT
STMWT = STMWT-EARWT
SWMIN = STMWT*0.8
```

The value of SWMIN is based on work by Hanway and Russell (1969) and Heuer (1982), which showed that by the end of grain filling the dry weight of the stem can decrease to 80 % of its value at silking.

When ISTAGE 5 begins, the maximum stem weight (SWMAX) allowed during grain filling is set equal to the present value of STMWT. Also, the minimum leaf weight allowed during grain filling is calculated.

```
LWMIN = LFWT*0.85
```

SUBROUTINE GROSUB

This subroutine is called from the MAIN program and calculates leaf area development, light interception, photosynthesis, and partitioning of biomass into various plant parts.

In the nitrogen version of the model, subroutine NFACTO is called to calculate nitrogen deficiency factors that modify crop growth.

Biomass production for the day (CARBO) is then calculated with a series of three equations. First, photosynthetically active radiation (PAR, MJ/m^2) is calculated from daily solar radiation (SOLRAD, langleys or cal/cm^2).

PAR = 0.02*SOLRAD

The constant 0.02 consists of a conversion factor from cal/cm^2 to MJ/m^2 (0.04) and the assumption that 50% of measured SOLRAD is PAR. Next, potential dry matter production (PCARB, g/plant) at optimum temperature and soil water is calculated from PAR, plant population (PLANTS), and leaf area index (LAI).

PCARB = 5.0*PAR/PLANTS*(1.-EXP(-0.65*LAI))

This equation implies that leaf interception of PAR obeys Beer's Law, the extinction coefficient is 0.65, and 5.0 g of dry biomass is produced per MJ of intercepted PAR under nonstressed conditions. Finally, using the FORTRAN function subprogram "AMIN1" to find the minimum of two or more values, the subroutine calculates actual dry matter production on the day from PCARB and a minimum of two zero-to-unity stress factors.

CARBO = PCARB*AMIN1(PRFT,SWDF1)

SWDF1 is a stress factor for suboptimal soil water that is calculated in subroutine WATBAL. PRTF is a stress factor for temperature calculated from minimum (TEMPMN) and maximum (TEMPMX) daily air temperatures.

PRFT = 1.-0.0025*((0.25*TEMPMN+0.75*TEMPMX)-26.)**2

Thus, a weighted daytime average of maximum and minimum air temperatures with an optimum of 26°C is used to calculate CARBO.

In the nitrogen version,

CARBO = PCARB*AMIN1(PRFT,SWDF1,NDEF1),

where NDEF1 is a zero-to-unity nitrogen stress factor calculated in subroutine NFACTO.

If leaves are still growing (ISTAGE is less than or equal to 3), the cumulative number of phyllochrons, or fully expanded leaves (CUMPH), is calculated from daily thermal time (DTT) for the day and the variable PC.

CUMPH = CUMPH+DTT/(38.9*PC)

When the number of fully expanded leaves (CUMPH) on the previous day is greater than or equal to 5.0, PC = 1.0. Otherwise,

PC = 0.66+0.068*CUMPH.

Thus, when five or more leaves are present, the fraction of a leaf emerging on a day (TI) is (DDT/38.9). The rate of appearance is faster for the first four leaves, where

TI = DTT/(38.9*PC).

The leaf number of the oldest expanding leaf (XN) is (CUMPH+1).

Next, the daily increases in leaf area and dry matter of the various plant parts are calculated. The calculations differ for each ISTAGE.

ISTAGE = 1 (Emergence to End of Juvenile Stage)

In ISTAGE 1, daily growth of leaf area per plant (PLAG) is calculated. XN is equal to CUMPH+1.0. If XN is less than 4.0,

PLAG = 3.0*XN*TI*SWDF2,

where SWDF2 is a zero-to-unity soil water deficit factor from subroutine WATBAL. For XN greater than or equal to 4.0,

PLAG = 3.5*XN*XN*TI*SWDF2.

Total plant leaf area (PLA) is then updated.

PLA = PLA+PLAG

New leaf weight (XLFWT) is calculated next.

XLFWT = (PLA/267.)**1.25

The daily growth in leaf weight (GROLF) is calculated from XLFWT and the previous day's value of leaf weight (LFWT).

GROLF = XLFWT-LFWT

Since only leaves and roots are growing during ISTAGE 1, daily root growth (GRORT) is the difference between CARBO and GROLF.

GRORT = CARBO-GROLF

If GRORT is less than (0.25*CARBO), reserve carbohydrate in the germinated seed (SEEDRV) is used to maintain the rate of root growth (GRORT=CARBO*0.25), and SEEDRV is reduced accordingly.

SEEDRV = SEEDRV+CARBO-GROLF-GRORT

If SEEDRV is exhausted, GROLF is reduced to (CARBO*0.75) and PLA is recalculated.

PLA = (LFWT+GROLF)**0.8*267.

LFWT is then updated by adding today's increment of leaf growth (GROLF). Finally, total leaf senescence since emergence due to normal phenological development (SLAN) is calculated.

SLAN = SUMDTT*PLA/10000.

ISTAGE = 2 (End of Juvenile Stage to Tassel Initiation)

During ISTAGE 2, calculations of PLAG, PLA, XLFWT, GROLF, LFWT, GRORT, and SLAN are similar to those during ISTAGE 1. One important exception occurs: SEEDRV is assumed to be exhausted by ISTAGE 2. Therefore, it is not available to support GROLF or GRORT when CARBO is inadequate.

ISTAGE = 3 (Tassel Initiation to End of Leaf Growth and Silking)

During ISTAGE 3, three sets of equations are used to calculate PLAG, GROLF, and daily stem growth (GROSTM). Choice of equations depends on leaf number (XN).

If XN is less than 12.0, the following equations are used:

PLAG = 3.5*XN*XN*TI*SWDF2,
GROLF = 0.00116*PLAG*PLA**0.25,
GROSTM = GROLF*0.0182*(XN-XNTI)**2,

where XNTI is the number of leaves at tassel initiation determined in subroutine PHASEI.

If XN is between 12.0 and the final leaf number (TLNO) minus 3.0, the following equations are used.

```
PLAG = 3.5*170.*TI*SWDF2
GROLF = 0.00116*PLAG*PLA**0.25
GROSTM = GROLF*0.0182*(XN-XNTI)**2
```

When the final three leaves are expanding, the following equations are used.

```
PLAG = 170.*3.5/((XN+5.-TLNO)**0.5)*TI*SWDF2
GROLF = 0.00116*PLAG*PLA**0.25
GROSTM = 3.1*3.5*TI*SWDF2
```

Root growth (GRORT) is then calculated.

```
GRORT = CARBO-GROLF-GROSTM
```

However, if GRORT is less than (0.10*CARBO), it is set equal to (0.10*CARBO), and the previously calculated values of GROLF and GROSTM are reduced by the factor GRF.

```
GRF = CARBO*0.90/(GROSTM+GROLF)
```

PLA, LFWT, and STMWT are updated as in ISTAGE 1, and SLAN is updated with the following equation.

```
SLAN = PLA/1000.
```

ISTAGE = 4 (Silking to Beginning of Effective Grain Filling Period)

After silking, ear growth (GROEAR) begins and leaf growth ceases.

GROEAR = 0.22*DTT*SWDF2

The stem continues to increase in weight during this period.

GROSTM = GROEAR*0.40

As long as GRORT is greater than (0.08*CARBO),

GRORT = CARBO-GROEAR-GROSTM.

However, if GRORT falls below (0.08*CARBO), it is set equal to that value, and GROEAR and GROSTM are reduced by the factor GRF.

GRF = CARBO*0.92/(GROEAR+GROSTM)

SLAN is calculated as follows:

SLAN = PLA*(0.05+SUMDTT/170.*0.05),

where SUMDTT is cumulative day degrees since silking.

Total ear weight (EARWT) and stem weight (STMWT) are updated.

EARWT = EARWT+GROEAR
STMWT = STMWT+GROSTM

Finally, the variables SUMP and IDURP (which are used in subroutine PHASEI to calculate grain numbers) are updated.

SUMP = SUMP+CARBO

IDURP = IDURP+1

ISTAGE = 5 (Effective Grain Filling Period)

> In the nitrogen version of the model, the effect of nitrogen deficiency on GPP is determined on the first day of ISTAGE 5. The maximum number of kernels (weighing 200 mg each with a nitrogen concentration of 0.95%) that can be produced from the plant's currently available nitrogen (NPOOL) is calculated. GPP is then set equal to the minimum of that number and the value of GPP determined previously in subroutine PHENOL.

During ISTAGE 5, SLAN is calculated as:

SLAN = PLA*(0.1+0.80*(SUMDTT/P5)**3),

where SUMDTT is cumulative DTT since silking and P5 is total DTT between silking and maturity.

A zero-to-unity relative rate of grain fill (RGFILL) is calculated eight times daily by the use of interpolated three-hour mean temperatures (TTMP) (see subroutine PHENOL).

When TTMP is greater than 6°C, RGFILL is summed over the eight daily time steps with the following equation.

RGFILL = RGFILL+(1.0-0.0025*(TTMP-26.)**2)/8.

The total grain growth during the day (GROGRN, g/plant) is calculated as follows:

GROGRN = RGFILL*GPP*G3*0.001*(0.45+0.55*SWDF1),

where GPP is the number of kernels per plant, G3 is the maximum daily rate of kernel fill (mg/kernel), and SWDF1 is an index of drought stress.

When grain filling is very slow (RGFILL less than 0.1) for two consecutive days, physiological maturity occurs. This is most likely to occur when TEMPMX is lower than 6°C for two consecutive days.

Next, CARBO is partitioned among the grain, stem, leaves, and roots. First, the growth and weights of stems, roots, and leaves are calculated. If all daily dry matter increase (CARBO) is not used for grain growth (GROGRN), it is partitioned equally to stems and roots.

GROSTM = CARBO-GROGRN
STMWT = STMWT+GROSTM*0.5
GRORT = GROSTM*0.5

If CARBO is less than GROGRN, a limited amount of dry weight can be translocated from the stem and leaves to the grain. The minimum stem weight (SWMIN) is calculated in subroutine PHASEI at the beginning of ISTAGE 4 and is 80% of the stem weight at that time. The minimum leaf weight (LWMIN) is calculated in subroutine PHASEI at the beginning of ISTAGE 5 and is 85% of the leaf weight at that time.

If translocation of dry weight from the stem to the grain does not reduce stem weight below (SWMIN*1.07), no dry matter is translocated from the leaves. However, when STMWT falls below that value, 0.5% of the leaf weight can be translocated daily to the stem as long as LFWT is greater than LWMIN. This translocation of leaf dry weight to the stem can then be translocated to the grain.

The rate of grain growth (GROGRN) is unaffected by declining STMWT until STMWT reaches SWMIN. At that point, translocation of dry weight from the stem to the grain ceases and GROGRN becomes source rather than sink limited.

GROGRN = CARBO

The nitrogen version next calculates the effects of nitrogen stress on the nitrogen concentrations and growth of the various plant parts. First, two factors, TFAC and SFAC, are calculated and are used to estimate the effects of mean temperature (TEMPMN) and drought stress (SWDF2) on the concentration of nitrogen (GNP) in GROGRN for the day. "AMAX1" is a FORTRAN function subprogram that finds the maximum of two or more values.

TFAC = 0.69+0.125*TEMPM

SFAC = 1.125-0.125*SWDF2

GNP = (0.007+0.010*NDEF2)*AMAX1(TFAC,SFAC)

Thus, high mean temperatures and drought stress can cause the value of AMAX1(TFAC,SFAC) to exceed 1.0. Nitrogen deficiency can cause NDEF2 (calculated in subroutine NFAC) to be less than 1.0. The net effect of these equations is to allow GNP to range from less than 0.010 when nitrogen deficiency is severe to about 0.018 when adequate nitrogen is available but high temperatures or drought stress limit grain growth.

Next, the total nitrogen demand of the growing grain (NSINK) is calculated.

NSINK = GROGRN*GNP

Nitrogen available for translocation to the grain (NPOOL) is the sum of nitrogen available in the stover (NPOOL1) and in the roots (NPOOL2).

NPOOL = NPOOL1+NPOOL2

NPOOL1 is the product of stover weight (STOVWT) and the fraction of stover nitrogen available for translocation.

NPOOL1 = STOVWT*(VANC-VMNC),

where VANC is the actual stover nitrogen concentration and VMNC is the minimum stover nitrogen concentration from subroutine NFAC.

NPOOL2 is the product of root weight (RTWT) and an analogous fraction of root nitrogen available for translocation (RANC-RMNC).

NPOOL2 = RTWT*(RANC-RMNC)

When NPOOL is not adequate to supply the grain nitrogen demand (NSINK), their ratio (NSDR) is used to reduce GROGRN and NSINK proportionately.

NSDR = NPOOL/NSINK

GROGRN = GROGRN*NSDR

NSINK = GROGRN*GNP

Plant nitrogen concentrations and pool sizes are now recalculated. If NSINK is greater than NPOOL or NPOOL1, the actual stover nitrogen concentration (VANC) is set equal to the minimum stover nitrogen concentration (VMNC), and total stover nitrogen content (STOVN) is calculated.

STOVEN = STOVWT*VANC

Next, NPOOL2, NPOOL1, ROOTN, and RANC are updated.

NPOOL2 = NPOOL2-(NSINK-NPOOL1)

NPOOL1 = 0.0

ROOTN = RTWT*RMNC+NPOOL2

RANC = ROOTN/RTWT

These equations permit NPOOL2 to go to zero if (NSINK=NPOOL). However, if NSINK is greater than NPOOL1 but less than NPOOL, NPOOL2 will be greater than zero, and RANC will be greater than RMNC.

If NSINK is less than or equal to NPOOL1, all nitrogen translocated to the grain comes from NPOOL1. Thus,

NPOOL1 = NPOOL1-NSINK,

STOVN = NPOOL1+VMNC*STOVWT,

VANC = STOVN/STOVWT.

Finally, NSINK is translocated to the grain nitrogen pool (GRAINN).

GRAINN = GRAINN+NSINK

Grain weight (GRNWT) and ear weight (EARWT) are now updated in both versions of the model.

GRNWT = GRNWT+GROGRN

EARWT = EARWT+GROGRN

If STMWT exceeds the value of STMWT at the beginning of the effective filling period (SWMAX), it is set equal to SWMAX.

The nitrogen version of the model now calculates potential shoot (PDWI) and root (PGRORT) growth, which are used in subroutine NUPTAK. The calculations are performed during ISTAGE 1 through ISTAGE 5.

PDWI = PCARB*(1.0-GRORT/CARBO)

PGRORT = PCARB*GRORT/CARBO

Subroutine NUPTAK is then called by the nitrogen version of the model.

Both the nitrogen and non-nitrogen versions of the model then calculate zero-to-unity factors for leaf senescence due to drought stress (SLFW), competition for light (SLFC), and low temperature (SLFT).

```
SLFW = 0.95+0.05*SWDF1
IF (LAI.GT.4.) SLFC = 1.-0.008*(LAI-4.)
SLFT = 1.-(6.-TEMPM)/6
IF (TEMPMN.LE.0.) SLFT = 0.0
```

Note that leaf area senescence due to low temperatures occurs at chilling mean temperatures (TEMPM lower than 6°C), and complete senescence occurs when the minimum temperature (TEMPMN) is lower than or equal to 0.0°C.

At any time, the total amount of green leaf area is the difference between the total amount of leaf area that has been produced (PLA) and the total amount of leaf area that has senesced (SENLA). Plant leaf area senescence on a day (PLAS) due to water, temperature, or competition stresses is calculated as follows.

```
PLAS = (PLA-SENLA)*(1.0-AMIN1(SLFW,SLFC,SLFT))
```

SENLA is then updated.

```
SENLA = SENLA+PLAS
```

If the new value of SENLA is less than the total amount of senescence that would occur because of normal phasic development (SLAN), SENLA is set equal to SLAN.

Leaf area index (LAI), above-ground dry biomass (BIOMAS, g/m^2); and plant top fraction (PTF) are calculated.

LAI = (PLA-SENLA)*PLANTS*0.0001
BIOMAS = (LFWT+STMWT+EARWT)*PLANTS
PTF = (LFWT+STMWT+EARWT)/(RTWT+LFWT+STMWT+EARWT).

In the nitrogen version, above-ground dry biomass (DM, kg/ha) and stover weight (STOVWT, g/plant) are calculated.

DM = BIOMASS*10.

STOVWT = LFWT+STMWT

Root weight is calculated with both growth and normal senescence taken into consideration. Half of GRORT is assumed to be lost to respiration, and root senescence is 0.5% per day.

RTWT = RTWT+0.5*GRORT-0.005*RTWT

The model now returns from subroutine GROSUB to the MAIN program.

SUBROUTINE WRITE

Subroutine WRITE is called daily from the MAIN program. It calculates cumulative variables related to hydrology and calls the output subroutines OUTWA and OUTGR when necessary.

SUBROUTINE OUTWA

Subroutine OUTWA is called by subroutine WRITE at the interval specified by the variable KOUTWA in the parameter file.

It calls subroutine CALDAT and writes soil-water-related outputs to the output file OWAT.DAT.

SUBROUTINE OUTGR

Subroutine OUTGR is called by subroutine WRITE at the interval specified by the variable KOUTGR in the parameter file. It calls subroutine CALDAT and writes growth-related outputs to the output file OBIO.DAT.

SUBROUTINE CALDAT

Subroutine CALDAT is called by several subroutines. It calculates the calendar date corresponding to a particular day of the year.

SUBROUTINE SOILNI

In the nitrogen version, subroutine SOILNI is called from the MAIN program on the first day of simulation. Fertilizer-related data are read from the parameter file.

The nitrogen contents of initial straw (STRAW) and root (ROOT) residues are calculated from the weight of the residues and their C/N ratios (from the parameter file), on the assumption that 40% of the dry weight is carbon. The organic matter (ROOT) and nitrogen contained in the root residues (WRN(I)) are distributed in each layer (I) of the soil profile with an exponential function:

WRN(I) = EXP(-3.0*DEPTH/DEPMAX),

where DEPTH is the depth (cm) to the bottom of soil layer I and DEPMAX is the maximum depth of the root zone calculated in subroutine SOILRI.

In addition, fresh organic matter (FOM(I)), nitrogen contained in the fresh organic matter (FON(I)), nitrate (SNO3(I)), ammonium (SNH4(I)), and humus nitrogen (NHUM(I)) pools for each soil layer are initialized from data in the parameter file.

Residue and humus decomposition rate constants are also specified in subroutine SOILNI. These include the basic rate constants for decomposition of carbohydrate (RDCARB = 0.8), cellulose (RDCELL = 0.05), lignin (RDLIGN = 0.0095), and humus (DMINR = 8.3 E-05*DMOD). DMOD is a zero-to-unity factor used to reduce the basic rate of mineralization for soils in which the organic matter is chemically or physically protected. The rate constants given above are those used by Seligman and van Keulen (1981).

Subroutine SOILNI is also used to initialize variables in the soil temperature subroutine (subroutine SOLT) and the nitrification subroutine (subroutine NITRIF). Those variables are discussed in the sections describing the appropriate subroutines.

SUBROUTINE MINIMO

Subroutine MINIMO calculates mineralization of organic nitrogen and immobilization of mineral nitrogen due to crop residue and soil organic matter decomposition. It is based on the mineralization immobilization routine in PAPRAN (Seligman and van Keulen, 1981). It also applies fertilizer NH_4-N and NO_3-N to the appropriate mineral N pools in the soil. The subroutine is called daily from the MAIN program.

The subroutine first updates the nitrate (SNO3(L)) and ammonium (SNH4(L)) contents of appropriate soil layers if nitrogen fertilizer is applied on the day. Fertilizer products are specified by the numeric code IFTYPE and can be urea (0 or 1), ammonium nitrate (2), anhydrous ammonia (3), calcium ammonium nitrate (4), and potassium or sodium nitrate (5).

The model then calculates transformations of soil organic matter and organic nitrogen. Two pools of organic matter are assumed to occur in each soil layer. The fresh organic matter in a layer (FOM(I)) is composed of the root and shoot residues of the previous crop, microbial biomass, and its rapidly decomposing products. The stable soil organic matter or "humus" in a layer (HUM(I)) is composed of all other organic matter in the soil.

The gross amount of nitrogen that is released (GRNOM) because of mineralization of nitrogen in the fresh organic matter (FON(I)) is:

GRNOM = DECR(I)*FON(I),

where DECR(I) is the fraction of FON(I) or FOM(I) mineralized that day. RDECR is a rate constant that is a function of the ratio (RATIO) of FOM today to initial FOM.

If RATIO   0.8, RDECR = RDCARB = 0.8 (from subroutine SOILNI).

If 0.8   RATIO   0.2, RDECR = RDCELL = 0.05.

If RATIO   0.2, RDECR = RDLIGN = 0.0095.

RDCARB, RDCELL, and RDLIGN are rate constants for decomposition of carbohydrate-like, cellulose-like, and lignin-like fractions of the residue, respectively.

TFAC is a temperature factor based on the soil temperature for layer I (ST(I)) (ST(I) is calculated in subroutine SOLT).

TFAC = 0.000977*ST(I)*ST(I)

MF is a moisture factor ranging from 0.0 when the soil is at half the lower limit (LL(I)) to 1.0 at the drained upper limit (DUL(I)). Values of SW(I), LL(I), and DUL(I) come from subroutine WATBAL.

MF = (SW(I)-LL(I)*0.5)/(DUL(I)-LL(I)*0.5)

CNRF is a zero-to-unity, C:N-ratio factor. It is based on CNR(I), the ratio of carbon in FOM(I) (assuming 40% of FOM(I) is carbon) to nitrogen available for decay. Nitrogen available for decay is assumed to be FON(I) plus TOTN, the sum of NO_3-N and NH_4-N.

CNR(I) = (0.4*FOM(I))/(FON(I)+TOTN)

CNRF is calculated as follows.

CNRF = EXP(-0.693*(CNR(I)-25)/25.)

The residue decomposition rate constant (DECR(I)) is a function of the maximum decomposition rate constant (RDECR) and the three factors described above.

DECR(I) = RDECR*TFAC*MF*CNRF

The gross rate of nitrogen immobilization associated with the decomposition of the FOM(I) pool (RNAC) is assumed to be the minimum of mineral nitrogen available for immobilization (TOTN) and the demand for nitrogen of the decaying FOM(I).

RNAC = AMIN1(TOTN,DECR(I)*FOM(I)*(0.02)),

where 0.02 is the nitrogen requirement for microbial decay of a unit of FOM(I). The value 0.02 is the product of the fraction of C in the FOM(I) (0.4), the biological efficiency of C turnover by the microbes (0.4), and the N:C ratio of the microbes (0.125). FOM(I) and FON(I) are updated daily with the following equations.

FOM(I) = FOM(I)-DECR(I)*FOM(I)

FON(I) = FON(I)+RNAC-GRNOM

The rate of nitrogen mineralization from the stable organic matter (RHMIN) is calculated as follows:

RHMIN = NHUM(I)*DMINR*TFAC*MF,

where NHUM(I) is the amount of nitrogen in the stable organic matter and DMINR is a soil-specific rate constant from subroutine SOILNI.

The sizes of the stable organic matter pool (HUM(I)) and nitrogen in HUM(I) (NHUM(I)) are updated daily by the use of the following equations.

HUM(I) = HUM(I)-RHMIN*10.0+0.2*GRNOM/0.04

NHUM(I) = NHUM(I)-RHMIN+0.2*GRNOM

Note that the model assumes that 20% of the gross amount of nitrogen released because of mineralization of FON(I) (.2*GRNOM) is incorporated into NHUM(I), and 0.04 is the concentration of nitrogen in the stable organic matter (0.1 g N/g C * 0.4 g C/g OM).

The net nitrogen released from all organic sources (NNOM) is:

NNOM(I) = 0.8*GRNOM+RHMIN-RNAC.

Note that 0.8 represents that fraction of GRNOM that is not incorporated into NHUM(I). Also note that NNOM can be negative if immobilization (RNAC) is greater than mineralization from fresh organic matter (0.8*GRNOM) and stable organic matter (RHMIN). NNOM is then used to update the soil NH_4-N pool (SNO3(I)).

SNH4(I) = SNH4(I)+NNOM(I)

The following equations are used to calculate the C:N ratios of the total soil (SCNR(I)) and fresh organic matter (FOCNR(I)), respectively.

SCNR(I) = 0.4*(FOM(I)+HUM(I))/
(FON(I)+ NHUM(I)+SNO3(I)+SNH4(I))

FOCNR(I) = 0.4*FOM(I)/FON(I)

SUBROUTINE NUPTAK

This subroutine calculates the demand and uptake of nitrogen by the crop, and the supply of nitrogen available to the crop. It is called from subroutine GROSUB.

A weighting factor for the influence of nitrogen on distribution of daily root growth among layers (RNFAC(L)) is calculated on the basis of mineral nitrogen availability. RNFAC(L) reaches 0.95 at 20 g N/Mg soil, which is similar to the critical nitrogen concentration of Burns (1980).

RNFAC(L) = 1.0-(1.17*EXP(-0.15*TOTN))

RNFAC(L) is constrained between 0.01 and 1.0 and subsequently used in subroutine WATBAL to calculate the distribution of daily root growth among layers.

The nitrogen demand of potential new top growth (DNG) is calculated from the potential dry weight increase of the top (PDWI) and its critical nitrogen concentration (TCNP).

DNG = PDWI*TCNP

This allows the actual top nitrogen concentration (TANC) to exceed TCNP when actual dry weight increase (expressed in g/plant) is less than PDWI.

Grain nitrogen is removed from the stover nitrogen pool in subroutine GROSUB, which later calls subroutine NUPTAK. Thus, the nitrogen required for grain growth has already been removed from the stover when the program enters subroutine NUPTAK, and the total nitrogen demand is the sum of the demand of the stover and the roots. Stover nitrogen demand consists of two components: first, the demand due to the difference between TANC and TCNP, which can be positive or negative; and second, the demand for nitrogen of the potential new growth (DNG).

TNDEM = STOVWT*(TCNP-TANC)+DNG

Root nitrogen demand is calculated in an analogous manner except that demand for new growth is calculated as (PGRORT*RCNP).

RNDEM = RTWT*(RCNP-RANC)+PGRORT*RCNP

The whole plant nitrogen demand (NDEM) is the sum of TNDEM and RNDEM. Since subsequent nitrogen balance calculations are performed in units of kg N/ha, nitrogen demand per hectare (ANDEM) is calculated from NDEM and plant population. If ANDEM is negative or zero, no nitrogen uptake calculations are performed, and plant nitrogen concentrations are updated for any growth that occurs.

The model simulates two pools of inorganic N, NH_4 and NO_3. This allows the inorganic nitrogen transformations and movement between layers to be sensitive to the relative amounts of the two ionic species. All calculations are in terms of elemental nitrogen in each pool.

Potential nitrogen availability factors for NH_4 and NO_3 uptake from each layer (FNH4 and FNO3, respectively) are calculated from the NH_4 and NO_3 concentrations of each layer.

FNH4 = 1.0-EXP(-0.030*NH4(L))

FNO3 = 1.0-EXP(-0.030*NO3(L))

These factors are constrained between 0.03 and 1.0.

A soil water factor (SMDFR) that can restrict NO_3 and NH_4 uptake at low soil water contents is calculated,

SMDFR = (SW(L)-LL(L))/ESW(L),

where ESW(L) is the extractable soil water in the layer. Next, an interim variable (RFAC) describing the effects of root length density (RLV(L)) and soil water on potential NH_4 and NO_3 uptake is calculated.

RFAC = RLV(L)*SMDFR*SMDFR*DLAYR(L)*100.

Potential uptake of NH_4 (RNH4U(L)) and NO_3 (RNO3U(L)) from the layer are then calculated.

RNO3U(L) = RFAC*FNO3*0.008

RNH4U(L) = RFAC*FNH4*0.008

Thus, potential NO_3 and NH_4 uptake from a layer, like their diffusion in soil, is sensitive to both soil water and mineral nitrogen content. However, the model assumes no plant preferences for NO_3 or NH_4, and at equal soil concentrations the values of RNO3U(L) and RNH4U(L) are equal. RNO3U(L) and RNH4U(L) are constrained so that a minimum of 0.1 and 2.0 g N/Mg soil, respectively, will remain in the layer. The larger value for RNH4U(L) reflects NH_4 adsorption by soil.

Potential nitrogen uptake (supply) from the whole profile (TRNU) is the sum of RNO3U(L) and RNH4U(L) uptake from all soil layers in which roots occur. Thus, it represents an integrated value that is sensitive to (a) rooting density, (b) the supply of each of the two ionic species, and (c) the ease of their extraction as a function of the soil water status of the different layers.

If potential nitrogen supply from the whole profile (TRNU) is greater than crop nitrogen demand (ANDEM), a zero-to-unity factor (NUF) is used to reduce total nitrogen uptake to the level of demand.

NUF = ANDEM/TRNU

NUF is then used to reduce the actual uptake of nitrate (UNO3) and ammonium (UNH4) from each layer in the root zone.

UNO3 = RNO3U(L)*NUF

UNH4 = RNH4U(L)*NUF

Plant nitrogen uptake from each layer (PNUP(L)) is the sum of UNO3 and UNH4 in each layer. The total nitrogen uptake by the root system (TNUP) is the sum of PNUP(L) in all layers.

Roots are assumed to die continually. The nitrogen lost from dying roots in each layer (RNLOSS(L)) is a function of the roots' actual nitrogen concentration (RNAC) and the root length density in the layer (RLV(L)). The constant 0.0067 is the product of 0.5% root death per day and a root nitrogen concentration of 1.33%.

RNLOSS(L) = RANC*RLV(L)*0.0067

The total loss of nitrogen from the root system (TRNLOS) is the sum of RNLOSS(L) in all layers. This nitrogen is assumed to mineralize immediately and is used to update SNH4(L) in subroutine WATBAL. The total mineral nitrogen remaining in the soil after uptake (TRNS) is the sum (SNO3(L)+SNH4(L)).

TRNU, the total root nitrogen uptake, is converted from kg N/ha to g N/plant. It is then used to calculate the change in stover N content (DSTOVN).

DSTOVN = TNDEM/NDEM*TRNU

The change in root nitrogen (DROOTN) due to uptake is then calculated.

DROOTN = RNDEM/NDEM*TRNU

In a separate statement, DROOTN is updated for nitrogen loss due to root death.

DROOTN = DROOTN-TRNLOS

Stover and root nitrogen contents (STOVN and ROOTN) as well as stover nitrogen concentration (TANC) are then updated.

STOVN = STOVN+DSTOVN

ROOTN = ROOTN+DROOTN

TANC = STOVN/STOVWT

Root nitrogen concentration (RANC) is then updated on the assumption that half the carbon translocated to the root system (GRORT) is converted to dry matter and root death is 0.5% of root weight (RTWT).

RANC = ROOTN/(RTWT+0.5*GRORT-0.005*RTWT)

The model then returns to subroutine GROSUB.

SUBROUTINE NFLUX

Subroutine NFLUX is called in subroutine WATBAL and calculates the downward movement of nitrate-N with percolating soil water. It also calculates upward and downward movement of nitrate caused by water movement between layers when the soil water content is less than the drained upper limit. Downward movement of nitrate-N (NOUT(L), kg N/ha) due to leaching is calculated as follows.

NOUT(L) = SNO3(L)*FLUX(L)/(SW(L)*DLAYR(L)+FLUX(L))

Flux(L) is the amount of water percolating out of the layer (cm), SW(L) is water content of the layer (cm/cm), and DLAYR(L) is the depth of the layer (cm). Percolation is not allowed to reduce the nitrate-N concentration below 1.0 g/Mg. Calculations are performed in a loop, beginning with the surface soil layer. With each pass through the loop, the values of NO3(L) and SNO3(L) are updated.

A similar method is used to calculate movement of nitrate-N in response to differences in water content of adjacent soil layers, usually due to evaporation from the soil surface. Separate loops are used to move nitrate-N upward and downward. The first loop is used when the movement of water between layers is upward (FLOW.GT.0.).

NUP(K) = SNO3(K)*FLOW(K)/(SW(K)*DLAYR(K)+FLOW(K))*0.5

NUP(K) is nitrate-N movement (in kg N/ha) upward, and FLOW(K) is water movement upward from the layer (cm).

A similar sequence of calculations is used in the second loop to calculate movement of nitrate-N downward when the upper layer is wetter than the lower layer (FLOW.LT.0.).

SUBROUTINE NFACTO

Subroutine NFACTO is called in subroutine GROSUB. It uses shoot nitrogen concentrations from subroutine NUPTAK to calculate the zero-to-unity nitrogen deficiency factors NDEF1 and NDEF2. NDEF1 affects photosynthesis, and NDEF2 affects leaf senescence and grain nitrogen concentration.

The tops critical nitrogen concentration (TCNP) is the stover (non-grain shoot) concentration below which nitrogen concentration begins to affect plant growth. It is a function of XSTAGE (Jones, 1983), which is calculated in subroutine PHENOL.

TCNP = EXP(1.52-0.160*XSTAGE)/100.0

The tops minimum nitrogen concentration (TMNC) is the stover nitrogen concentration below which shoot nitrogen does not fall (Jones, 1983). It is also a function of XSTAGE. Below XSTAGE 4.0,

TMNC = (1.25-0.20*XSTAGE)/100.0.

When XSTAGE is greater than 4.0, TMNC equals 0.0045.

A zero-to-unity nitrogen factor (NFAC) is calculated:

NFAC = 1.0-(TCNP-TANC)/(TCNP-TMNC).

Thus, NFAC is 1.0 when TANC equals TCNP, and it decreases linearly to zero as TANC decreases from TCNP to TMNC. Since all plant processes are not equally susceptible to nitrogen stress, the nitrogen deficiency factors NDEF1 and NDEF2 are calculated from NFAC and are used to affect different processes.

NDEF1 = 1.25*NFAC

NDEF2 = NFAC

Neither of these factors is allowed to exceed 1.0.

SUBROUTINE DNIT

Subroutine DNIT is called in subroutine WATBAL and calculates denitrification whenever the soil water in the layer (SW(L)) is greater than the drained upper limit (DUL(L)) (Godwin et al., 1984). No denitrification occurs in a layer if its NO_3-N concentration is less than 1 g/mg.

Soil carbon content (SOILC) is calculated from the carbon in (FOM(L)) and humus (HUM(L)).

SOILC = 0.40*FOM(L)+0.58*HUM(L)

This is converted into a concentration with the conversion factor FAC(L), and a carbon availability factor (CW) is calculated.

CW = (SOILC*FAC(L))*0.0031+24.5

A water factor (FW) is calculated from the soil water content of the layer (SW(L)), the drained upper limit (DUL(L)), and the layer's water content at saturation (SAT(L)).

FW = (SAT(L)-SW(L))/(SAT(L)-DUL(L))

A temperature factor (FT) is calculated from the soil temperature of the layer (ST(L)).

FT = 0.1*EXP(0.046*ST(L))

The denitrification rate (DNRATE) of the layer is then calculated.

DNRATE = 6.0*1.E-05*CW*NO3(L)*BD(L)*FW*FT*DLAYR(L)

The NO_3-N content (SNO3(L)) and concentration (NO3(L)) of the layer are updated. NO3(L) is not allowed to fall below 1 g NO_3-N/Mg soil.

SUBROUTINE NITRIF

Subroutine NITRIF is called in subroutine MINIMO and calculates nitrification of NH_4 in each soil layer (Godwin et al., 1984). First, an NH_4 concentration factor (SANC) is calculated.

SANC = 1.0-EXP(-0.01363*SNH4(L))

Note that SANC approaches zero at 1 g NH_4-N/Mg soil. It is about 0.13 at 10 g/Mg, and is 0.75 at 100 g/Mg.

A zero-to-unity water factor (WFD) is then calculated. When SW(L) is less than (0.25*(DUL(L)-LL(L))),

WFD = (SW(L)-LL(L))/((DUL(L)-LL(L))*0.25), where DUL(L) is the drained upper limit of plant-extractable water, LL(L) is the lower limit of plant-extractable water, and SW(L) is the volumetric water content of the layer.

WFD is 1.0 when SW(L) is between (0.25*(DUL(L)-LL(L))) and the DUL(L). When SW(L) is greater than DUL(L),

WFD = 1.0-((SW(L)-DUL(L))/(SAT(L)-DUL(L))).

A temperature factor (TF) is calculated from the soil temperature of the layer (ST(L)).

TF = (ST(L)-5.0)/30.0

TF is not allowed to decrease below zero.

Next, a nitrification capacity factor (ELNC) is calculated.

ELNC = AMIN1(TF,WFD,SANC)

ELNC and an index of the previous day's relative microbial nitrification potential in the layer (CNI(L)) are used to calculate the interim variable RP2, representing the relative nitrification potential for today.

RP2 = CNI(L)*EXP(2.302*ELNC)

RP2 is constrained between 0.01 and 1.0.

Today's value of microbial nitrification potential (CNI(L)) is then set equal to RP2. Since EXP(2.302*ELNC) varies from 1.0 when ELNC = 0 to 10.0 when ELNC = 1.0, relative nitrification potential can increase rapidly, up to tenfold per day.

The interim variable A, a zero-to-unity index of nitrification potential today, is then calculated.

A = AMIN1(RP2,WFD,TF)

This interim variable is then used to calculate the actual rate of nitrification (RNTRF) for the layer.

RNTRF(L) = A*40.0*SNH4(L)/(SNH4(L)+90.)

Thus, under ideal temperature and soil water conditions in a soil with maximum microbial nitrification potential (A = 1.0), addition of 100 kg NH_4-N/ha could result in nitrification of 21 kg NH_4-N the first day.

The soil pools of mineral nitrogen SNH4(L) and SNO3(L) are updated for today's nitrification.

SNH4(L) = SNH4(L)-RNTRF(L)

SNO3(L) = SNO3(L)+RNTRF(L)

Finally, the soil temperature, moisture, and NH_4 levels after nitrification are used to update CNI(L), which will be used for tomorrow's calculations.

SARNC = 1.0-EXP(-0.1363*SNH4(L))

XW = AMAX1(WFD,WFY(L))

XT = AMAX1(TF,TFY(L))

CNI(L) = CNI(L)*AMIN1(XW,XT,SARNC)

SARNC is a zero-to-unity factor for NH_4 availability. WFD and WFY(L) are today's and yesterday's soil water factors, respectively. TF and TFY(L) are today's and yesterday's soil temperature factors, respectively. Note that the maximum of WFD and WFY(L) are used to calculate the interim variable XW, and the maximum of TF and TFY(L) are used to calculate XT. This prevents a single day of low soil temperature or water from severely reducing CNI(L).

It is important to note that the relative nitrification potential CNI(L) is calculated twice each day. Since (EXP(2.302*ELNC)) varies from 1.0 to 10.0, CNI(L) increases prior to the calculation of actual nitrification (RNTRF(L)). After nitrification is calculated, CNI(L) is again reduced. The relative magnitudes of (EXP(2.302 * ELNC)) and (AMIN1(XW, XT, SARNC)) determine whether relative mineralization potential increases or decreases over time.

SUBROUTINE SOLT

Subroutine SOLT is called in subroutine MINIMO. It calculates daily average soil temperature at the center of each soil layer. It is based on the soil temperature model of the Erosion-Productivity Impact Calculator (Williams et al., 1984).

On any day the average soil temperature of a layer (ST(L)) is calculated as follows:

ST(L) = TAV+(AMP/2.*COS(ALX+ZD)+DT)*EXP(ZD),

where TAV is average annual air temperature (°C), AMP is the annual amplitude in mean monthly air temperature (°C), ALX is a factor used to calculate normal soil surface temperature on this day, ZD is a factor that reduces changes in soil temperature with depth, and DT is the rate of change of actual soil surface temperature with time.

JDATE 200 is assumed to have the warmest average soil temperature during the year, and normal soil temperature varies as a cosine function of ALX.

ALX = ANG*(JDATE-200.),

where ANG is 2 pi/365 or 0.0174.

Therefore, on JDATE 200, the normal temperature of the surface soil is (TAV+AMP/2). On JDATE 15 (180 days later), the normal temperature of the surface soil is (TAV-AMP/2).

However, on a particular day, the actual soil surface temperature (TO(1)) is affected by current weather conditions:

TO(1) = (1.-SALB)*(TMN+(TEMPMX-TMN)*
SQRT(SOLRAD/800.))+SALB*TO(1),

where SALB is soil albedo, TMN and TEMPMX are mean and maximum air temperatures for the day (°C), SOLRAD is solar radiation (langleys/d), and the TO(1) on the right side of the equation is yesterday's actual surface soil temperature.

A rate of change in soil surface temperature with time (DT) is the difference in a five-day moving average of TO(1) and the normal surface soil temperature for the day. The difference in temperature between surface and subsurface layers (EXP(ZD)) is an exponential function of the ratio of the depth to the bottom of the layer (Z) and the temperature damping depth of the soil (DD).

ZD = -Z/DD

The damping depth is a function of the average bulk density of the soil (ABD) and the amount of water above the lower limit (AW).

F = ABD/(ABD+686.*EXP(-5.63*ABD)),

DP = 1000.+2500.*F,

B = ALOG(500./DP),

WW = 0.356-0.144*ABD,

WC = AW/(WW*CUMDEP),

DD = DP*EXP(B*((1.-WC)/(1.+WC))**2),

where CUMDEP is the total depth of the soil profile and DP, B, WW, and WC are temporary variables.

Note that the term (COS(ALX+ZD)) allows subsurface temperature changes to lag behind surface temperature changes. For example, on day 200, when "normal" soil surface temperatures are at a maximum, the value of COS(ALX+ZD) is 1.0 for the soil surface (ZD = 0) and 0.89 at half the damping depth (ZD = -0.5).

SUBROUTINE NWRITE

Subroutine NWRITE is called in the MAIN program. The subroutine calls three further subroutines (NBAL, OUTMN, and OUTNU) to produce output describing nitrogen-related parameters.

The first subroutine, NBAL, is called only if the output frequency specifying variable KOUTMN is greater than zero. The remainder of the routine is concerned with calculating period averages and cumulative totals for the parameters to be printed. The call to OUTMN occurs when the day counter (IOUTMN) equals the specified output frequency (KOUTNB). Similarly, the call to OUTNU is controlled by the variables IOUTNU and KOUTNU. KOUTMN, KOUTNB, and KOUTNU are specified in the parameter file.

SUBROUTINE NBAL

This subroutine is called by subroutine NWRITE and writes detailed information on the soil nitrogen balance at a user-specified output frequency (KOUTMN, days) to the output file OMIN.DAT.

SUBROUTINE OUTMN

This subroutine is called by subroutine NWRITE and writes the average values of various soil nitrogen parameters over a specified time interval (KOUTNB, days) to output file ONIS.DAT.

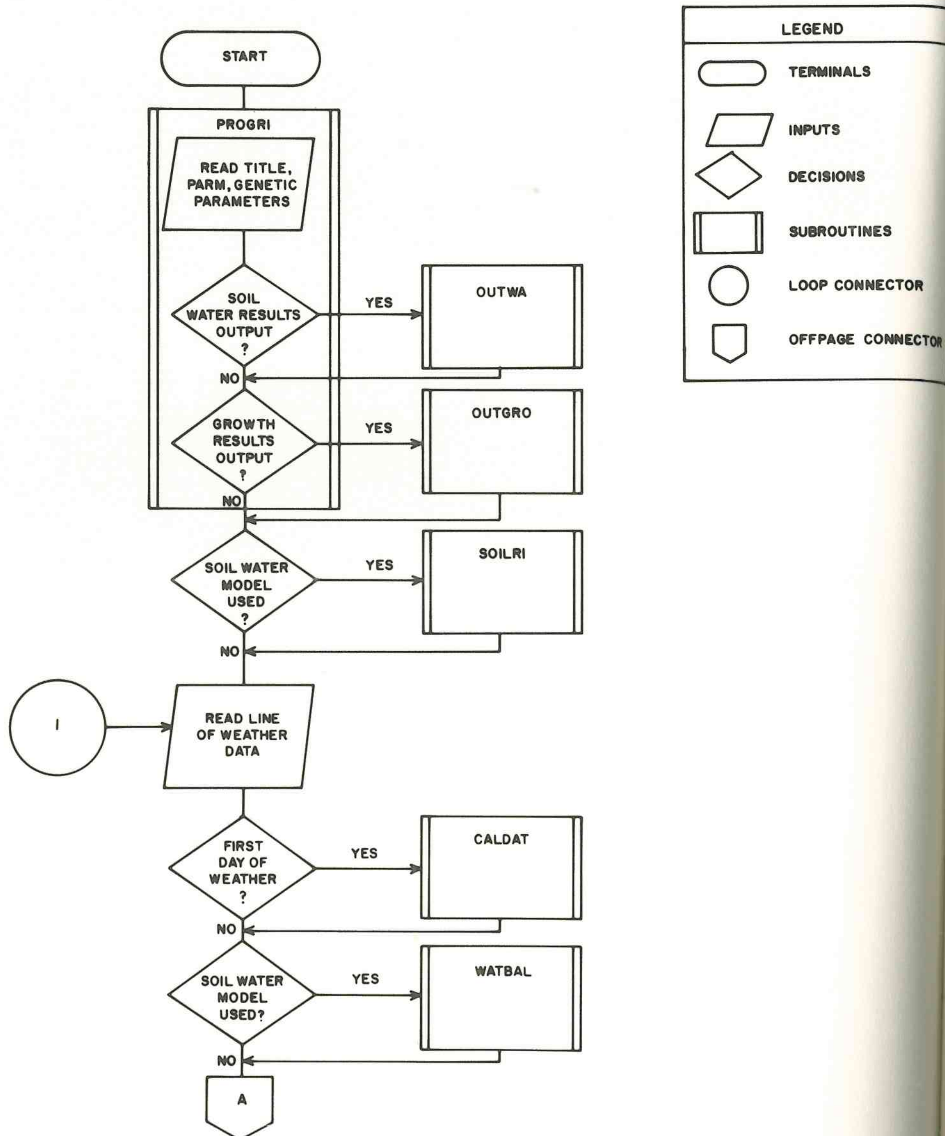

Fig. 4.1. Flow chart of the CERES-Maize model STANDARD version (D. Spanel, personal communication).

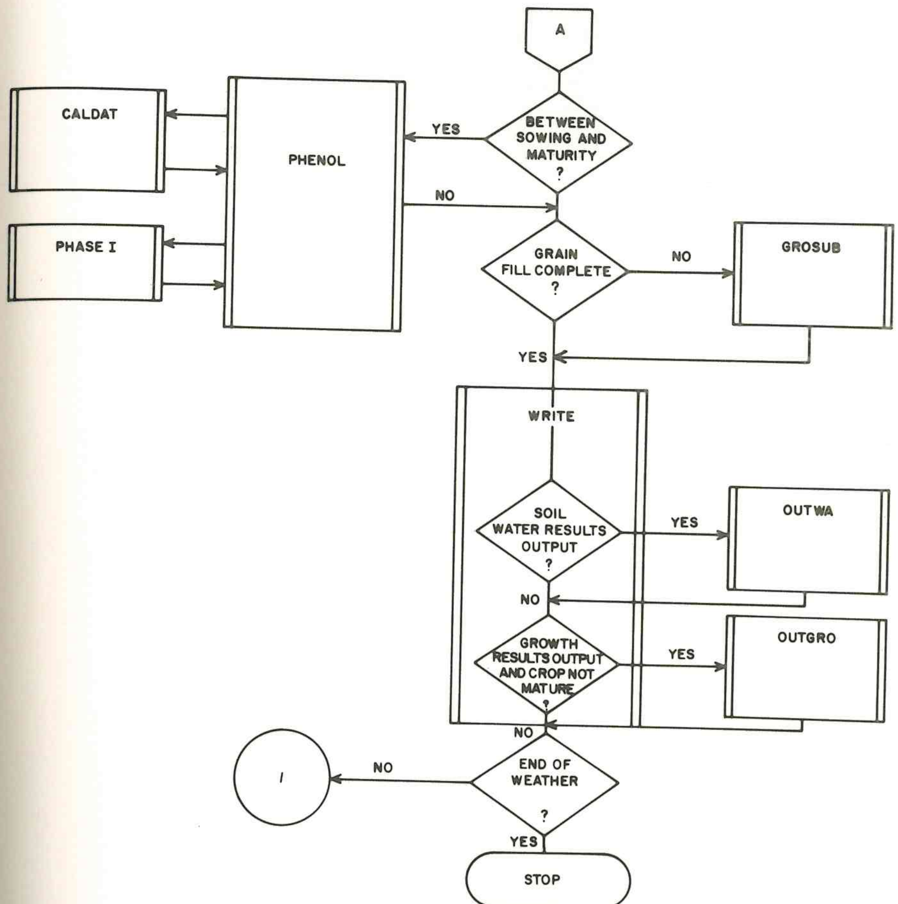
A
CALDAT
PHENOL
YES
BETWEEN SOWING AND MATURITY ?
PHASE I
NO
GRAIN FILL COMPLETE ?
NO
GROSUB
YES
WRITE
SOIL WATER RESULTS OUTPUT ?
YES
OUTWA
NO
GROWTH RESULTS OUTPUT AND CROP NOT MATURE ?
YES
OUTGRO
NO
I
NO
END OF WEATHER ?
YES
STOP

Fig. 4.1 (cont.)

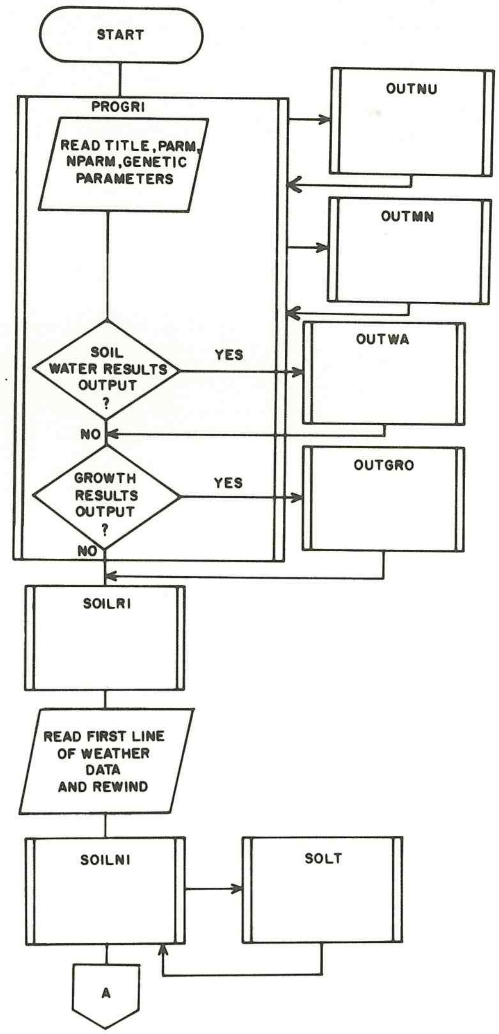

Fig. 4.2. Flow chart of the CERES-Maize model NITROGEN version (D. Spanel, personal communication).

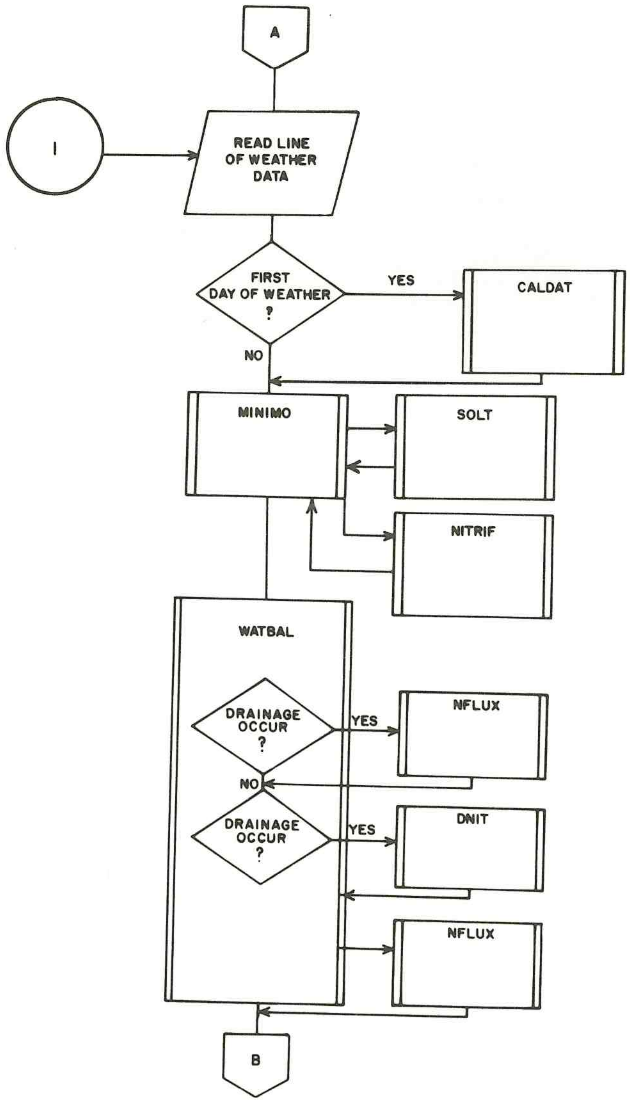
A
I
READ LINE OF WEATHER DATA
FIRST DAY OF WEATHER ?
YES
CALDAT
NO
MINIMO
SOLT
NITRIF
WATBAL
DRAINAGE OCCUR ?
YES
NFLUX
NO
DRAINAGE OCCUR ?
YES
DNIT
NFLUX
B

Fig. 4.2 (cont.)

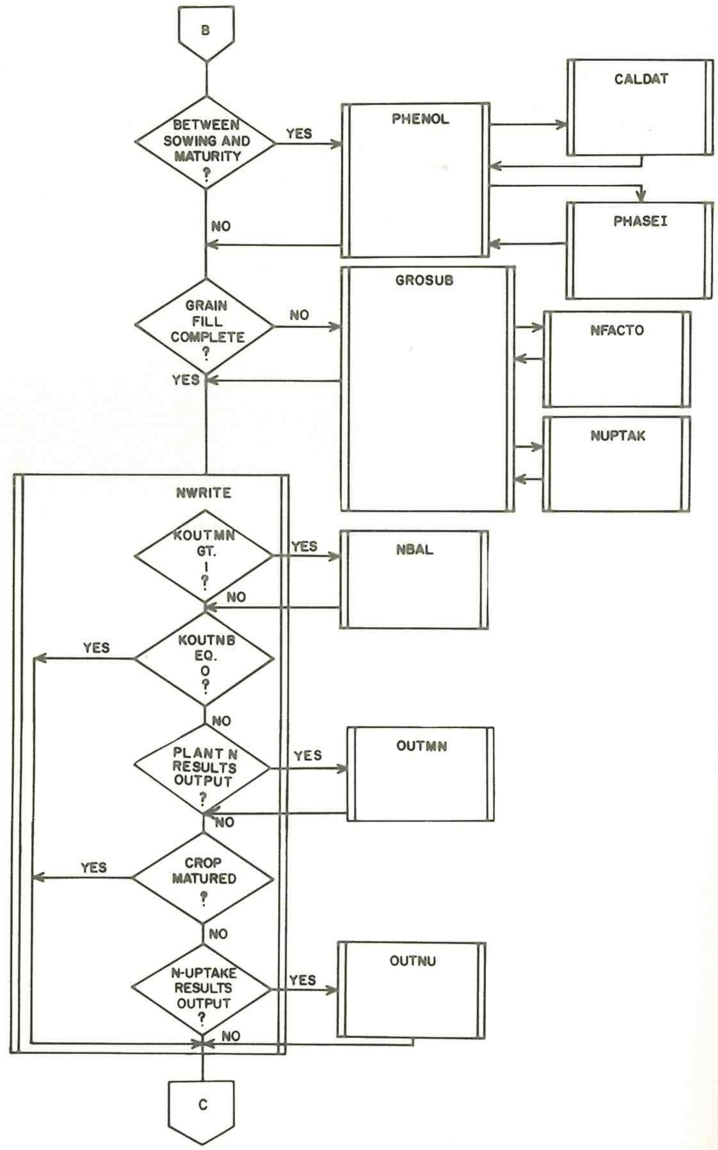
B
BETWEEN SOWING AND MATURITY ?
YES
PHENOL
CALDAT
PHASEI
NO
GROSUB
GRAIN FILL COMPLETE ?
NO
NFACTO
YES
NUPTAK
NWRITE
KOUTMN GT. I ?
YES
NBAL
NO
KOUTNB EQ. O ?
YES
NO
PLANT N RESULTS OUTPUT ?
YES
OUTMN
NO
CROP MATURED ?
YES
NO
N-UPTAKE RESULTS OUTPUT ?
YES
OUTNU
NO
C

Fig. 4.2 (cont.)

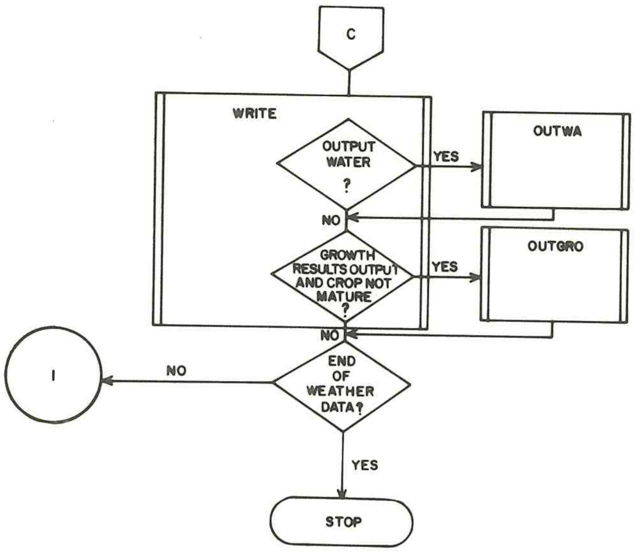
C
WRITE
OUTPUT WATER ?
YES
OUTWA
NO
GROWTH RESULTS OUTPUT AND CROP NOT MATURE ?
YES
OUTGRO
NO
I
NO
END OF WEATHER DATA?
YES
STOP

Fig. 4.2 (cont.)

5. Model Evaluation

J. R. Kiniry and C. A. Jones

The development, verification, and validation of the CERES-Maize model has been an iterative process. For most processes simulated by the model, initial development was based on one or a few data sets. For example, the phenology subroutine is largely based on the work of Kiniry et al. (1983a, 1983b). Grain number calculations are based on the work of Edmeades and Daynard (1979) and Kiniry and Ritchie (1985). Leaf initiation, appearance, and growth are based on the work of Kiniry and Ritchie (1981), Tollenaar et al. (1979), and Warrington and Kanemasu (1983). Plant dry matter partitioning is based on the work of Hanway and Russell (1969). Critical crop nitrogen concentrations are based on Jones (1983). The water balance is based on the work of Ritchie (1972) adapted to a layered soil. The water balance and nitrogen subroutines are nearly identical to those used in the CERES-Wheat model (Godwin et al., 1984).

This chapter compares measured and simulated data from a number of independent studies conducted at a wide range of locations. Components of the model were not developed directly from these studies. However, as Dent and Blackie (1979) point out, model evaluation is a long-term process in which confidence in the model is enhanced (or reduced) through a succession of formal and informal tests. Comparison of measured results from these studies with simulated results revealed both logical errors in the program and a few cases of inadequate calibration. We have attempted to correct these problems. Therefore, the test data reported in this chapter have affected the model and cannot be considered completely independent.

Our experience suggests that input errors are a much more likely and, in practical terms, a more serious source of poor model predictions than are logical or calibration errors. Common input errors include inaccurate estimates of initial soil water content, the lower limit of plant extractable water (LL), the drained upper limit (DUL), and inaccurate estimates of rooting depth due to actual (or imagined) root-restricting layers.

The sensitivity of the model to relatively small errors in estimation of LL and initial soil water are illustrated in Fig. 5.1. The measured data are from an experiment conducted in 1979 by W. W. Wilhelm at Lincoln, NE. Yields were limited by drought stress, but careful measurement of soil water at the site allowed us to estimate LL, DUL, and initial soil water accurately. Under-estimation of LL by 0.02 cm/cm in all soil layers caused simulated grain yield to increase by 2300 kg/ha. Over-estimation of LL by the same amount caused simulated grain yield to decrease by 400 kg/ha. When initial soil water was assumed to be equal to DUL rather than to the measured value, simulated grain yield increased by 3300 kg/ha.

Simulated yields are sensitive to LL, DUL, and initial soil water when yields are limited by water stress. However, the model is less sensitive to these input parameters when rainfall or irrigation is abundant.

In the nitrogen version of the model, initial nitrate (NO3(L)) and ammonium (NH4(L)) concentrations are important inputs when nitrogen fertility limits yield. This sensitivity is shown in Fig. 5.2 by the use of data from an unpublished study conducted by C. A. Jones at

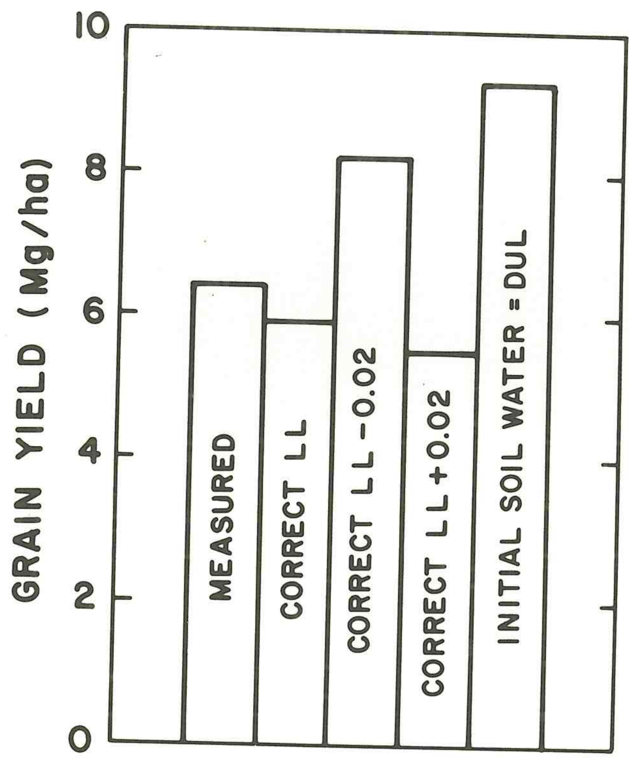

Fig. 5.1. Sensitivity of simulated grain yields to the lower limit of plant-extractable water (LL) and the initial soil water content. Initial conditions, weather, and measured yield from unpublished data of W. W. Wilhelm (see text).

Temple, TX, in 1982. Increasing initial NO3(L) and NH4(L) by 3 g N/Mg in all soil layers caused simulated grain yields to increase more for the zero and 80 kg N/ha treatments than for the 240 kg N/ha treatment.

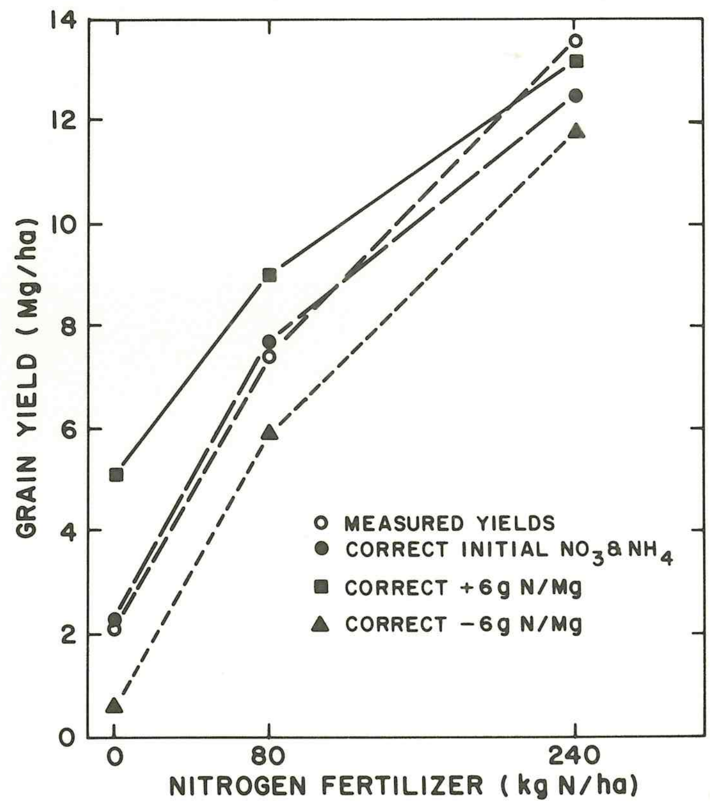

Fig. 5.2. Sensitivity of simulated grain yields to initial soil NO_3 and NH_4 concentrations. Initial conditions, weather, and measured yields from unpublished data of C. A. Jones (see text).

Similar results were obtained when initial NO3(L) and NH4(L) were decreased by 3 g N/Mg.[1]

This type of sensitivity analysis clearly illustrates the importance of accurate measurements of initial soil conditions and the limits of plant-extractable soil water. Similar analyses (not shown) illustrate the importance of using accurate weather, irrigation, and plant population data.

In this chapter, model predictions that are tested with the standard version include durations of phenological stages, leaf area index (LAI) development, and grain yield. The nitrogen version is used to test model response to different levels of nitrogen fertilizer.

The data sets used in testing represent the cooperative efforts of many individuals and institutions (Table 5.1). Our gratitude for their work and their willingness to share unpublished data cannot be overstated, and the accuracy of the CERES-Maize model depends in large part on the data they have provided for testing the model.

PHENOLOGICAL PREDICTIONS

As described in the sections on subroutines PHENOL and GROSUB, silking date depends on the total number of leaves produced by the apical meristem. This, in turn, depends on the date of tassel initiation. Thus, the accuracy with which the model predicts silking date depends on its ability to predict total leaf

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[1] Sections of documentation that refer only to the nitrogen version are printed with bold type and are indented and single spaced.

Table 5.1. Data used for verification of the CERES-Maize model.

Location	Years	Researchers	Phenology	Yield	Nitrogen
College Park, PA	1979	Yao, N. G., D. P. Knievel	+	+	
Bloomington, IL	1979	Malcolm, J. L.	+		
Greeley, CO	1976	Cuany, R. L. et al.	+		
Columbia, MO	1978-1979	Kiniry, J. R., M. E. Keener	+		
Columbia, MO	1979	Griffin, J. L., M. E. Keener	+	+	
Ames, IA	1964-1965	Hanway, J. J., W. A. Russell	+	+	
Quincy, FL	1980	Wright, D. L., F. M. Rhoads		+	
Tyron, NE	1979	Clawson, K. L., B. L. Blad	+	+	
Garden City, KS	1981	Hooker, M. L.		+	+
Temple, TX	1979	Stapper, M., G. F. Arkin	+		
Temple, TX	1981-1982	Jones, C. A.	+	+	+
Temple, TX	1982-1984	Kiniry, J. R.	+	+	+

Table 5.1. (cont.)

Location	Years	Researchers	Phenology	Yield	Nitrogen
Swift Current, Sask.	1979	Davidson, H. R.	+		
Hawaii	1978-1984	Singh, U., G. Uehara	+	+	+
Davis, CA	1979-1980	Hills, F. J., F. E. Broadbent, O. A. Lorenz		+	+
Florence, SC	1980-1982	Karlen, D. L., C. R. Camp		+	+
Europe	1977-1978	Derieux, M., R. Bonhomme (1982)	+		
Manhattan, KS	1976-1978	Stone, L. R., C. K. Anderson, L. S. Murphy		+	+
Lincoln, NE	1979	Wilhelm, W. W.	+	+	+

number and date of tassel initiation. Likewise, the interval from silking to physiological maturity depends on the length of the lag phase between silking and the beginning of grain filling as well as the duration of the effective filling period. However, dates of tassel initiation and beginning of grain filling are not available for most field experiments. Therefore, only predictions of the silking date and the interval from silking to physiological maturity (black layer formation) were tested.

Silking Date

Model predictions of silking date were tested with the standard version of the model. Accurate prediction of silking date requires accurate weather data and correct adjustment of the genotype-specific coefficients P1 and P2. In addition, the use of air temperature instead of soil temperature and inaccurate estimates of initial soil water content can cause errors in predicted dates of germination, emergence, and ultimately silking and maturity.

In this section, predicted and measured silking dates for four hybrids, each grown at a different set of locations, were compared. For these comparisons, the genetic coefficient P2 was adjusted with data from controlled environment studies. For the hybrids B73 X Mo17 and McCurdy 67-14, P1 was also obtained from controlled environment studies. For Pioneer 3780 and H610, P1 was adjusted by using the field studies reported below. The values of P1 and P2 used in this testing are given in Table 3.4.

In addition, predicted and measured silking dates were compared for eleven cultivars grown at seven locations in Europe. For this testing, the values of P1 and P2 were obtained from an independent field experiment.

The silking date was measured for Pioneer 3780 as far north as University Park, PA, and as far south as Temple, TX (Table 5.2). The mean error in the simulated date (predicted date - measured date) was -1.2 d, and the standard deviation (SD) of the error was 5.3 d. The greatest error occurred for data from Greeley, CO, where the silking date was underestimated by 12 d. This error may have been due to delays in germination and emergence caused by dry soil conditions or very cool soil temperatures early in the season. When this observation was deleted, the mean error was 0.1 d with an SD of 3.7 d.

Table 5.2. Predicted and measured dates of silking of maize hybrid Pioneer 3780.

Location	Year	Silking Date Predicted	Measured	Difference
		day of year		d
University Park, PA	1979	216	214	2
		220	222	-2
		237	232	5
		247	243	4
Greeley, CO	1976	202	214	-12
Tyron, NE	1978	209	211	-2
Temple, TX	1982	149	151	-2
	1983	160	158	2
	1984	154	160	-6
Mean				-1.2
Standard Deviation				5.3

B73 X Mo17 was the hybrid with the most extensive test data: nine planting dates at Columbia, MO, in 1978 and 1979 (Kiniry, 1979; Griffin, 1980); a multilocation study (Stapper and Arkin, 1980); four years at Temple, TX (Stapper and Arkin, 1980; J. R. Kiniry, unpublished); and a multilocation study in Europe (Derieux and Bonhomme, 1982) (Table 5.3). Errors in predicted silking date were similar to those for Pioneer 3780. When large errors occurred, they were underpredictions of silking date, probably due to errors in predicting dates of germination or seedling emergence. The mean error in silking date was -3.7 d and

Table 5.3. Predicted and measured dates of silking of maize hybrid B73 X Mo17.

Location	Year	Silking Date: Predicted	Silking Date: Measured	Difference
		day of year	day of year	d
Columbia, MO				
Location 1	1978	192	203	-11
	1978	201	207	-6
	1979	195	195	0
	1979	209	211	-2
Location 2	1978	222	221	1
	1978	226	226	0
	1979	197	205	-8
	1979	217	223	-6
Location 3	1979	208	207	1
Swift Current, Sask.	1979	232	246	-14
Bloomington, IL	1979	201	209	-8
Temple, TX	1979	186	198	-12
	1982	150	157	-7
	1983	161	164	-3
	1983	154	157	-3
Europe				
Mons, France	1978	235	248	-13
Fuchs, France	1978	215	220	-5
Rome, Italy	1978	204	202	2
Martonvasar, Hungary	1978	223	220	3
Debrecen, Hungary	1978	220	219	1
Zajecar, Yugoslavia	1978	15	209	6

Table 5.3. (cont.)

Location	Year	Silking Date Predicted	Silking Date Measured	Difference
		——day of year——		d
Radzikow, Poland	1978	238	236	2
Mean				-3.7
Standard Deviation				5.7

the SD was 5.7 d. When three data sets with large negative errors were deleted, the mean error was -2.3 d with an SD of 4.6 d.

The tropical hybrid H610 was planted in drip-irrigated experiments at several dates and locations in Hawaii (Table 5.4). Large negative errors in predicted silking date were not found with H610, probably because of drip irrigation and the absence of cool soil temperatures that may have caused delays in emergence in the other two hybrids. The mean error in predicted silking date was 2.2 d with an SD of 4.3 d.

The hybrid McCurdy 67-14 was planted eight times near Columbia, MO, and twice near Temple, TX (Table 5.5). The mean error of the predicted silking date was 1.3 d with an SD of 3.0 d.

For all four hybrids described above, the mean error was -0.3 d with an SD of 4.6 d. Large errors were usually underpredictions of silking date, probably due to delay in germination and/or emergence caused by dry or cold soil at the depth of planting.

A final test compared predicted and measured silking dates for ten hybrids grown at seven locations in Europe (Table 5.6). Genetic parameters for all hybrids were derived from data

Table 5.4. Predicted and measured dates of silking of maize hybrid H610 in Hawaii.

Location	Year	Silking Date Predicted	Silking Date Measured	Difference
		day of year	day of year	d
Waipio	1983	43	43	0
Iole	1982	218	208	10
	1979	134	130	4
	1978	114	110	4
	1978	239	235	4
Kukaiau	1978	125	123	2
	1979	206	209	-3
	1978	91	87	4
	1979	113	118	-5
	1979	97	94	3
	1978	240	243	-3
Halawa	1978	265	259	6
Mean				2.2
Standard Deviation				4.3

obtained at Fuchs, France. Data for this location were not included in the testing. Among hybrids, mean errors in silking date ranged from 2.0 to 9.2 d with SDs ranging from 3.0 to 7.5 d. The mean error for all hybrids over all locations was 3.5 d with an SD of 5.1 d. This SD is similar to those in Tables 5.2 through 5.5; therefore, over a variety of hybrids and locations the SD of errors in silking date were approximately 4 to 5 d.

Table 5.5. Predicted and measured dates of silking of maize hybrid McCurdy 67-14.

Location	Year	Silking Date Predicted	Silking Date Measured	Difference
		day of year	day of year	d
Columbia, MO				
Location 1	1978	202	207	-5
	1978	210	210	0
	1979	205	199	6
	1979	216	214	2
Location 2	1978	228	225	3
	1978	233	231	2
	1979	208	208	0
	1979	227	225	2
Temple, TX	1981	178	174	4
	1982	144	145	-1
Mean				1.3
Standard Deviation				3.0

Silking to Physiological Maturity

Predictions of the interval from silking to physiological maturity were tested with the standard version of the model. Accurate prediction of this interval requires accurate air temperatures and correct adjustment of the genotype-specific coefficient P5. The value of P5 is usually obtained by adjusting the value until an accurate prediction of the interval is obtained for one or more field studies. The values of P5 used in this testing are given in Table 3.4.

Table 5.6. Predicted silking date minus measured silking date for 10 cultivars grown at seven locations in Europe in 1977 and 1978.

Location	Year	INRA4	F7xF2	CP170	LG11	A654x F2	F478x W705A	A632x W117	F16x F19	W69Ax XF546	A632x Va 26
		d									
Aubiat, France	1977	4	—	6	4	6	3	0	4	—	—
Mons, France	1978	-1	-3	-6	-5	-2	-3	-1	-2	-3	-4
Rome, Italy	1978	2	2	3	2	4	3	4	5	7	6
Martonvasan, Hungary	1978	6	5	6	5	—	5	0	—	—	13
Debrecen, Hungary	1978	7	6	6	5	—	8	6	—	—	9
Zajecar, Yugosalvia	1978	6	6	4	6	7	7	6	9	15	15
Radzikow, Poland	1978	-4	0	1	-3	-5	-9	4	-3	6	6
Mean error		2.9	2.7	2.9	2.0	2.0	2.0	2.7	2.6	6.25	9.2
Standard Deviation		4.1	3.7	4.3	4.3	5.2	6.0	3.0	5.0	7.4	7.5

Multiple plantings of two maize hybrids in Missouri and Texas were used to test model predictions of the interval from silking to physiological maturity. In both cases the value of P5 was adjusted to minimize the mean error of the test data set.

For the hybrid B73 X Mo17 (Table 5.7) the SD of the errors was 6.8 d. This was similar to the SD of errors in predicting silking date for the same hybrid (Table 5.3). The two greatest errors were overpredictions of the interval.

Table 5.7. Predicted and measured days from silking to physiological maturity for B73 X Mo17.

Location	Year	Silking Date		Difference
		Predicted	Measured	
		day of year		d
Columbia, MO				
Location 1	1978	52	51	1
	1978	53	52	1
	1979	52	55	-3
	1979	58	65	-7
Location 2	1978	61	47	14
	1978	70	51	16
	1979	56	54	2
	1979	74	74	0
Location 3	1979	63	64	-1
Temple, TX	1979	46	45	1
Temple, TX	1984	47	43	4
Mean error				2.5
Standard deviation				6.8

For McCurdy 67-14 (Table 5.8) the SD of the errors in predicting the silking-to-maturity interval was 9.1 d. This is over three times the size of the error in predicting silking date. For this hybrid, three of the four largest errors were underpredictions of the interval when the hybrid was grown in Missouri. In Missouri, this hybrid often is exposed to low temperatures as it approaches physiological maturity. Thus, the present model may be too simple to predict physiological maturity accurately as minimum temperatures approach freezing.

Table 5.8. Predicted and measured days from silking to physiological maturity for McCurdy 67-14.

Location	Year	Interval		Difference
		Predicted	Measured	
		—— day of year ——		d
Columbia, MO				
Location 1	1978	49	53	-4
	1978	50	52	-2
	1979	50	66	-16
	1979	55	72	-17
Location 2	1978	60	52	8
	1978	67	68	-1
	1979	53	72	-19
Temple, TX	1981	41	41	0
Temple, TX	1982	44	50	-6
Mean error				-6.3
Standard deviation				9.1

We have found two situations in which the model of phenological development appears to be inadequate. First, the silking date and date of physiological maturity may be underestimated if the genetic coefficients are determined under long days in the temperate zone but the cultivar is grown under short days in the tropics. Second, the model may underestimate differences in phenological development between the summer and winter seasons in the tropics, especially if the difference in mean temperatures between the two seasons is small. Work is in progress to correct these deficiencies.

LEAF AREA INDEX

Total canopy photosynthesis is strongly dependent on leaf area index (LAI). This is especially true at values of LAI below about 2.0, where light interception is a strong function of LAI. Therefore, it is important for CERES-Maize to simulate LAI accurately. The standard version was used to simulate LAI for five cultivars grown at six locations. Simulated and measured leaf area development were compared at one location, and maximum simulated and measured LAI (measured at silking) were compared for 23 combinations of cultivars, location, and years.

Simulated and measured seasonal LAI development (LAI) were similar for Pioneer 3780 grown at College Park, PA, in 1979 (Fig. 5.3). Simulated LAI was slightly greater than measured LAI on the first two dates; however, errors were less than 10% for the last five measurements.

A highly significant relationship ($P = 0.0005$) was found between simulated and measured LAI at silking (Fig. 5.4). The relationship had a slope of 0.52, a Y-intercept of 1.78, and an r^2 of 0.47. The low r^2 was primarily due to overprediction of LAI for several experiments with measured LAI of 2.0 to 3.5. However, the model was responsive throughout the range of measured LAI,

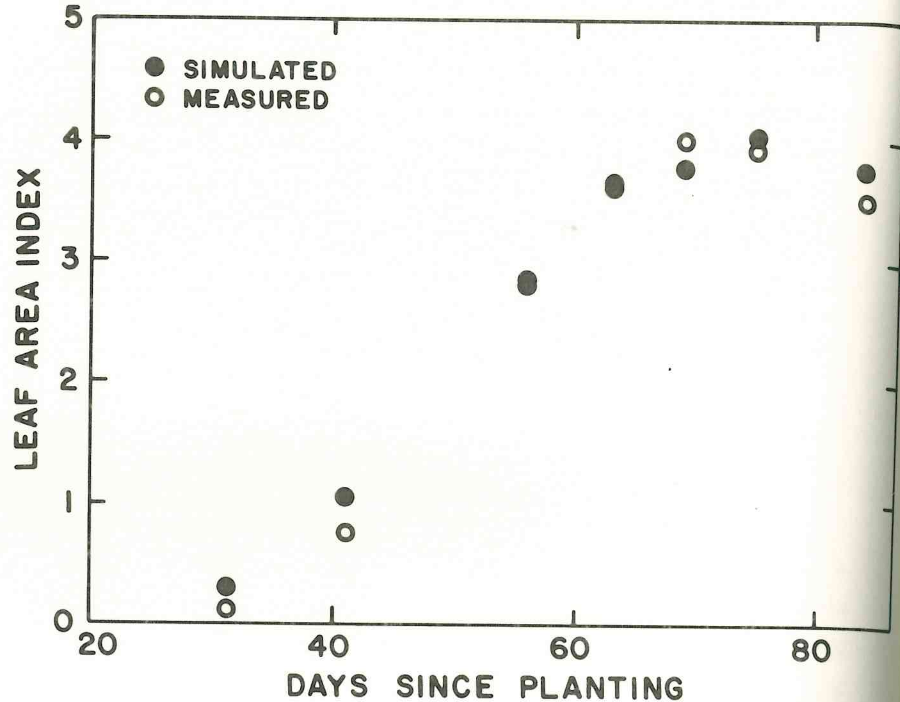

Fig. 5.3. Simulated and measured leaf area index of Pioneer 3780 throughout the 1979 season at College Park, PA. Initial conditions, weather, and measured leaf area index from D. P. Knievel (see text).

and the 1:1 line was within the 95% confidence band for the regression line.

BIOMASS

Accurate simulation of total above-ground dry biomass is important for accurate simulation of nutrient and carbon cycling. As with LAI, simulated and measured seasonal biomass accumulation were compared for one experiment, and maximum

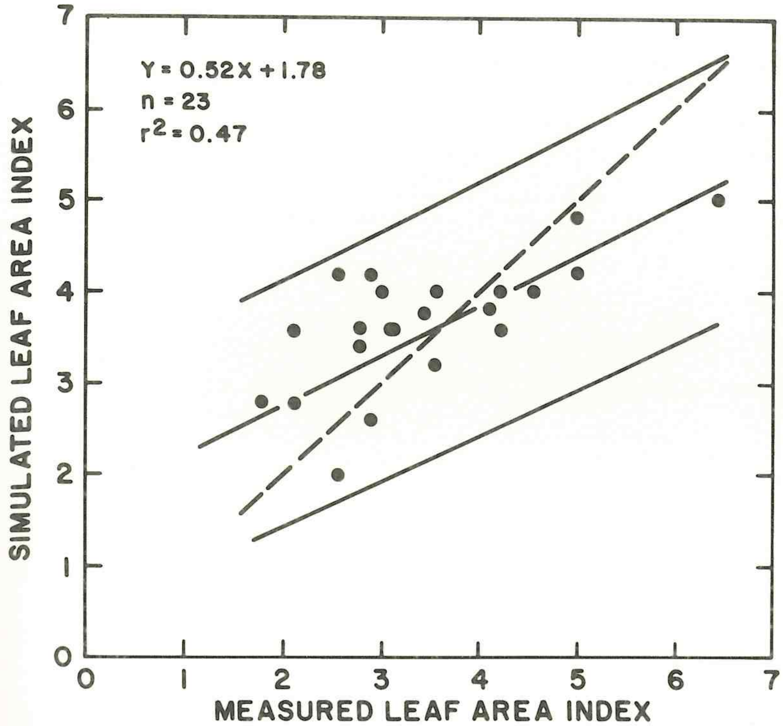

Fig. 5.4. **Simulated and measured maximum leaf area index for five cultivars at six locations.**

biomass accumulation (at physiological maturity) were compared for 38 combinations of cultivars, locations, and years.

Simulated and measured total above-ground dry biomass development were similar for McCurdy 67-14 grown at Temple, TX, in 1981 (Fig. 5.5). For the first two dates of measurement, simulated and measured values were nearly identical. The mean error of the simulated values for the seven measurement dates was 12% of the measured values.

Comparisons of 38 simulated and measured values of final biomass are given in Fig. 5.6. The relationship was highly

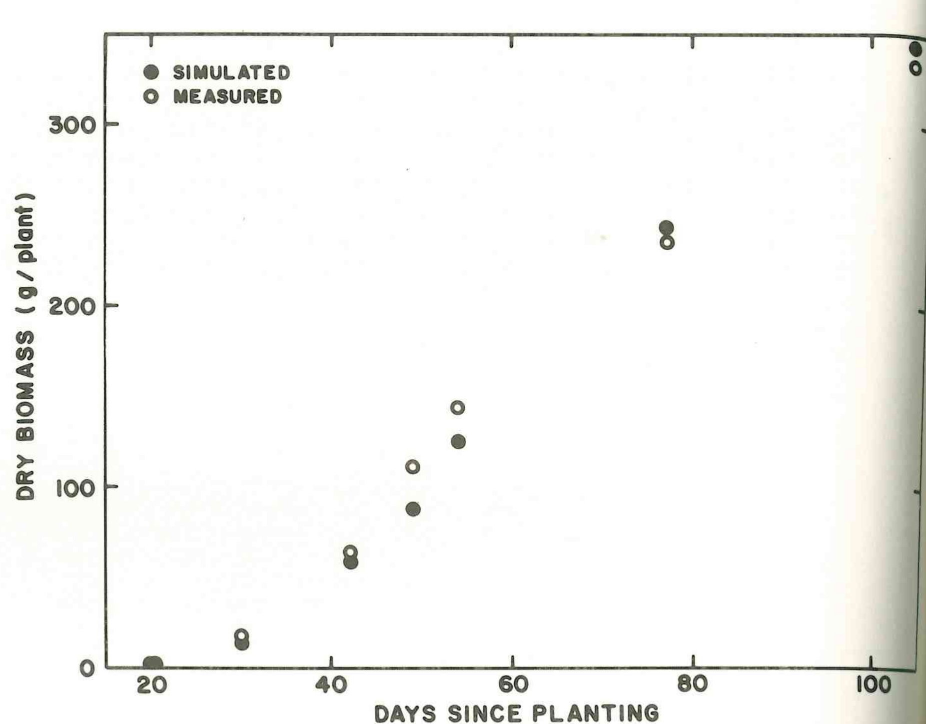

Fig. 5.5. Simulated and measured plant biomass for McCurdy 67-14 throughout the 1981 season at Temple, TX. Initial conditions, weather, and measured data from C. A. Jones (see text).

significant ($P = 0.0001$) with a slope of 0.60, a Y-intercept of 563 g/plant, and an r^2 of 0.54. Data points were fairly evenly distributed around the 1:1 line, and the greatest errors occurred near the midrange of measured values. The 1:1 line was within the 95% confidence band for the regression line.

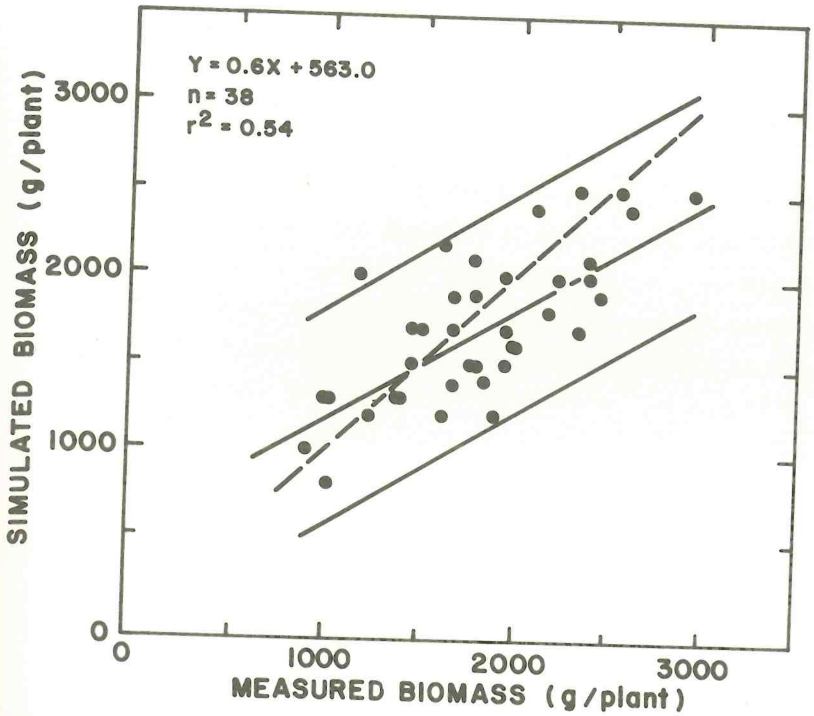

Fig. 5.6. Simulated and measured plant biomass at harvest for 13 cultivars at 12 locations.

GRAIN GROWTH

Grain yield is the most important variable in many experiments. Its prediction is affected by virtually every process simulated by the model. The model's ability to simulate grain numbers, grain yield, and the response of grain yield to drought stress are discussed below.

Grain Number

Grain number is an important component of grain yield that is sensitive to environmental stresses occurring near the silking date. When grain number is reduced due to stress, sink size and potential grain yield are reduced.

Simulated and measured grain numbers (grains/ear, GPE) were compared for 28 combinations of cultivars, locations, and years using the standard version (Fig. 5.7). The simulated values of GPE were consistently greater than the measured values when the latter were below about 450 GPE. The relationship was highly significant ($P = 0.0001$), but the regression line had a slope of 0.54 with a Y-intercept of 287 GPE. The value of r^2 was 0.54. The

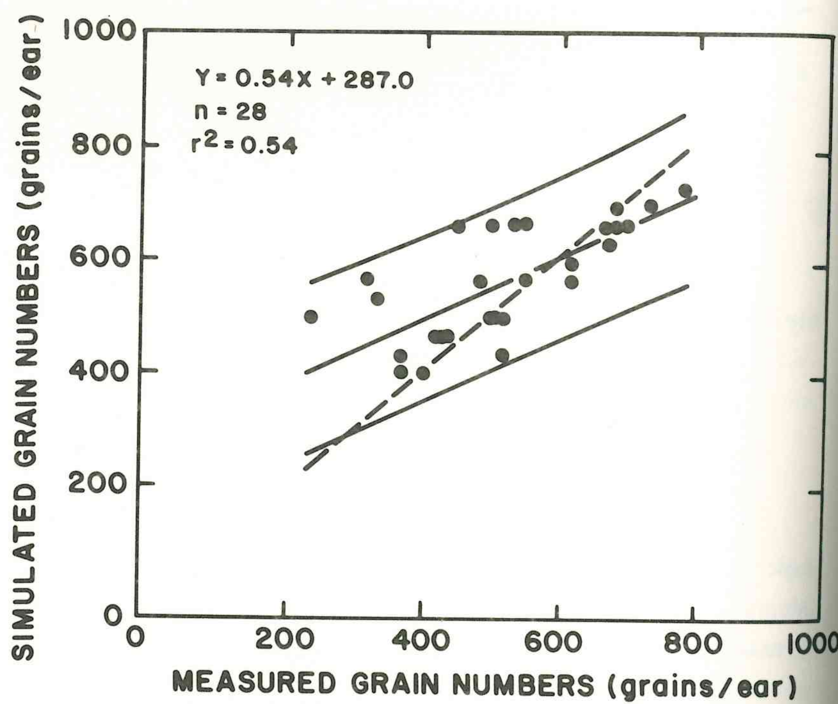

Fig. 5.7. Simulated and measured grain numbers for ten cultivars at eight locations.

overprediction of low values of GPE may have been due in part to underestimation of stresses during the period around silking.

Grain Yield

Grain yield prediction represents the integration of virtually every system operative in the model. Simulated and measured grain yields (at 15.5% moisture) were compared for 51 data sets representing 15 cultivars and 14 locations (Fig. 5.8). Measured yields ranged from 3475 to 17106 kg/ha. The relationship between simulated and measured yields was highly significant (P = 0.0001)

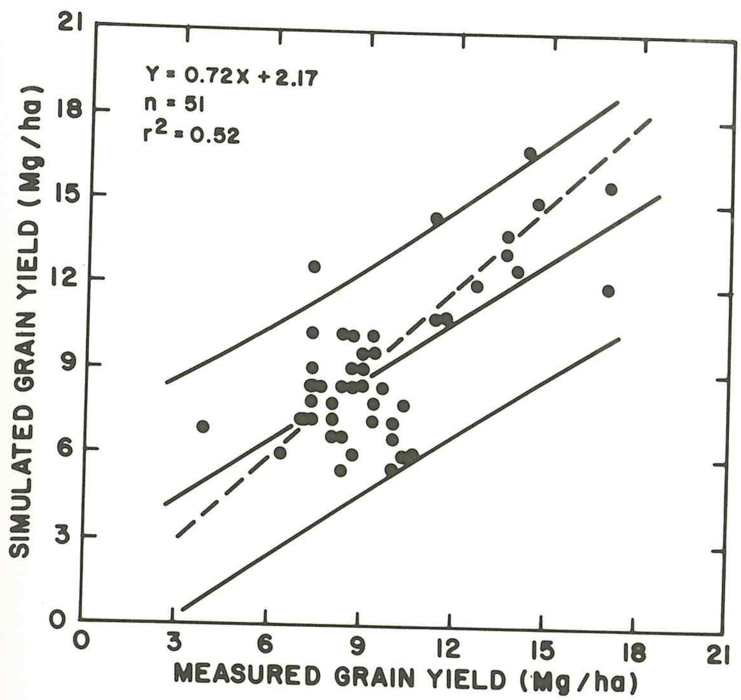

Fig. 5.8. Simulated and measured grain yields for 15 cultivars at 14 locations.

with a slope of 0.72, a Y-intercept of 2170 kg/ha, and an r^2 of 0.52. In addition, the 1:1 line was within the 95% confidence band for the regression line.

Caution should be used in interpreting the preceding data. In many cases soils were not carefully characterized, and inaccurate estimates of initial soil water, plant-extractable soil water, or soil depth could produce large errors in simulated grain yields. In addition, genetic coefficients used in the model were often unavailable from independent studies and had to be estimated. Finally, all the testing necessarily assumed that nutrients were never limiting. In the event that there was a nutrient deficiency, the standard version should overpredict biomass, leaf area, and yield.

Response to Drought Stress

Response of simulated grain yield to drought stress was evaluated by the use of data from Griffin (1980) and Clawson (1980). In the first case, the crop was grown on disturbed soils of different depths (33 to 84 cm) over plastic sheeting. In the second study, varying amounts of irrigation were applied during the season.

Both simulated and measured results indicated that grain yields increase in an almost linear manner with increasing soil depth (Fig. 5.9). With different amounts of irrigation (Fig. 5.10), both simulated and measured results indicated that the first two increments of irrigation each caused grain yields to increase by over 1000 kg/ha. However, the third increment causes an increase of only about 500 kg/ha (Fig. 5.10).

In conclusion, the standard version of the CERES-Maize model produced estimates of maximum leaf area index, maximum above-ground dry biomass, grain numbers, and grain yields that had highly significant correlations with measured values. The measured data accounted for 47% to 54% of the variation found in the simulated data and, except for estimation of grain number, the 1:1 line was within the 95% confidence band for the regression line.

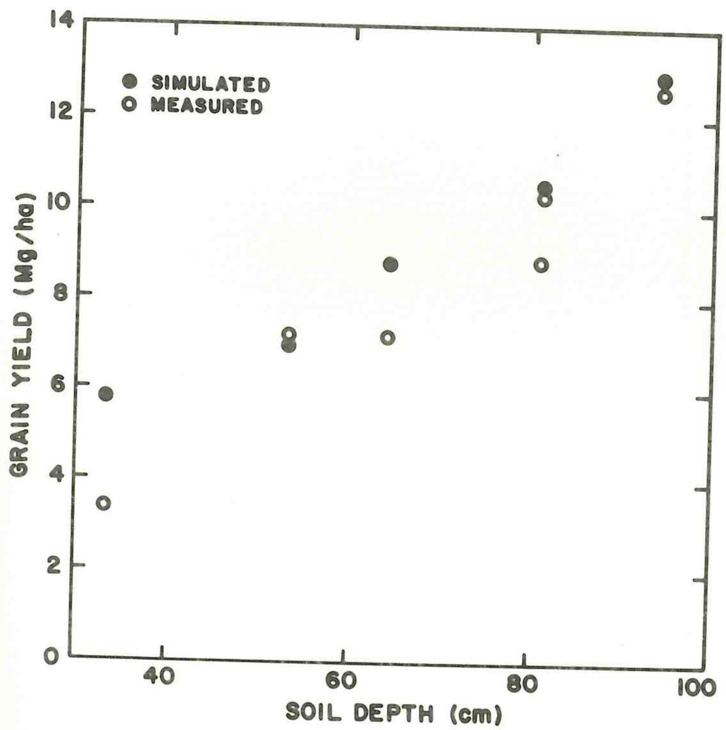

Fig. 5.9. Effect of soil depth on simulated and measured grain yields of B73 X Mo17 at Columbia, MO, in 1979. Initial conditions, weather, and measured yield data from J. L. Griffin (see text).

TESTING THE NITROGEN VERSION

The nitrogen version of the CERES-Maize model was tested to evaluate the effects of nitrogen deficiency on simulated crop growth, nitrogen uptake, and grain yields. When nitrogen is available in adequate amounts, the nitrogen version produces yields identical

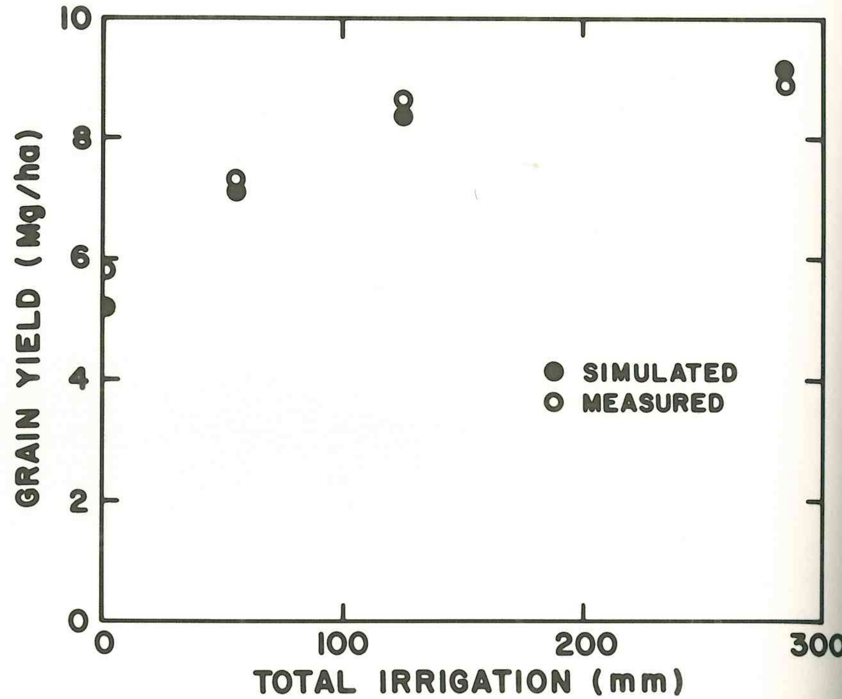

Fig. 5.10. Effect of total irrigation amounts on simulated and measured grain yields of Pioneer 3901 at Tyron, NE, in 1979. Initial conditions, weather, management, and measured yield data from K. L. Clawson (see text).

to those produced by the standard version. Therefore, so that only the nitrogen components of the model would be tested, the experiments used in testing were those in which the simulated yields at the highest nitrogen fertilizer levels were within 2000 kg/ha of the measured yields.

Total Biomass—Nitrogen Version

Accurate simulation of total biomass is important because of its effect on total nitrogen demand of the crop. The relationship between simulated and measured biomass at physiological maturity is given for 29 observations representing seven cultivars and seven locations (Fig. 5.11). A highly significant relationship was found ($P = 0.0001$) with a slope of 0.69, an intercept of 5200 kg/ha, and an r^2 of 0.77. In addition, the 1:1 line falls within the 95% confidence band for the regression lines.

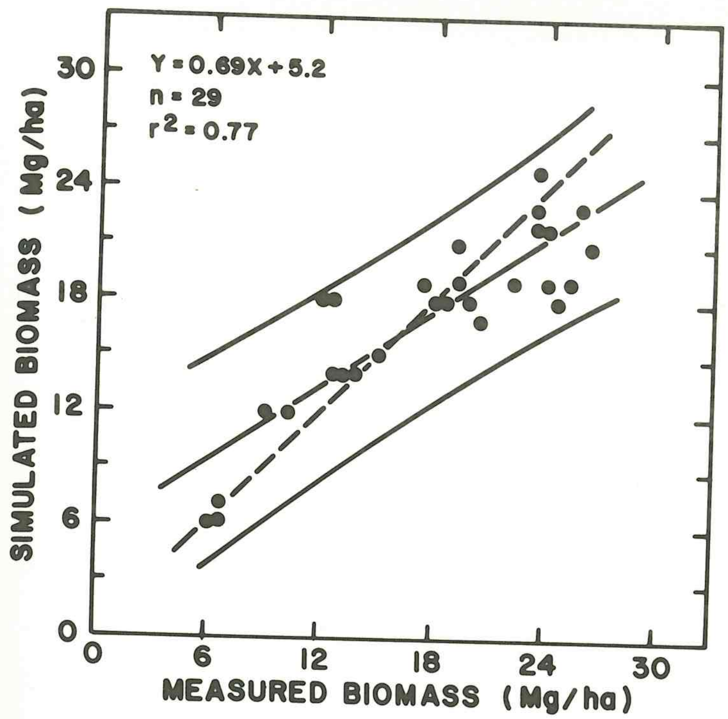

Fig. 5.11. Simulated and measured crop biomass at maturity for seven cultivars at seven sites using the nitrogen version of the model.

Total Nitrogen Uptake

Accurate simulation of total nitrogen uptake by the above-ground biomass is important because of its effect on the total nitrogen available for crop growth. The relationship between simulated and measured total nitrogen uptake is given for 18 observations representing four cultivars and four locations (Fig. 5.12). A highly significant relationship was found ($P = 0.0001$) with a slope of 0.72, an intercept of 33 kg N/ha, and an r^2 of 0.89. The 1:1 line was within the 95% confidence band for the regression line.

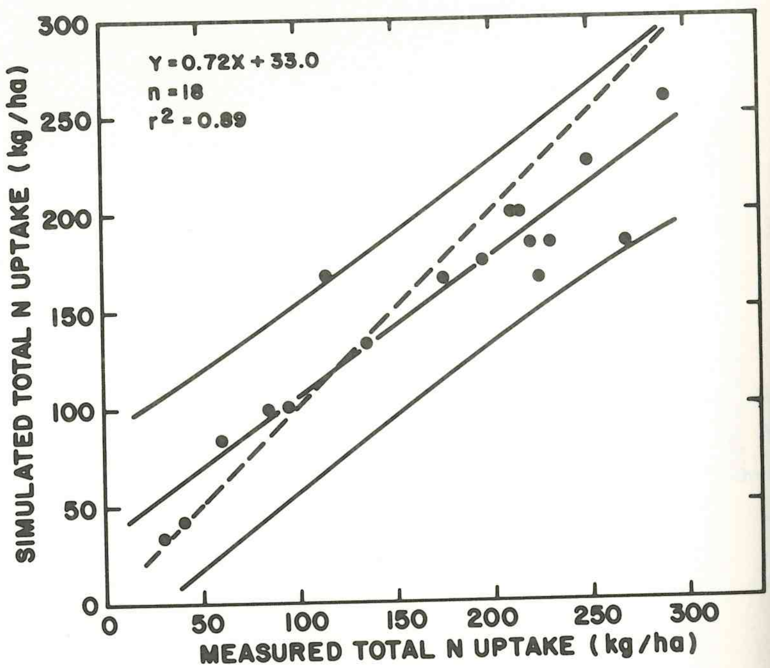

Fig. 5.12. Simulated and measured crop nitrogen uptake at maturity for four cultivars at four locations.

Grain Nitrogen Concentration

Grain nitrogen concentration is sensitive to nitrogen deficiency. The relationship between simulated and measured grain nitrogen concentration is given for 37 observations representing nine cultivars and seven locations (Fig. 5.13). A highly significant relationship was found (P = 0.0001) with a slope of 0.84, an intercept of 0.17, and an r^2 of 0.66. The 1:1 line was within the 95% confidence band for the regression line.

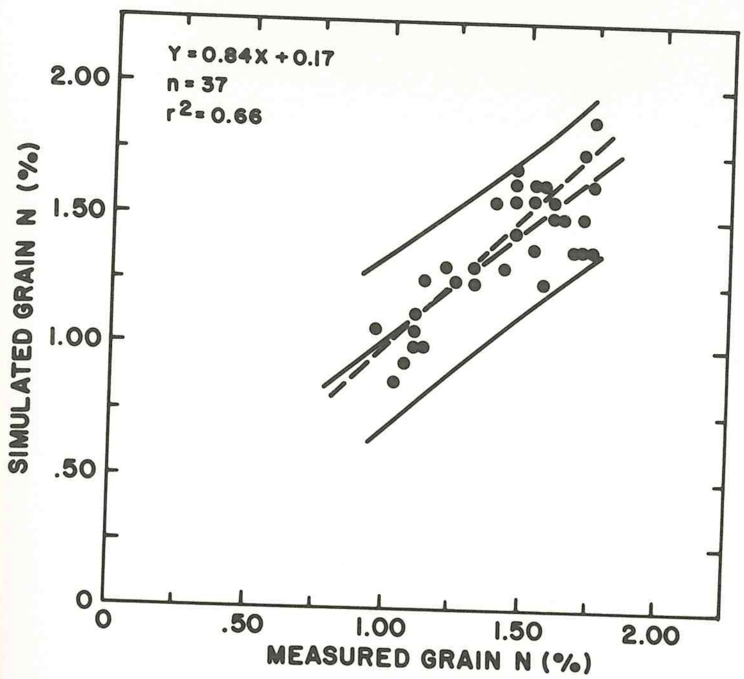

Fig. 5.13. Simulated and measured grain nitrogen concentration at maturity for nine cultivars at seven sites.

Total Nitrogen in the Grain

Total nitrogen translocated to the grain must be simulated accurately in order to simulate the effect of nitrogen deficiency on grain yield. The relationship between simulated and measured grain nitrogen content is given for 37 observations representing nine cultivars and seven locations (Fig. 5.14). A highly significant relationship was found ($P = 0.0001$), with a slope of 0.89, an intercept of 13 kg N/ha, and an r^2 of 0.88. The 1:1 line was within the 95% confidence band for the regression line.

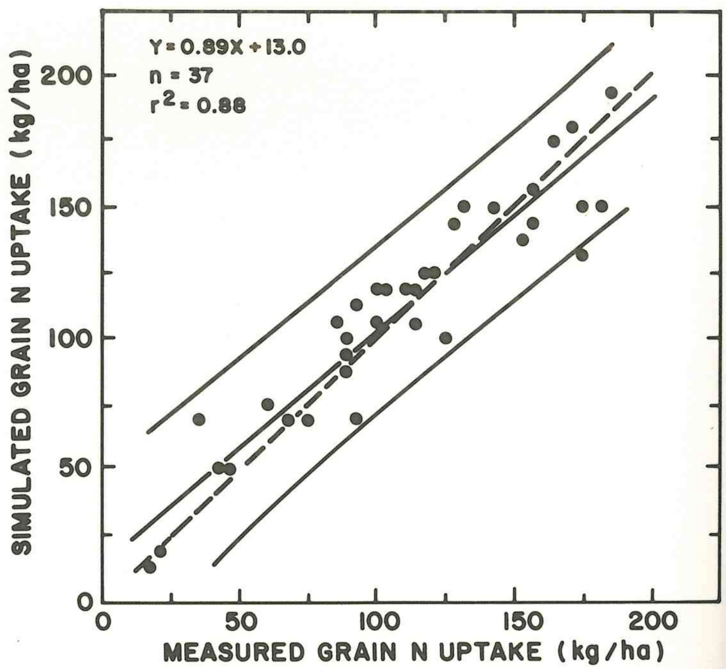

Fig. 5.14. Simulated and measured grain nitrogen uptake at maturity for nine cultivars at seven sites.

Grain Yield - Nitrogen Version

Grain yield is usually considered the most important variable simulated by the model. When nitrogen is deficient, yield depends on the amount of nitrogen taken up by the crop, the amount translocated to the grain, and the nitrogen concentration of the grain. The relationship between simulated and measured grain yield is given for 37 observations representing nine cultivars and seven locations (Fig. 5.15). A highly significant relationship was found, with a slope of 0.94, an intercept of 600 kg/ha, and an r^2 of 0.87. The regression line was nearly identical to the 1:1 line.

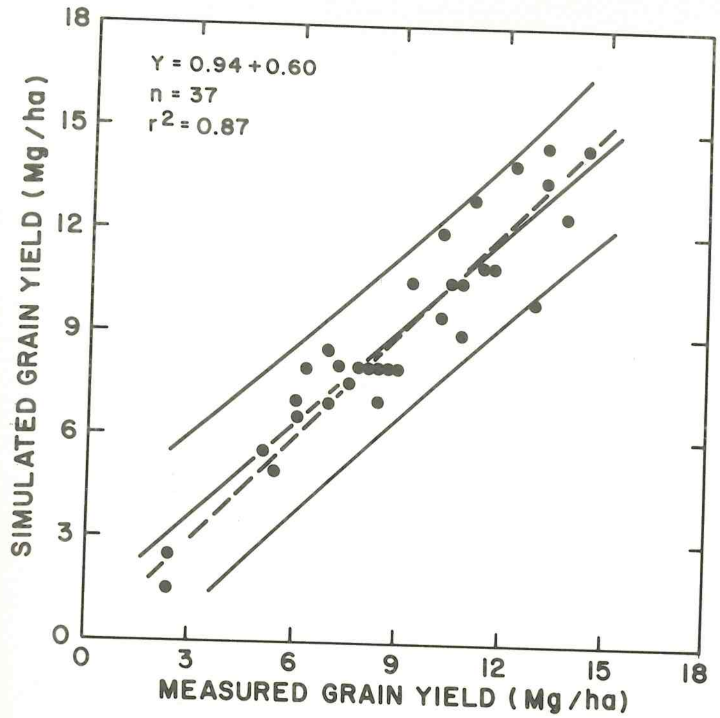

Fig. 5.15. Simulated and measured grain yield for nine cultivars at seven sites using the nitrogen version of the model.

In conclusion, the nitrogen version of the CERES-Maize model produces realistic simulations of the effects of nitrogen on biomass, total nitrogen uptake, grain nitrogen concentration, total nitrogen in the grain, and grain yield. The accuracy of the nitrogen components depend on (a) the ability of the non-nitrogen components to simulate growth and yield in the absence of nitrogen deficiency and (b) the accuracy with which initial soil conditions are measured. For this evaluation, the simulated results were highly correlated with measured results, the 1:1 line was within the 95% confidence band of the regression line, and the r^2 ranged from 0.66 to 0.89.

6. A Step-by-Step Procedure to Run the CERES-Maize Model on a Personal Computer

S. H. Parker[1]

The CERES-Maize (standard and nitrogen versions) source programs, compiled programs, and input and output files are on the two diskettes included with this publication. Lists of the programs and files on each diskette are in Tables 6.1 and 6.2. The following instructions will enable you to run the model, view the results, and change or create the input files.

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[1]The Texas Agricultural Experiment Station, Texas A&M University System, Blackland Research Center, Temple, Texas. All programs and information of the Texas Agricultural Experiment Station are available to everyone without regard to race, color, religion, sex, age, handicap, or national origin.

In order to run the CERES-Maize model, you must have an IBM-PC[2] compatible computer with at least 256K RAM memory, and the Microsoft Disk Operating System (MS-DOS), version 2.0 or higher. The MS-DOS diskette must be altered in order to run the model; therefore, a copy should be made to prevent possible errors during the alterations. If your computer has a resident MS-DOS on a hard disk, you should consult the person who installed it to make these alterations.

In this chapter, words within parentheses ( ) refer to the names of the files listed in Tables 6.1 and 6.2. When a file name is entered, the period and extension must be included as part of the name (i.e., always type the ".DAT" or ".FOR" following the file name). The spacing given in the text must be duplicated exactly, but commands can be in all capitals or lower case.

Words within brackets [ ] refer to specific keys on the keyboard. When more than one key is listed, they should be pressed in the order in which they were listed, held, and then released after all have been pressed. This is similar to the use of the shift key on a typewriter to obtain upper case letters.

A drive prompt appears at the bottom of the screen when the system is ready to execute a system command. It also indicates the diskette drive that the computer will read. On a computer with two diskette drives, the prompt will be either A >or B >. On a hard disk system, the hard disk is usually indicated by the prompt C >.

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[2]Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the Texas Agricultural Experiment Station or by the USDA-ARS and does not imply its approval to the exclusion of other products that also may be suitable.

TO PREPARE THE SYSTEM

Before the CERES models can be run for the first time, the operating system of the computer and the model diskettes must be prepared for operation. Once the MS-DOS and model diskettes have been prepared, steps 1 through 3 do not have to be repeated.

Step 1

If your system includes a hard disk drive, this step is unnecessary. Consult the person who installed the operating system on the hard disk, and have him perform step 2B.

If you have a copy of the MS-DOS diskette and are using it, go to step 2. If not, it is better to make a copy and use it to protect the original from possible errors.

Step 1A Making a copy of the MS-DOS diskette:

With the MS-DOS diskette in drive A, turn on the machine. When the prompts appear, enter the date and time, or simply press the return key twice. Now you will receive several lines of copyright information and the drive prompt A> . Insert a blank diskette in drive B and type:

DISKCOPY A: B: [RETURN]

The following prompts will appear:

Insert the Source Diskette in Drive A
Insert the Target Diskette in Drive B
Strike any key when ready

You have inserted both diskettes, so you may simply strike any key. When the copy is almost complete, the following prompt will appear:

Would you care to copy any more diskettes (Y/N)?

You should now type:

N

for "No" as your response.

The blank diskette has now been formatted and the MS-DOS files have been copied to it. Remove the original MS-DOS diskette from drive A and replace it with the copy you just created. Go to step 2.

Step 2 Altering the operating system:

The operating system must be altered slightly to accommodate the size and complexity of the CERES model. The CONFIG.SYS file must either be created or changed to allow the number of open files required by the model. If the system being used has diskette drives only, go to step 2A. If the system has a hard disk drive, go to step 2B.

Step 2A Altering the MS-DOS diskette:

The following instructions will use the EDLIN editor provided on the MS-DOS diskette. More complete instructions for use of this editor are included with the documentation received from Microsoft.

With a copy of the original MS-DOS diskette in drive A, type:

EDLIN CONFIG.SYS [RETURN]

If you receive the prompt:

End of Input File
*

the CONFIG.SYS file already exists. Go to step 2AA to continue.

If you receive the prompt:

New File
*

the CONFIG.SYS file has just been created. You should now type:

I1 [RETURN]

You will be prompted:

1:*

You are now in the insert mode. Any information you enter will appear to the right of the asterisk. Type:

FILES=20 [RETURN]

Now the prompt will be:

2:*

To leave the insert mode, press the [CTRL] and [BRK] keys. The prompt should now be:

*

In order to exit and save the file you have just created, type:

E [RETURN]

Your MS-DOS copy diskette is now ready for use. Go to step 3.

<u>Step 2AA Altering an existing CONFIG.SYS file:</u>

You should now type:

1P [RETURN]

This will give you a listing of the file CONFIG.SYS. If there is a line "FILES =", type in the number at the beginning of that line and [RETURN]. This places you in the alter mode. You will receive the prompt:

(line number):*FILES=(number)
(line number):*

When you begin typing, your input will appear just to the right of the asterisk on the second line. Type:

FILES=20 [RETURN]

The prompt should now be:

*

You are no longer in the alter mode.

If there is not a line "FILES=", type:

I1 [RETURN]

This places you in the insert mode. You will receive the prompt:

1:*

When you begin typing, your input will appear just to the right of the asterisk on this line. Type:

FILES=20 [RETURN]

The prompt should now be:

2:*

Press the [CTRL] and [BRK] keys to break out of the insert mode. The prompt should now be:

*

In order to exit and save the file you have just altered, type:

E [RETURN]

Your MS-DOS diskette is now ready for use. Go to step 3.

Step 2B Altering the MS-DOS on the hard disk:

The CERES models require up to eight files to be open at one time. The CONFIG.SYS file in the root directory of the hard disk must contain the line "FILES=20" to allow this. Please be sure to re-boot the operating system after making this alteration. Go to step 3.

Step 3 Copying EDLIN to the model diskettes:

Once the model has been run, EDLIN can be used for viewing the output files on the screen. It is more convenient if a copy of the EDLIN.COM file is on each of the CERES model diskettes. If you plan to print the files or use another method for viewing the results, this step is unnecessary.

With the MS-DOS diskette in drive A, insert the CERES standard model diskette in drive B and type:

COPY A:EDLIN.COM B: [RETURN]

Once the file has been copied, remove the CERES standard model diskette from drive B, replace it with the CERES nitrogen model diskette and type:

COPY A:EDLIN.COM B: [RETURN]

You are now ready to run either of the CERES models on your computer. Steps 1 through 3 are necessary only the first time you run the model.

TO RUN THE MODEL

To run either of the CERES models on an IBM-PC compatible computer you must have the special MS-DOS version loaded. If you have not created this special MS-DOS version, return to the section "To prepare the system." Once the alteration has been made, perform step 1. This step must be performed only if another version of the MS-DOS was used when the computer was turned on. Step 2 can be repeated as many times as desired after step 1 has been performed once.

Step 1 Loading the Operating System:

If you have a computer with a hard disk, be sure that there are no diskettes in any disk drives. If you have a computer with diskette drives only, insert the altered version of the MS-DOS diskette drive A. For either computer, press the following keys:

[CTRL] [ALT] [DEL]

When prompted, enter the date and time, or press the return key twice. You will receive several lines of copyright information and a drive prompt. Go to step 2.

Step 2 Running the model:

Refer to Tables 6.1 and 6.2 for model names and example parameter and weather file names to be entered.

With a model diskette in the prompted drive, type:

(Model name) [RETURN]

You will be prompted:

TYPE IN PARAMETER FILE NAME

Type:

(Parameter file name) [RETURN]

You will then be prompted:

TYPE IN WEATHER FILE NAME

Type:

(Weather file name) [RETURN]

The program is now executing the requested simulation and saving the data in the output files. This takes up to five minutes. The prompt:

STOP - PROGRAM TERMINATED

is normal. It simply means the program has finished. The output files can be viewed using the EDLIN commands as described in the following section.

TO LIST A FILE

To list any of the files on the diskette, except the compiled version of the program, you can use the EDLIN.COM editor provided on the MS-DOS diskette. It is more convenient to do so with the EDLIN.COM file on your model diskette. Instructions on

Table 6.1. Names and descriptions of files on the STANDARD model diskette.

Name**	Description
DIRECT.DAT	Directory of the files on the diskette
MODEL	
CERES.EXE	Compiled version of the CERES-Maize standard model
PARAMETER FILES (EXAMPLES)	
STDUL.DAT	Initial soil water at upper limit, irrigation specified
STDLL,DAT	Initial soil water at lower limit, no irrigation
STDSP.DAT	Initial soil water specified, irrigation specified
WEATHER FILE (EXAMPLE)	
STDWTH.DAT	1979 Missouri weather
DATA OUTPUT FILES	
OYLD.DAT	Yield information
OBIO.DAT	Biomass and leaf weight, etc.
OWAT.DAT	Water in the soil by layers
SOURCE PROGRAM FILES	
CERES1.FOR	MAIN program through subroutine WATBAL
CERES2.FOR	Subroutine PHENOL through subroutine CALDAT

**The names listed are those to be inserted when you are prompted during a run, or when you are listing a file. The entire name, including the period and extension, must be entered.

Table 6.2. Names and descriptions of files on the NITROGEN model diskette.

Name**	Description
DIRECT.DAT	Directory of the files on the diskette
MODEL	
CERESN.EXE	Compiled version of the CERES-Maize nitrogen model
PARAMETER FILES (EXAMPLES)	
NITLL.DAT	Initial soil water at lower limit, no irrigation specified, fertilizer specified
NITSP.DAT	Initial soil water specified, irrigation and fertilizer specified
WEATHER FILE (EXAMPLE)	
NITWTH.DAT	1981 Florence, South Carolina weather
DATA OUTPUT FILES	
OYLD.DAT	Yield information
OBIO.DAT	Biomass and leaf weight, etc.
OWAT.DAT	Water in the soil by layers
ONIS.DAT	Nitrogen in the soil by layers
OMIN.DAT	Mineralization information
ONIP.DAT	Nitrogen uptake by the plant
SOURCE PROGRAM FILES	
CERESN1.FOR	MAIN program through subroutine WATBAL
CERESN2.FOR	Subroutine PHENOL through subroutine CALDAT

Table 6.2. (cont.)

Name**	Description
CERESN3.FOR	Subroutine SOILNI through subroutine OUTNU

**The names listed are those to be inserted when you are prompted during a run, or when you are listing a file. The entire name, including the period and extension, must be entered.

copying this file are found in step 3 of the section "To Prepare the System."

To use the file you wish to list, insert the model diskette containing the file in the drive that matches the drive prompt and type:

EDLIN (name of file) [RETURN]

You should receive the prompt:

End of input file
*

Table 6.3 contains a list of ways that portions of the file you have just called can be displayed on the screen. In order to see the portion described on the right side of the table, type in the option listed on the left side and [RETURN].

If you misspell the name of the file and the prompt comes back that a new file has been created, simply type Q (for quit) and [RETURN]. When the prompt "Abort Edits (Y/N)?" appears, type Y

Table 6.3. EDLIN.COM list commands and their results.

Command	Result
P	This will display 23 lines of the file beginning with the line following the one with the asterisk beside it. If you have just called the file, it will begin with the first line.
1P	This will display the first 23 lines of the file.
(Line number)P	This will display 23 lines of the file beginning with the line you inserted for (Line number).
(First line),(Last line)P	This will display a specific range of lines of the file, beginning with the (First line) entered, and going through the (Last line).
[CTRL] [BRK]	Striking these two keys will stop a listing. This is useful if you have asked for a long range and no longer need to see it all.

for Yes, you do wish to abort the edit. This returns you to the system.

Now retype the "EDLIN" line, checking your spelling carefully. If you are still prompted that a new file has been created, check to be sure that the correct diskette is in the designated disk drive.

When you have finished listing a file and want to look at another, or simply do something else, type:

Q [RETURN]

You will see the prompt:

Abort Edits? (Y/N)

and you should type either

Y

if you are through or

N

if you decide you should return to viewing the file.

TO CREATE OR CHANGE A FILE

Either of the CERES models can be run using the demonstration files as they are, or by modifying them to simulate different situations. Chapters 2 and 3 should be read carefully before attempting to create or change any of the input files.

If you wish to create your own simulation input data, you must create a Parameter file and a Weather file. The following steps give instructions for creating these files using the EDLIN editor available on the MS-DOS diskette. It is more convenient to use this editor if it has been copied to the CERES model diskette. Step 3 in the section "To prepare the system" gives instructions for doing this. Any other editor familiar to the user can be used for these alterations.

The names of the files you create can be up to eight letters or numbers long. This name must be followed by the extension .DAT (i.e., STDLL.DAT or NITSP.DAT).

Step 1 Creating a new file:

To create a file, insert one of the model diskettes and type:

EDLIN (new file name) [RETURN]

You will receive the prompt:

New file
*

To enter data or make any changes or corrections, refer to steps 3, 4, and 5.

Once you are satisfied that the file is correct, type:

E [RETURN]

This will exit and save the file you just created.

Step 2 Changing an existing file:

To make changes or additions to an existing file, type:

EDLIN (name of existing file) [RETURN]

You should receive the prompt:

End of input file.
*

Refer to steps 3, 4, and 5 of this section to make the additions, changes, or deletions you need.

If you misspell the name of the file and the prompt indicates that a new file has been created, simply type Q (for "Quit") and [RETURN]. When the prompt "Abort Edits (Y/N)?" appears, type Y (for Yes, you do wish to abort the edit). This returns you to the system.

Now retype the "EDLIN" line, checking your spelling carefully. If you are still prompted that a new file has been created, check to be sure that the correct diskette is in the designated disk drive.

Once you are satisfied that the file is correct, type:

E [RETURN]

This will exit and save the file you just changed. The previous version of the file has now been renamed (file name).BAK. If you need to erase one of these backup files to make room on the diskettes, type:

ERASE (file name).BAK [RETURN]

Step 3 Creating new lines in a file:

To insert a new line of data in a file, type:

I(Line number) [RETURN]

If the file is new or empty, the Line number should be "1" and the prompt will be:

1:*

If the file has some data, and you need to insert a line between lines 7 and 8, type:

I8 [RETURN]

and you will receive the prompt:

8:*

meaning that the new line 8 can now be entered, and that the old line 8 is now line 9. This renumbering is taken care of automatically by EDLIN. After you have entered the new line of information and hit the [RETURN] key, you will receive the prompt:

9:*

If you need to insert another line, or a group of lines, simply enter the new line, strike the [RETURN] key, and continue until all the lines that need to be entered at this location have been completed. Remember to strike the [RETURN] key at the end of each complete line of data. If you notice a mistake after you strike the [RETURN] key, simply continue entering lines. Corrections can be made later using steps 4 and 5 of this section. After each line is entered, all lines following it are automatically renumbered by EDLIN.

Once you are through entering new lines, strike the [CTRL] and [BRK] keys. Your prompt should be:

*

If you need to insert several lines in different locations, carefully check each location before typing the line number to be inserted. Remember that the automatic renumbering process takes place following each insertion.

Step 4 Correcting existing data in a file:

To make corrections to an existing line of data, you must first locate the line. Refer to the "To list a file" section to determine the location of the error.

Once you know the location of the error, and the prompt is:

*

type:

(Line number to be corrected) [RETURN]

The entire line with the error will appear on the screen, followed by the prompt:

(Line number):*

The [F1] and [F3] keys can be used to copy part or all of the old line to the new line. The [F1] key will copy a single letter for each strike, or it can be held to copy rapidly across the line. The [F3] key copies the entire line with one strike. It is a good practice to press the [F3] key after any changes to be sure that the entire line has been copied.

If you need to change a letter or number in the line, strike the [F1] key until you reach the incorrect letter or number. Type in any corrections, and then continue copying the rest of the line. When the entire line is copied, press the [RETURN] key. YOU MUST COPY THE ENTIRE LINE! Once you strike the [RETURN] key, the line is entered as it appears by the second line number and asterisk. If you strike the [RETURN] key by accident before you are finished, you must type in the line number again, and add any information that was deleted.

If you need to insert a letter or group of letters, strike [F1] as many times as necessary to move the cursor to the position where the new letter is to be inserted and press the [INS] key. Anything typed now will be inserted into the text of the line, and the rest of the text will be shifted to the right. You remain in the insert mode until you either press the [INS] key again, or the [RETURN] key. Remember, if you strike the [RETURN] key without copying the rest of the line, the information will be deleted.

If you need to delete a letter or group of letters from a line, strike [F1] repeatedly to copy the line to the letter to be deleted, and then strike the [DEL] key. Each strike of the [DEL] key will delete a single character from the line. Once you have deleted the erroneous characters, the [F1] or [F3] keys can be used to copy the remainder of the line. The entire line of text will automatically be shifted to the left the same number of spaces as the number of characters that were deleted.

Step 5 Deleting entire lines of data from a file:

To delete an entire line of a file, type:

(Line number)D [RETURN]

where the (Line number) is the one to be deleted.

If you need to delete a group of lines, type:

(First line number),(Last line number)D [RETURN]

This will delete the line at the first location and all others after it, up to and including the line at the second location.

Both forms of line deletion cause the automatic renumbering of all lines following those deleted. Be very careful that the line numbers you are entering are the exact lines you wish to delete. If several single lines or groups of lines are to be deleted, remember to check after each deletion to find the exact location of the next lines to be deleted.

Appendix

The following are typical soil pedon data for 20 important agricultural soils in the U.S. The first two lines of each data set contain the soil series name and taxonomic classification. The third line contains estimates of the variables SALB, U, SWCON, and CN2 in the same format used in line 5 of the parameter file. Subsequent lines contain typical values of DLAYR, LL, DUL, SAT, WR, SW, OC, BD, PH, NH4, and NO3 by soil layer and in the same format used in the parameter file. Note that SW, NH4, and NO3 are set to zero. These values normally vary dramatically during the year, and the user should obtain accurate estimates of their initial values.

```
ASTATULA
HYPERTHERMIC UNCOATED TYPIC QUARTIZIPSAMMENT
.13 6.00 0.69 67.0
15.0 .040 .154 0.32 1.00 .000 0.53 1.35 5.80 00.0 00.0
23.0 .033 .124 0.28 0.59 .000 0.16 1.50 6.00 00.0 00.0
30.0 .033 .124 0.28 0.35 .000 0.16 1.50 6.00 00.0 00.0
30.0 .031 .115 0.27 0.19 .000 0.06 1.55 5.40 00.0 00.0
29.0 .031 .115 0.27 0.11 .000 0.06 1.55 5.40 00.0 00.0
25.0 .031 .115 0.27 0.06 .000 0.06 1.55 5.40 00.0 00.0
30.0 .031 .115 0.27 0.04 .000 0.06 1.55 5.40 00.0 00.0
18.0 .031 .114 0.27 0.02 .000 0.04 1.55 5.70 00.0 00.0
```

CECIL
CLAYEY, KAOLINITIC, THERMIC TYPIC HAPLUDULT
.16 9.00 0.20 78.0

15.0	.114	.246	0.35	1.00	.000	1.17	1.43	5.00	00.0	00.0
05.0	.120	.243	0.34	0.71	.000	0.64	1.52	5.00	00.0	00.0
13.0	.192	.317	0.38	0.59	.000	0.32	1.46	5.30	00.0	00.0
25.0	.244	.398	0.46	0.40	.000	0.22	1.28	5.30	00.0	00.0
13.0	.255	.421	0.48	0.25	.000	0.17	1.22	5.30	00.0	00.0
26.0	.263	.429	0.48	0.15	.000	0.11	1.23	4.90	00.0	00.0
30.0	.201	.385	0.46	0.09	.000	0.07	1.25	4.90	00.0	00.0

CRIDER
FINE-SILTY, MIXED, MESIC TYPIC PALEUDALF
.14 12.0 0.25 78.0

15.0	.163	.316	.384	1.00	.000	0.86	1.36	5.60	00.0	00.0
03.0	.163	.316	.384	0.72	.000	0.86	1.36	5.60	00.0	00.0
23.0	.164	.326	.390	0.55	.000	0.32	1.36	5.60	00.0	00.0
27.0	.173	.374	.446	0.34	.000	0.28	1.18	5.60	00.0	00.0
23.0	.168	.344	.413	0.22	.000	0.22	1.28	5.60	00.0	00.0
26.0	.166	.342	.415	0.13	.000	0.12	1.26	6.00	00.0	00.0
27.0	.216	.372	.421	0.07	.000	0.07	1.34	5.90	00.0	00.0
26.0	.213	.370	.420	0.04	.000	0.08	1.34	5.90	00.0	00.0
30.0	.218	.370	.418	0.03	.000	0.06	1.35	6.00	00.0	00.0

HAGERSTOWN
FINE, MIXED, MESIC TYPIC HAPLUDALF
.13 12.0 0.11 85.0

15.0	.176	.314	.407	1.00	.000	3.35	1.20	6.52	00.0	00.0
08.0	.202	.304	.362	0.68	.000	0.89	1.46	6.60	00.0	00.0
30.0	.301	.413	.434	0.47	.000	0.39	1.42	5.80	00.0	00.0
30.0	.298	.419	.445	0.26	.000	0.27	1.37	5.60	00.0	00.0
30.0	.298	.419	.445	0.14	.000	0.27	1.37	5.60	00.0	00.0
30.0	.319	.448	.470	0.08	.000	0.23	1.32	6.10	00.0	00.0
28.0	.319	.448	.470	0.04	.000	0.23	1.32	6.10	00.0	00.0
29.0	.319	.448	.470	0.03	.000	0.23	1.32	6.10	00.0	00.0

HANFORD

COARSE-LOAMY, MIXED, NONACID, THERMIC TYPIC XERORTHENT

.15 9.00 0.46 78.0

15.0	.088	.185	.277	1.00	.000	0.51	1.67	7.20	00.0	00.0
15.0	.088	.185	.277	0.64	.000	0.51	1.67	7.20	00.0	00.0
30.0	.099	.229	.326	0.41	.000	0.41	1.53	7.80	00.0	00.0
30.0	.085	.183	.271	0.22	.000	0.22	1.70	8.00	00.0	00.0
30.0	.051	.150	.245	0.12	.000	0.06	1.75	7.60	00.0	00.0
15.0	.051	.150	.245	0.08	.000	0.06	1.75	7.60	00.0	00.0
23.0	.036	.106	.223	0.05	.000	0.03	1.75	7.70	00.0	00.0
27.0	.036	.106	.223	0.03	.000	0.03	1.75	7.70	00.0	00.0
15.0	.033	.094	.217	0.02	.000	0.03	1.75	7.60	00.0	00.0

HIDALGO

FINE-LOAMY, MIXED, HYPERTHERMIC TYPIC CALCIUSTOLL

.15 9.00 0.33 78.0

15.0	.130	.261	.357	1.00	.000	0.88	1.45	7.80	00.0	00.0
15.0	.130	.261	.357	0.64	.000	0.88	1.45	7.80	00.0	00.0
30.0	.131	.268	.362	0.41	.000	0.72	1.44	8.10	00.0	00.0
28.0	.169	.308	.394	0.23	.000	0.55	1.38	8.10	00.0	00.0
19.0	.169	.306	.389	0.14	.000	0.38	1.40	7.90	00.0	00.0
30.0	.174	.304	.382	0.09	.000	0.22	1.43	8.00	00.0	00.0
30.0	.179	.328	.409	0.05	.000	0.13	1.35	7.80	00.0	00.0
30.0	.179	.328	.409	0.03	.000	0.10	1.35	8.00	00.0	00.0

HOUSTON BLACK

FINE, MONTMORILLONITIC, THERMIC UDIC PELLUSTERT

.13 9.00 0.13 89.0

15.0	.292	.429	.469	1.00	.000	1.50	1.25	7.99	00.0	00.0
13.0	.292	.429	.469	0.72	.000	1.50	1.25	7.99	00.0	00.0
30.0	.289	.444	.487	0.52	.000	1.28	1.20	8.26	00.0	00.0
23.0	.298	.445	.478	0.30	.000	1.09	1.25	8.19	00.0	00.0
20.0	.302	.444	.470	0.20	.000	0.84	1.30	7.98	00.0	00.0
21.0	.301	.445	.477	0.13	.000	0.87	1.26	7.95	00.0	00.0
23.0	.285	.428	.461	0.09	.000	0.47	1.30	8.07	00.0	00.0
25.0	.277	.411	.441	0.05	.000	0.38	1.36	8.27	00.0	00.0
20.0	.269	.411	.447	0.03	.000	0.28	1.32	8.18	00.0	00.0
20.0	.269	.411	.447	0.02	.000	0.28	1.32	8.18	00.0	00.0

JUDITH
FINE-LOAMY, CARBONATIC, TYPIC CALCIBOROLL
.13 9.00 0.26 78.0

15.0	.192	.340	.423	1.00	.000	2.06	1.20	7.80	00.0	00.0
08.0	.224	.363	.435	0.68	.000	1.74	1.21	7.80	00.0	00.0
30.0	.238	.352	.410	0.47	.000	1.40	1.33	7.90	00.0	00.0
28.0	.240	.342	.389	0.26	.000	0.56	1.43	8.10	00.0	00.0
25.0	.211	.316	.366	0.15	.000	0.27	1.48	8.00	00.0	00.0
30.0	.153	.287	.346	0.09	.000	0.20	1.50	0.00	00.0	00.0
30.0	.139	.275	.339	0.05	.000	0.07	1.50	0.00	00.0	00.0
30.0	.139	.275	.339	0.03	.000	0.07	1.50	0.00	00.0	00.0

KEITH
FINE-SILTY, MIXED, MESIC ARIDIC ARGIUSTOLL
.14 12.0 0.37 78.0

15.0	.147	.299	.391	1.00	.000	1.08	1.25	6.50	00.0	00.0
15.0	.174	.329	.409	0.64	.000	0.54	1.25	7.30	00.0	00.0
25.0	.175	.349	.432	0.43	.000	0.66	1.15	7.40	00.0	00.0
30.0	.164	.343	.428	0.25	.000	0.51	1.15	7.80	00.0	00.0
30.0	.123	.267	.356	0.14	.000	0.31	1.35	8.20	00.0	00.0
28.0	.121	.269	.358	0.08	.000	0.21	1.35	8.50	00.0	00.0
30.0	.121	.269	.358	0.04	.000	0.21	1.35	8.50	00.0	00.0
27.0	.114	.266	.356	0.02	.000	0.17	1.35	8.60	00.0	00.0

LAKE CHARLES
FINE, MONTMORILLONITIC, THERMIC TYPIC PELLUDERT
.13 9.00 0.16 89.0

15.0	.243	.344	0.39	1.00	.000	1.20	1.43	5.70	00.0	00.0
03.0	.243	.344	0.39	0.72	.000	1.20	1.43	5.70	00.0	00.0
20.0	.252	.370	0.42	0.57	.000	1.23	1.35	5.60	00.0	00.0
24.0	.253	.352	0.39	0.37	.000	1.01	1.45	5.90	00.0	00.0
22.0	.256	.366	0.41	0.23	.000	0.72	1.42	6.50	00.0	00.0
30.0	.264	.389	0.43	0.14	.000	0.57	1.36	7.00	00.0	00.0
28.0	.282	.414	0.45	0.08	.000	0.48	1.34	7.30	00.0	00.0
30.0	.280	.411	0.44	0.04	.000	0.25	1.35	7.70	00.0	00.0
28.0	.274	.404	0.44	0.02	.000	0.12	1.36	7.90	00.0	00.0

MARLETTE

FINE-LOAMY, MIXED, MESIC GLOSSOBORIC HAPLUDALF

.13 9.00 0.34 78.0

15.0	.102	.198	.309	1.00	.000	1.56	1.54	5.80	00.0	00.0
13.0	.102	.198	.309	0.65	.000	1.56	1.54	5.80	00.0	00.0
08.0	.091	.146	.222	0.53	.000	0.33	1.86	6.20	00.0	00.0
15.0	.144	.240	.307	0.42	.000	0.21	1.66	6.00	00.0	00.0
16.0	.159	.258	.325	0.31	.000	0.22	1.61	6.20	00.0	00.0
19.0	.135	.228	.305	0.22	.000	0.14	1.64	7.90	00.0	00.0
30.0	.108	.154	.226	0.13	.000	0.14	1.86	8.00	00.0	00.0
30.0	.102	.144	.215	0.07	.000	0.07	1.89	8.10	00.0	00.0
30.0	.102	.144	.215	0.04	.000	0.07	1.89	8.10	00.0	00.0
24.0	.102	.144	.215	0.02	.000	0.07	1.89	8.10	00.0	00.0

NEBISH

FINE-LOAMY, MIXED, TYPIC EUTROBORALF

.13 9.00 0.21 78.0

15.0	.078	.193	.323	1.00	.000	2.03	1.45	6.70	00.0	00.0
03.0	.080	.226	.349	0.72	.000	0.90	1.40	6.60	00.0	00.0
05.0	.121	.247	.359	0.66	.000	1.40	1.40	5.80	00.0	00.0
07.0	.121	.247	.359	0.59	.000	1.40	1.40	5.80	00.0	00.0
30.0	.188	.254	.287	0.41	.000	1.80	1.57	5.50	00.0	00.0
26.0	.145	.224	.272	0.23	.000	1.30	1.57	5.20	00.0	00.0
30.0	.152	.241	.281	0.13	.000	0.80	1.57	6.20	00.0	00.0
30.0	.132	.221	.309	0.07	.000	0.50	1.60	7.60	00.0	00.0
30.0	.153	.241	.319	0.04	.000	0.20	1.60	8.10	00.0	00.0
24.0	.153	.241	.319	0.02	.000	0.20	1.60	8.10	00.0	00.0

PARLEYS

FINE-SILTY, MIXED, MESIC CALCIC ARGIXEROLL

.14 9.00 0.31 78.0

15.0	.142	.316	.409	1.00	.000	0.83	1.20	7.70	00.0	00.0
15.0	.159	.329	.416	0.64	.000	0.80	1.20	7.70	00.0	00.0
13.0	.202	.352	.423	0.48	.000	0.49	1.25	7.70	00.0	00.0
21.0	.192	.360	.427	0.34	.000	0.40	1.25	8.00	00.0	00.0
17.0	.183	.345	.418	0.24	.000	0.27	1.25	8.40	00.0	00.0
30.0	.178	.318	.384	0.15	.000	0.08	1.37	8.80	00.0	00.0
30.0	.187	.334	.394	0.08	.000	0.06	1.37	8.60	00.0	00.0
30.0	.187	.334	.394	0.04	.000	0.06	1.37	8.60	00.0	00.0
29.0	.187	.334	.394	0.03	.000	0.06	1.37	8.60	00.0	00.0

RITZVILLE
COARSE-SILTY, MIXED, MESIC CALCIORTHIDIC HAPLOXEROLL
.14 12.0 0.38 78.0

15.0	.167	.335	.420	1.00	.000	0.77	1.20	6.20	00.0	00.0
15.0	.167	.335	.420	0.64	.000	0.77	1.20	6.20	00.0	00.0
15.0	.167	.337	.421	0.47	.000	0.64	1.20	6.50	00.0	00.0
25.0	.167	.337	.421	0.32	.000	0.64	1.20	6.50	00.0	00.0
20.0	.162	.315	.393	0.20	.000	0.47	1.30	7.10	00.0	00.0
20.0	.163	.318	.395	0.14	.000	0.35	1.30	8.20	00.0	00.0
30.0	.163	.316	.393	0.08	.000	0.42	1.30	8.60	00.0	00.0
25.0	.084	.250	.354	0.05	.000	0.28	1.30	9.10	00.0	00.0
30.0	.082	.217	.319	0.03	.000	0.24	1.40	9.00	00.0	00.0

SHARKEY
VERY-FINE, MONTMORILLONITIC, NONACID, THERMIC VERTIC HAPLAQUEPT
.15 9.00 0.16 89.0

15.0	.224	.362	.413	1.00	.000	1.52	1.35	6.53	00.0	00.0
05.0	.228	.367	.416	0.71	.000	1.48	1.35	6.60	00.0	00.0
13.0	.246	.383	.426	0.59	.000	1.44	1.35	6.80	00.0	00.0
28.0	.246	.383	.426	0.39	.000	1.44	1.35	6.80	00.0	00.0
30.0	.245	.384	.427	0.22	.000	1.10	1.35	6.60	00.0	00.0
30.0	.259	.400	.436	0.12	.000	0.71	1.35	6.70	00.0	00.0
30.0	.259	.400	.436	0.07	.000	0.71	1.35	6.70	00.0	00.0
30.0	.261	.398	.426	0.04	.000	0.46	1.40	7.00	00.0	00.0
19.0	.261	.398	.426	0.02	.000	0.46	1.40	7.00	00.0	00.0

TAMA
FINE-SILTY, MIXED, MESIC TYPIC ARGIUDOLL
.13 12.0 0.28 78.0

15.0	.185	.355	.432	1.00	.000	1.77	1.20	7.30	00.0	00.0
07.0	.185	.355	.432	0.69	.000	1.77	1.20	7.30	00.0	00.0
16.0	.195	.328	.387	0.55	.000	1.42	1.39	6.60	00.0	00.0
29.0	.204	.345	.400	0.35	.000	1.13	1.37	5.90	00.0	00.0
28.0	.204	.353	.407	0.20	.000	0.79	1.36	5.70	00.0	00.0
28.0	.188	.333	.390	0.11	.000	0.54	1.40	5.60	00.0	00.0
30.0	.169	.314	.376	0.06	.000	0.29	1.41	5.50	00.0	00.0
20.0	.145	.252	.323	0.04	.000	0.20	1.51	6.00	00.0	00.0
29.0	.145	.223	.273	0.02	.000	0.07	1.73	5.80	00.0	00.0

WILEY
FINE-SILTY, MIXED, MESIC USTOLLIC HAPLARGID
.13 12.0 0.37 78.0

15.0	.150	.282	.370	1.00	.000	1.05	1.32	7.81	00.0	00.0
15.0	.155	.285	.367	0.64	.000	0.75	1.35	7.90	00.0	00.0
28.0	.164	.303	.378	0.42	.000	0.47	1.35	8.00	00.0	00.0
26.0	.160	.304	.379	0.24	.000	0.30	1.35	8.00	00.0	00.0
26.0	.144	.290	.370	0.14	.000	0.18	1.35	8.30	00.0	00.0
30.0	.161	.310	.382	0.08	.000	0.17	1.35	8.70	00.0	00.0
30.0	.161	.310	.382	0.05	.000	0.17	1.35	8.70	00.0	00.0
30.0	.161	.310	.382	0.03	.000	0.17	1.35	8.70	00.0	00.0

WILLIAMS
FINE-LOAMY, MIXED, TYPIC ARGIBOROLL
.13 9.00 0.34 78.0

15.0	.175	.319	.413	1.00	.000	2.81	1.18	7.18	00.0	00.0
10.0	.199	.351	.423	0.67	.000	1.26	1.24	7.11	00.0	00.0
26.0	.186	.326	.399	0.47	.000	1.01	1.30	7.88	00.0	00.0
25.0	.195	.325	.394	0.28	.000	0.55	1.33	8.30	00.0	00.0
28.0	.185	.316	.381	0.17	.000	0.36	1.38	8.65	00.0	00.0
25.0	.185	.316	.381	0.10	.000	0.36	1.38	8.65	00.0	00.0
30.0	.171	.299	.368	0.06	.000	0.28	1.40	8.28	00.0	00.0
25.0	.171	.299	.368	0.32	.000	0.28	1.40	8.28	00.0	00.0
16.0	.171	.299	.368	0.02	.000	0.28	1.40	8.28	00.0	00.0

WOODBURN
FINE-SILTY, MIXED, MESIC AQUULTIC ARGIXEROLL
.13 12.0 0.45 85.0

15.0	.110	.215	.312	1.00	.000	1.86	1.44	5.90	00.0	00.0
08.0	.110	.215	.312	0.68	.000	1.86	1.44	5.90	00.0	00.0
20.0	.112	.215	.298	0.52	.000	0.56	1.53	6.20	00.0	00.0
21.0	.128	.252	.334	0.34	.000	0.34	1.44	6.00	00.0	00.0
17.0	.117	.242	.325	0.24	.000	0.25	1.46	5.80	00.0	00.0
18.0	.113	.252	.340	0.17	.000	0.14	1.40	5.70	00.0	00.0
30.0	.110	.240	.328	0.10	.000	0.09	1.43	5.90	00.0	00.0
30.0	.122	.263	.351	0.06	.000	0.07	1.37	5.90	00.0	00.0
30.0	.112	.255	.346	0.03	.000	0.06	1.37	6.00	00.0	00.0

Glossary

The following section is a glossary of important variables used in the CERES-Maize model. Many intermediate variables used for ease of computation or for ease of output are not included in the glossary. The function of intermediate variables can be determined by examination of the code.

A	- index of daily nitrification potential (0-1)
AFERT(J)	- amount of fertilizer nitrogen added on JFDAY(J) (kg N/ha)
AIRR(J)	- amount of irrigation added on JDAY(J) (mm)
ALBEDO	- integrated crop and soil albedo (unitless)
ALX	- current day of year as a radian fraction of one year for soil temperature calculations
AMP	- annual amplitude in mean monthly temperature (°C)
ANDEM	- crop nitrogen demand (kg N/ha)
ANG	- factor to convert day of year to radian fraction of year
ACOS	- FORTRAN function for calculating the arcosine in radians
AW	- available water used in soil temperature calculations (cm)

B	-	interim variable used in the gamma function to predict soil temperature
BD	-	moist bulk density of soil (g/cm^3)
BIOMAS	-	the accumulated dry weight biomass of plant material following seedling emergence (g/m^2)
CARBO	-	the daily biomass production (g/plant)
CEP	-	cumulative transpiration after germination (mm)
CES	-	cumulative evaporation after germination (mm)
CET	-	cumulative evapotranspiration after germination (mm)
CNI	-	index for microbial nitrification (0-1)
CNR	-	C:N ratio calculated; used to calculate residue decomposition
CNRF	-	C:N ratio factor for decomposition rate (0-1)
CNSD1	-	average nitrogen deficit factor (NDEF1) during a growth stage
CNSD2	-	average nitrogen deficit factor (NDEF2) during a growth stage
CN1	-	intermediate quantity used to calculate daily runoff
CN2	-	curve number input used to calculate daily runoff
CRAIN	-	cumulative precipitation after germination (mm)
CSD1	-	average soil water deficit factor (SWDF1) during a growth stage
CSD2	-	average soil water deficit factor (SWDF2) during a growth stage
CTNUP	-	cumulative total plant nitrogen uptake (kg N/ha)
CUMDEP	-	cumulative depth of the soil profile (cm)

CUMDTT - cumulative daily thermal time after germination (°C d)

CUMPH - cumulative phyllochron intervals or fully expanded leaves

CW - carbon availability factor

C1 - cosine of the latitude, used for day length calculation

DBAR - average soil water diffusivity used to calculate upward flow in top layers

DEC - solar declination angle (radians)

DECR(I) - residue decomposition rate in layer I for the day

DEF - interim variable used to ensure soil nitrogen pools remain positive

DEPMAX - maximum depth of root zone (mm)

DEPTH - depth of root zone below the surface (mm)

DFERT - depth of incorporation of fertilizer (cm)

DLAYR(I) - thickness of soil layer I (cm)

DL1 - upper depth limit of a soil layer (mm)

DL2 - lower depth limit of a soil layer (mm)

DM - above-ground dry matter (kg/ha)

DMINR - humic fraction decay rate (1/d)

DMOD - basic mineralization rate factor (0-1)

DNG - nitrogen demand of potential new growth of tops (g N/plant)

DNRATE - denitrification rate (kg N/ha d)

DP - maximum damping depth for the soil layer (mm)

DRAIN - drainage rate from a layer (cm/d)

DROOTN - daily change in plant root nitrogen content (g N/plant)

DSTOVSN - daily change in plant tops nitrogen content (g N/plant)

DT - temperature range (max - min) (°C)

DTNOX	- denitrification loss from layer L (kg N/ha)
DTT	- daily accumulation of growing degree days (°C d)
DUL(L)	- drained upper limit soil water content for soil layer L (cm/cm)
EARS	- ear number (ears/m^2)
EARWT	- ear weight (g/ear)
EEQ	- equilibrium evaporation rate (mm/day)
ELNC	- nitrification capacity factor (0-1)
EO	- potential evapotranspiration (mm/d)
EOS	- potential rate of soil evaporation (mm/d)
EP	- actual plant evaporation (transpiration) (mm/d)
ES	- actual soil evaporation (mm/d)
ESW(L)	- extractable soil water content for soil layer L (cm/cm)
FAC(L)	- factor that converts mg elemental N/kg soil to kg N/ha for layer L
FACTOR	- weighting factor to distribute crop root residues at the beginning of run
FLOW	- volume of water moving from layer L because of unsaturated flow; positive value indicates upward movement, negative value indicates downward movement (cm)
FLUX(L)	- water moving downward into layer L (cm)
FNH4	- potential nitrogen availability factor for NH4 (0-1)
FNO3	- potential nitrogen availability factor for NO3 (0-1)
FOCNR	- C:N ratio of the decaying crop residue (FOM) in layer L
FOM(L)	- fresh organic matter (residue) in layer L (kg/ha)

FON(L)	–	nitrogen in fresh organic matter in layer L (kg N/ha)
FT	–	temperature factor affecting denitrification rate
FTYPE(M)	–	fertilizer type code
FW	–	soil moisture factor affecting denitrification rate (0–1)
GNP	–	grain nitrogen concentration (g N/g grain)
GNUP	–	nitrogen concentration in daily increment of grain growth (g N/g dry matter)
GPP	–	grain number (grains/plant)
GPSM	–	grain number (grains/m^2)
GRAINN	–	grain nitrogen pool (g N/plant)
GRF	–	growth factor for above-ground biomass
GRNOM	–	gross release of nitrogen from organic matter
GRNWT	–	grain weight (g/plant)
GROEAR	–	ear growth rate (g/ear d)
GROGRN	–	grain growth rate (g/plant d)
GROLF	–	leaf growth rate (g/plant d)
GRORT	–	root growth rate (g/plant d)
GROSTM	–	stem growth rate (g/plant d)
G2	–	maximum kernel number (kernels/plant)
G3	–	potential kernel growth rate (mg/kernel d)
HOLD	–	the amount of water a soil layer will hold above its present level, used to calculated downward flow (cm)
HRLT	–	day length including civil twilight (h)
HUM(L)	–	stable organic matter in layer L (kg/ha)
ICSDUR	–	accumulates days of each growth stage for calculating mean soil water deficit factors CSD1 and CSD2
IDIM(I)	–	days in month I

IDURP	- duration of ISTAGE 4 (d)
IFOM(I)	- initial fresh organic matter in layer L (kg/ha)
IFON(I)	- initial nitrogen in fresh organic matter in layer L (kg/ha)
IFTYPE(J)	- code number for type of fertilizer
IIRR	- switch describing irrigation management
INSOIL	- switch describing initial soil water
ISOW	- day of year of sowing
IST	- number of layers considered in unsaturated flow
ISTAGE	- phenological stage
ISWSWB	- switch that determines whether the model calculates the soil water components of the model (standard version only)
IYR	- last two digits of current simulation year
JDATE	- day of year
JDATEX	- index number; equals 367 on first day of execution
JDAY(I)	- day of year of irrigation
JFDAY(J)	- day of year of fertilizer application J
KOUTGR	- frequency in days for printing growth output
KOUTMN	- frequency in days for printing mineralization output
KOUTNB	- frequency in days for printing soil nitrogen output
KOUTNU	- frequency in days for printing plant nitrogen output
KOUTWA	- frequency in days for printing water use output
LAI	- leaf area index (m^2 leaf/m^2 land)
LAT	- latitude (degrees, negative for southern hemisphere)
LFWT	- leaf weight (g/plant)

LL(L)	- lower limit of plant-extractable soil water for soil layer L (cm/cm)
LN	- number of leaf tips that have emerged
LO	- layer in the soil identified with the sowing depth
LWMIN	- minimum leaf weight allowed during grain filling (g/plant)
MAXLAI	- predicted LAI at silking for output
MF	- moisture factor for layer I (0-1)
MO	- number of month of year
NAME	- name of the cultivar
ND	- day of the month
NDAS	- number of days after sowing
NDEF1	- nitrogen deficiency factor for crop photosynthesis rate (0-1)
NDEF2	- nitrogen deficiency factor for leaf senescence and grain nitrogen concentration (0-1)
NDEM	- total nitrogen demand per plant (g N/plant)
NFAC	- nitrogen stress factor based on actual and critical nitrogen concentrations (0-1)
NFERT	- number of fertilizer applications
NHUM(I)	- nitrogen associated with the stable humic fraction in layer I (kg N/ha)
NH4(L)	- soil ammonium in layer L (mg elemental N/ kg soil)
NLAYR	- number of layers in soil
NNOM(I)	- net nitrogen released from all organic sources in layer, (kg N/ha)
NOUT(L)	- nitrate nitrogen leaching from a layer (kg N/ha)
NO3(L)	- soil nitrate in layer L (mg elemental N/kg soil)
NPOOL	- sum of nitrogen available in plant for grain (g/plant)

NPOOL1	-	nitrogen available in stover for grain (g/plant)
NPOOL2	-	nitrogen available in roots for grain (g/plant)
NSINK	-	total nitrogen demand of growing grain
NSDR	-	factor used to reduce grain nitrogen demand (0-1)
NUF	-	nitrogen uptake factor relating supply and plant demand (dimensionless)
NUP(L)	-	nitrogen movement out of a layer by upflux (kg N/ha)
OC(L)	-	organic carbon concentration in layer L (%)
PAR	-	photosynthetically active radiation (MJ/m^2 d)
PCARB	-	potential dry matter production with optimum water, nitrogen, and temperature conditions (g/plant)
PDWI	-	potential shoot dry weight increase (g/plant)
PESW	-	total plant-extractable soil water in the profile (cm)
PGRORT	-	potential new root growth (g/plant)
PH(L)	-	pH of soil in layer L in a 1:1 soil:water slurry
PINF	-	precipitation that infiltrates into the soil (cm)
PLA	-	total plant leaf area (cm^2/plant)
PLAG	-	leaf area growth (cm^2/plant)
PLANTS	-	plant population ($plants/m^2$)
PLAS	-	leaf senescence rate (cm^2/d)
PNUP(L) or (I)	-	potential nitrogen uptake from a layer (kg/ha)
POMR	-	fresh organic matter remaining in a layer (%)
PONR	-	fresh organic nitrogen remaining in a layer (%)
PRECIP	-	sum of irrigation and rain (mm)
PRFT	-	photosynthetic reduction factor for low and high temperatures (0-1)
PSKER	-	average rate of photosynthesis during ISTAGE 4

PTF	- ratio of above-ground biomass to total biomass
P1	- growing degree days (base 8°C) from seedling emergence to the end of the juvenile phase
P2	- photoperiod sensitivity coefficient (1/hr)
P3	- cumulative growing degree days (base 8°C) required to complete ISTAGE 3
P5	- cumulative growing degree days (base 8°C) from silking to physiological maturity
P9	- cumulative growing degree days (base 8°C) from germination to seedling emergence
RAIN	- precipitation (mm/d)
RANC	- root actual nitrogen concentration (g N/g root)
RATEIN	- rate of floral induction (sums to 1.0)
RATIO	- ratio of current fresh organic matter to initial fresh organic matter
RCN	- root residue C:N ratio (kg C/kg N)
RCNP	- root critical nitrogen concentration (g N/g root)
RDCARB	- maximum rate constant for decay of residue carbohydrate fraction (1/d)
RDCELL	- maximum rate constant for decay of residue cellulose fraction (1/d)
RDECR	- maximum rate constant for decay of residue components (1/d)
RDLIGN	- maximum rate constant for decay of residue lignin fraction (1/d)
RFAC	- interim variable describing the effects of water stress and root length density on potential nitrogen uptake from a layer
RGFILL	- relative rate of grain fill (0-1)
RHMIN	- nitrogen mineralized from stable organic matter in a layer (kg N/ha)

RLDF(L) - root length density factor for soil layer L used to calculate new root growth distribution (0-1)

RLNEW - new root length to be added to the total root system length (cm root/cm^2 land)

RLV(L) - root length density for soil layer L (cm root/cm^3 soil)

RMNC - minimum root nitrogen concentration (g N/g dry weight)

RNAC - gross rate of nitrogen immobilization associated with the decay of residues (kg N/ha d)

RNDEM - plant root demand for nitrogen (g/plant)

RNFAC(L) - factor describing mineral nitrogen availability effect on root growth in layer L (0-1)

RNH4U(L) - potential ammonium uptake from layer L (kg N/ha)

RNKG - nitrogen contained in root residue of previous crop (kg N/ha)

RNLF - factor used to calculate distribution of new root growth in the soil (0-1)

RNLOSS(L) - nitrogen loss from roots in a layer (kg N/ha)

RNO3U(L) - potential nitrate uptake from layer L (kg N/ha)

RNTRF(L) - rate of nitrification for layer L (kg N/ha)

ROOT - dry weight of root residue of previous crop (kg/ha)

ROOTN - plant root nitrogen content (g N/plant)

RTDEP - depth of rooting (cm)

RTWT - root weight (g/m^2)

RUNOFF - daily runoff (cm)

RWU(L) - maximum water uptake per unit root length, constrained by soil water (cm^3 water/cm root)

RWUMX	- maximum water uptake per unit root length, not constrained by soil water (cm^3 water/cm root)
SALB	- bare soil albedo (unitless)
SANC	- ammonium supply factor affecting nitrification capacity (0-1)
SARNC	- factor relating ammonium supply to nitrification capacity (0-1)
SAT(L)	- saturated water content for layer L (cm/cm)
SCN	- C:N ratio of surface residue of previous crop (kg C/kg N)
SCNR(I)	- total soil C:N ratio
SDEP	- depth of incorporation of surface residue (cm)
SDEPTH	- depth of seeding in soil (cm)
SEEDRV	- reserve carbohydrates in seed (g)
SENLA	- area of leaf that senesces from a plant on a given day (cm^2/plant)
SIND	- summed photoperiod induction rate (0-1)
SFAC	- drought stress factor for grain nitrogen concentration (unitless)
SKERWT	- weight of a single kernel (g)
SLAN	- total normal leaf senescence since emergence (cm^2/plant)
SLFC	- leaf senescence factor due to competition for light (0-1)
SLFT	- leaf senescence factor due to low temperature (unitless from zero to one)
SLFW	- leaf senescence factor due to water stress (unitless from zero to one)
SMDFR	- soil moisture deficit factor affecting nitrogen uptake at low soil water (unitless)

SMIN	- minimum value allowed for soil mineral nitrogen concentrations (kg N/ha in a layer)
SNH4(L)	- ammonium nitrogen in layer L (kg N/ha)
SNO3(L)	- nitrate nitrogen in layer L (kg N/ha)
SOLRAD	- solar radiation (langleys/day)
ST(L)	- soil temperature in layer L (°C)
STMWT	- stem weight (g/plant)
STOVN	- stover nitrogen content (g N/plant)
STOVWT	- stover weight (g/plant)
STRAW	- weight of surface residue of previous crop (kg/ha)
SUM	- weighted sum of the relative amounts of plant-extractable water in soil layers
SUMDTT	- the sum of growing degree days for a phenological stage (°C d)
SUMES1	- cumulative soil evaporation in stage 1 (mm)
SUMES2	- cumulative soil evaporation in stage 2 (mm)
SW(L)	- soil water content of layer L (cm/cm)
SWCON	- soil water conductivity constant (1/d)
SWDF	- soil water deficit factor for root growth in a layer (0-1)
SWDF1	- soil water deficit factor used to calculate the reduction in photosynthesis (0-1)
SWDF2	- soil water deficit factor used to calculate the reduction in plant cell expansion (0-1)
SWEF	- soil water evaporation fraction, the fraction of the lower limit of water content to which evaporation can reduce soil water
SWMIN	- minimum value that stem weight can reach during linear grain fill (g/plant)
SWSD	- extractable soil water at the seeding depth (cm/cm)

S1	– sine of latitude, used for photoperiod calculation
T	– time after 2nd-stage soil evaporation begins (d)
TAIR	– amount of automatic irrigation needed to bring all layers to drained upper limit (mm) (nitrogen version)
TANC	– tops actual nitrogen concentration (g N/g dry weight)
TAV	– annual average ambient temperature (°C)
TBASE	– base temperature for development (°C)
TCNP	– tops critical nitrogen concentration (g N/g dry weight)
TD	– mean temperature during daylight hours (°C)
TDUL	– total soil water held in the profile at the drained upper limit (cm)
TEMPM	– mean air temperature (°C)
TEMPMN	– minimum air temperature (°C)
TEMPMX	– maximum air temperature (°C)
TF	– temperature factor affecting nitrification rate (0–1)
TFAC	– temperature factor for nitrogen concentration in grain
TFY(L)	– yesterday's temperature factor for nitrification
THET1	– soil water content above the lower limit (LL) for an upper layer of soil (cm/cm)
THET2	– soil water content above the lower limit (LL) for a lower layer of soil (cm/cm)
TIFOM	– total initial fresh organic matter (kg/ha)
TIFON	– total nitrogen in initial fresh organic matter (kg N/ha)
TIMOB	– total nitrogen immobilization in the profile (kg N/ha)

TLL	- water in the soil profile at the lower limit of plant-extractable water (cm)
TLNO	- total number of leaves the plant produces
TMFAC(I)	- eight 3-hourly correction factors for air temperature
TMINF	- total nitrogen released by mineralization of fresh organic matter in the profile (kg N/ha)
TMINH	- total nitrogen released by mineralization of stable humic fraction in the profile (kg N/ha)
TMN	- mean temperature used in soil temperature subroutine (°C)
TMNC	- plant tops minimum nitrogen concentration (g N/g dry matter)
TNDEM	- plant tops demand for nitrogen (g N/plant)
TNH4	- total ammonium nitrogen present in profile (kg N/ha)
TNO3	- total nitrate nitrogen present in the profile (kg N/ha)
TNUP	- total nitrogen uptake from the profile (kg N/ha)
TOTN	- total mineral nitrogen in a layer (kg N/ha)
TPESW	- total potential extractable soil water in the soil profile (cm)
TRLDF	- total root length density factor (sum of RLDF for all layers)
TRNLOS	- total loss of nitrogen from the root system (g N/plant)
TRNU	- total potential root nitrogen uptake (kg N/ha)
TRWU	- total potential daily root water uptake (cm)
TSAT	- total soil water in profile at field saturation (cm)
TSW	- total soil water in the profile (cm)
TTMP	- 3-hour mean air temperature (°C)

U - upper limit of stage 1 soil evaporation (mm)
UNH4 - plant uptake of ammonium nitrogen from a layer (kg N/ha)
UNO3 - plant uptake of nitrate nitrogen from a layer (kg N/ha)
VANC - plant vegetative actual nitrogen concentration (g N/g plant)
VMNC - plant vegetative minimum nitrogen concentration (g N/g plant)
WC - moisture content effect on soil temperature (unitless)
WF(L) - weighting factor for soil layer L used to determine runoff amount (unitless)
WFD - today's water factor for nitrification (0-1)
WFY(L) - yesterday's water factor for nitrification (0-1)
WINF - precipitation that infiltrates into the soil (cm)
WR(L) - weighting factor for soil depth L to determine new root growth distribution (unitless)
WRN - nitrogen contained in root residues (kg N/ha)
WSUM - variable used to calculate distribution of nitrogen in root residues
WUF - water use factor used to calculate root water uptake (0-1)
XL - minimum water content of a soil layer (cm)
XLFWT - new leaf weight for the day
XN - number of the oldest expanding leaf
XNTI - number of leaves at tassel initiation
XSTAGE - non-integer growth stage indicator (nitrogen version)
YIELD - grain yield (kg/ha at 15.5% moisture)

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