INTRODUCTION

This document details the model-specific algorithms of OILCROP-SUN V5.1, a process-oriented, management-level model of the development, growth and yield of the sunflower (Helianthus annuus L.) crop that also simulates the soil water and nitrogen balances that are associated with the growth of the crop. It is a daily-incrementing, menu-driven model written and compiled in Microsoft FORTRAN V5.01 and Quick BASIC V4.0 that may be run on IBM or IBM-compatible microcomputers. A User's Guide and a program for OILCROP-SUN V5.1 are available (Villalobos et al., 1993a)

OILCROP-SUN has been developed by Dr. F. J. Villalobos of Córdoba University, Spain, Dr. A.J. Hall of the University of Buenos Aires, Argentina and Dr. Joe T. Ritchie of Michigan State University, United States of America. The first version of this document was prepared by F.J. Villalobos in September 1990, and was later expanded and modified by Villalobos and Hall in April 1991, October 1992 and August 1993.

This explanation of the model code is focused on those subroutines specific to OILCROP-SUN and on those needed for an initial understanding of model functioning. Subroutines related to data input/output and soil nitrogen are not discussed as they are common to other models of the same family (CERES-Maize, CERES-Wheat, etc., see Jones and Ritchie, 1990). The logic for the algorithms presented here and which are specific to OILCROP-SUN can be found in the documentation on model structure and rationale (Villalobos et al., 1993b and 1993c) and references given therein .

This document is organized at the subroutine level. The sequence in which the subroutines are explained reflects the order in which they are called by the main program or by other subroutines. A listing of subroutines and their relationships is given in Fig.1 (see page 2). Subroutines marked with an asterisk in Fig. 1 and elsewhere are mentioned but not explained in this document. Details for the algorithms in these subroutines are the same as those for CERES-Maize V. 3.2 and are described in Jones and Kiniry (1986). A glossary of the variables and parameters used in OILCROP-SUN V5.1 forms part of this document.

```
  [3] MAIN
        |
        |
        |---------[5] PROGRI
        |
        |---------[7] SOILRI
        |
        |------------ SOILNI(*)
        |
        |------------ SOLT(*)
        |
        |------------ NTRANS(*)
        |
        |---------[9] WATBAL------- IRRIGE(*)
        |                 |
        |                 |---------- RUNOFE(*)
        |                 |
        |                 |---------- DRAINE(*)
        |                 |
        |                 |---------- POTEV(*)
        |                 |
        |                 |---------- SOILEV(*)
        |                 |
        |                 |---------- WATFLO(*)
        |                 |
        |                 |---------- WATDEF(*)
        |                 |
        |                 |------[11] TRANSP
        |                 |
        |                 |------[12] ROOTGR
        |                 |
        |                 |------[14] WATUP
        |
        |--------[16] GROSUB----[20] NFACTO
        |                 |
        |                 |------[22] STAGE1/2 ----[24] INCPLA
        |                 |
        |                 |------[26] STAGE3 ------[24] INCPLA
        |                 |
        |                 |------[31] STAGE4 ------[35] NGRAIN
        |                 |
        |                 |------[39] STAGE5 ------[35] NGRAIN
        |                 |
        |                 |------[44] NUPTAK
        |
        |--------[50] PHENOL----[58] PHASEI
                          |
                          |------[64] PHOTOP
```

Fig. 1. Block diagram of OILCROP-SUN subroutine structure. Numbers in brackets are page numbers of this document where subroutine code explanations start. Subroutines marked (*) are described in Jones and Kiniry (1986).

PROGRAM MAIN- OILCROP-SUN

The main program opens the weather file and reads from it, identifies the day on which the simulation must start, and calls the necessary subroutines as required.

CALLS:

PROGRI
SOILRI
SOILNI(*)
SOLT(*)
NTRANS(*)
WATBAL
GROSUB
PHENOL

INPUT DATA:

Weather file name
ISIM (starting day for the simulation)
Code to identify input files

1. Open the appropriate weather file and read latitude (LAT, degrees), longitude (XLONG, degrees), conversion factor for PAR data (PARFAC) and switch indicating if PAR data are available (PARDAT).

2. Read from the weather file:

IYR : Year.

DOY : Day of the year.

SOLRAD : Shortwave incoming radiation (MJ/m2/day).

TEMPMX : Maximum temperature (C).

TEMPMN : Minimum temperature (C).

RAIN : Precipitation (mm).

2.1. Keep on reading weather data until the starting day of the simulation (ISIM) is found:

3. Call subroutine PROGRI to initialize program variables.

4. Call subroutine SOILRI to initialize program variables related to the water balance.

5. Call subroutine SOILNI(*) to initialize program variables related to the nitrogen balance in the soil.

6. Repeat until the end of stage 6 (physiological maturity):

6.1. Read daily weather data as in (2). If run out of weather data, then open weather file for next year and read daily weather data as in (2).

6.2. Calculate average temperature (TEMPM, C):

TEMPM = (TEMPMX + TEMPMN) * 0.5

6.3. Call subroutine SOLT(*) to calculate daily average soil temperature at the center of each soil layer.

6.4. Call subroutine NTRANS(*) to calculate soil nitrogen transformations.

6.5. Call subroutine WATBAL to calculate the components in the soil water balance.

6.6. If the crop has emerged (ISTAGE<6) then call subroutine GROSUB to simulate plant growth processes.

6.7. Call subroutine PHENOL to simulate plant phenological development if the crop has been sown already.

SUBROUTINE PROGRI-OILCROP-SUN

Subroutine PROGRI calculates geographical transforms, sets up the function to estimate daily temperature cycle, and initializes the variables needed to start running the model:

CALLED BY:
MAIN program.

INPUT DATA:
LAT

OUTPUT DATA:
S1
C1
TMFAC(I) I=1,8
ISTAGE
TBASE

1. Calculate the sine (S1) and cosine (C1) of the latitude:

S1=SIN(LAT*0.01745)

C1=COS(LAT*0.01745)

2. Calculate a set of eight factor (TMFAC) used to simulate air temperatures for three-hour periods:

TMFAC(I)=0.931+0.114*I-0.0703*I**2+0.0053*I**3 ,I=1 to 8

3. Initialize variables:

3.1. Set initial values for the following variables:

3.1.1. Soil water deficit factors.

SWDF1 = SWDF2 = 1.0

3.1.2. Nitrogen deficit factors.

NDEF1 = NDEF2 = NDEF3 = NFAC = 1.0

3.1.3. Nitrogen concentrations.

XLANC=XSANC=XHANC=TANC=XNGLF=XNSLF=RANC=0.0

3.1.4. Nitrogen contents:

XHEADN=XLEAFN=XSTEMN=STOVN=ROOTN=GRAINN=PERN=EMBN=0.0

3.1.5. Other variables.

XSTAGE=0.1

ISTAGE=7

TBASE=6

LN=0

LAI=0

```
            GNP=TNUP=NHDUP=GNUP=TOTNUP=0
            CUMDTT = SUMDTT = DTT = 0
            CRAIN = PRECIP = 0
```

- END of subroutine PROGRI.

- RETURN to MAIN program.

SUBROUTINE SOILRI- OILCROP-SUN

Subroutine SOILRI initializes soil variables

CALLED BY:
MAIN program

INPUT DATA:
TSW
TLL

OUTPUT DATA:
ESW(I)
SUMES1
SUMES2
T
CN1
CN3
SWEF
RWUMX

1. Calculate potential extractable soil water in the soil profile (cm).

PESW=TSW-TLL

2. Set a default value for first-stage soil water evaporation:

U = 6.0 mm

3. Set initial values for variables related to soil water evaporation:

SUMES1 : Cumulative soil evaporation (mm) during the first stage.

SUMES2 : Cumulative soil evaporation (mm) during the second stage.

T : Time (days) since the beginning of the second stage.

3.1. Calculate fraction of available water content in the first layer:

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

3.2. If SWR > 0.9 then

SUMES2 = 0.0

SUMES1 = 100-SWR*100

T = 0.0

3.3. If SWR < 0.9 then

SUMES2 = 25-27.8*SWR

SUMES1 = U

T = (SUMES2/3.5)**2

4. Calculate for each layer in the soil profile (from L=1 to L=NLAYR).

4.1. Fraction of extractable soil water:

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

4.2. Distance from the soil surface to the bottom of the layer (CUMDEP, cm):

CUMDEP(L) = CUMDEP(L-1) + DLAYR(L)

4.3. Factor used for runoff calculations:

WF(L) = WX - XX

where

WX = 1.016*(1.-EXP(-4.16*CUMDEP(L)/45.0))

and XX = 1.016*(1.-EXP(-4.16*CUMDEP(L-1)/45.0))

4.4. Initialize variables for the soil layer:

RWU(L) = FLUX(L) = 0.0

FLOW(L) = 0 IF L < 6

5. Calculate total water content at the lower limit for the soil profile (TLL, cm):

TLL = TLL+LL(L)*DLAYR(L)

6. Calculate total water content for the soil profile (TSW, cm):

TSW = TSW+SW(L)*DLAYR(L)

7. Determine curve number from the SCS curve number table for future calculations of runoff:

X=EXP(2.533-6.360001E-02*(100-CN2))

CN1 = CN2 - 20*(100-CN2)/(100-CN2+X)

CN3 = CN2*EXP(.00673*(100-CN2))

8. Set a maximum value of 100 for CN1 and CN3.

If CN1 > 100   then CN1 = 100

If CN3 > 100   then CN3 = 100

9. Calculate the factor used to estimate runoff:

SWEF = 0.9-0.00038*(DLAYR(1)-30.0)**2

10. Initialize variables:

CET = CES = CEP = CRAIN = 0.0

RWUMX = 0.03

- END of subroutine SOILRI.

- RETURN to MAIN program.

SUBROUTINE WATBAL- OILCROP-SUN

Subroutine WATBAL calculates crop water balance.

CALLED BY:
MAIN program.

CALLS:
DRAINE(*)
IRRIGE(*)
POTEV(*)
ROOTGR
RUNOFE(*)
SOILEV(*)
TRANSP
WATDEF(*)
WATFLO(*)
WATUP

INPUT DATA
PRE
TEMPMX
TEMPMN
SOLRAD

OUTPUT DATA
CSD1
CSD2
ET
CET
CEP
CRAIN

1. Call IRRIGE(*) to determine irrigation amount. If precipitation (PRECIP, mm) is greater than zero then:

1.1. Call subroutine RUNOFE(*) to calculate runoff (RUNOFF, mm/day).

1.2. Calculate amount of rainfall infiltrated into the soil (PINF, mm/day):

PINF = PRECIP - RUNOFF

1.3. Calculate water flux into the upper soil layer (FLUX(1), cm/day):

FLUX(1) = PINF*0.1

1.4. Call subroutine DRAINE(*) to calculate the amount of water lost by drainage from the profile (DRAIN, cm/day).

2. Call subroutine POTEV(*) to determine potential soil evaporation (EOS, mm/day) and potential evaporation (EO, mm/day). In OILCROP-SUN V5.1 potential crop evaporation calculated in subroutine POTEV is augmented by a factor of 1.2 if LAI>0.

3. Call subroutine SOILEV(*) to calculate actual soil evaporation (ES, mm/day).

4. Call subroutine WATFLO(*) to calculate water flux in the soil profile and modify water content in the soil layers.

5. Call subroutine WATDEF(*) to calculate soil water deficit for irrigation

scheduling purposes (SWDEF, mm).

6. If ISTAGE < 6 then:

6.1. Call subroutine TRANSP to estimate plant evaporation (EP, mm/day).

6.2. If root weight increased (GRORT>0) then call subroutine ROOTGR to distribute root length density in the soil profile.

6.3. Call subroutine WATUP to calculate water extraction in the soil profile, soil water deficit factor affecting photosynthesis (SWDF1) and soil water deficit factor affecting growth (SWDF2).

6.4. Calculate cumulative water stress coefficients for photosynthesis (CSD1) and growth (CSD2):

CSD1 = CSD1+1.0-SWDF1

CSD2 = CSD2+1.0-SWDF2

7. Calculate evapotranspiration (ET, mm/day):

ET = ES+EP

8. Accumulate ET, EP and PRECIP:

CET = CET+ET

CEP = CEP+EP

CRAIN = CRAIN+PRECIP

- END of subroutine WATBAL.

- RETURN to MAIN program.

SUBROUTINE TRANSP - OILCROP-SUN

Subroutine TRANSP calculates potential transpiration

CALLED by:
WATBAL.

INPUT DATA:
EO
ES
LAI
K2

OUTPUT DATA:
EP

1. Calculate maximum plant transpiration as a function of intercepted radiation:

```
FI=0.5*((1.0-EXP(-K2*LAI))+(1.0-EXP(-0.5*K2*LAI)))

FT=FI*((0.5+0.25*FI)*30-8)/14.5+LAI/3

EP = EO*FT                       if LAI<3

   EP = EO                     if LAI>3
```

2. Reduce plant evaporation if the sum of EP and ES exceedes potential evaporation (EO):

```
If EP+ES > EO  then  EP=EO-ES
```

- END of subroutine TRANSP.

- RETURN to subroutine WATBAL.

SUBROUTINE ROOTGR - OILCROP-SUN

Subroutine ROOTGR calculates root growth, depth and density distribution.

CALLED BY:
WATBAL

INPUT DATA:
GRORT
PLANTS
DLAYR(I)
SW(I)
LL(I)
DUL(I)
ESW(I)
NO3(I)
NH4(I)
WR(I)
RTDEP
DTT
SWDF1
DEPMAX
RLV(I)

OUTPUT DATA:
RLV(I)
RTDEP

1. Convert biomass available for root growth (g/plant/day) to root length growth per unit soil area (cm root/cm2):

RLNEW = GRORT*1.70*PLANTS

2. For each layer in which roots are present calculate factor for soil limitations to root growth RLDF:

2.1. Calculate distance from the soil surface to the bottom of the layer:

CUMDEP = CUMDEP+DLAYR(L)

2.2. Calculate soil water deficit factor for root growth in the layer (SWDF):

SWDF = 4.0*(SW(L)-LL(L))/ESW(L) if SW(L)-LL(L)<0.25

SWDF = 1.0 if SW(L)-LL(L)>0.25

2.3. Calculate nitrogen factor for root growth:

RNFAC = 1.0-(1.17*EXP(-0.15*(NO3(L)+NH4(L))))

If RNAC < 0.1 then set RNFAC = 0.1

2.4. Calculate factor for root length density distribution in the layer (RLDF(L)), as a function of the limiting factor.

RLDF(L) = min(SWDF,RNFAC)*WR(L)*DLAYR(L)

where WR(L) is a user-defined soil factor restricting root growth.

3. Calculate average extractable soil water content in the layers colonized by roots (SWDF3):

```
SWDF3=SWDF3+(SW(L)-LL(L))/(DUL(L)-LL(L))*DLAYR(L)/CUMDEP
```

4. Calculate rooting depth (RTDEP, cm) assuming that sunflower roots grow at a potential rate of 0.2 cm per growing degree-day.

```
RTDEP = RTDEP+DTT*0.20*min((SWDF1*2.0),SWDF)
```

4.1. Rooting depth cannot exceed soil depth (DEPMAX):

```
If RTDEP > DEPMAX  then   RTDEP = DEPMAX
```

5. Correct RLDF for the deepest layer to account for possible incomplete exploration by roots of layer (L1 is the number for this layer):

```
RLDF(L1) = RLDF(L1)*(1.0-(CUMDEP-RTDEP)/DLAYR(L1))
```

6. Accumulate RLDF for all layers explored by roots to obtain summed value of soil limitations to growth:

```
TRLDF = TRLDF+RLDF(L)  from L=1 to L=L1
```

7. If TRLDF>RLNEW/100000 (to avoid calculation overflow), pro-rate new root length among the layers explored by roots from L=1 to L1:

7.1. Define RNLF = RLNEW/TRLDF

7.2. If ISTAGE < 4 (before first anthesis):

```
RLV(L) = RLV(L)+RLDF(L)*RNLF/DLAYR(L)
```

7.3. If ISTAGE > 4 (after anthesis) 0.5 % of root biomass/day is lost by senescence. For purposes of calculation, this is deducted directly from daily growth:

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

7.4. Set a limit to root length density in any layer:

```
If RLV(L) > 10   then  RLV(L) = 10
```

- END of subroutine ROOTGR.

- RETURN to subroutine WATBAL.

SUBROUTINE WATUP - OILCROP-SUN

Subroutine WATUP calculates crop water uptake and crop deficit factors affecting photosynthesis and expansion growth.

CALLED BY:
WATBAL

INPUT DATA:
SW(I)
LL(I)
RWUMX
LAI
EP1

OUTPUT DATA:
SW(I)
PESW
SWDF1
SWDF2
EP

1. Calculate root water uptake (RWU(L), cm3/cm root/day) for each layer explored by roots:

1.1. If SW(L) < LL(L) then RWU(L) = 0.0

1.2. If SW(L) > LL(L) then

```
RWU(L)=2.67E-3*exp(min(62*(SW(L)-LL(L)),10))/(6.68-LOG(RLV(L)))
```

1.3. RWU can not exceed a maximum value (RWUMX):

```
If  RWU(L) > RWUMX  then  RWU(L) = RWUMX
```

1.4. Calculate root water uptake per layer as a function of RLV and convert units of RWU to cm/day.

```
RWU(L)=RWU(L)*DLAYR(L)*RLV(L)**(0.18+0.00272*(RLV(L)-18.0)**2)
```

1.5. Accumulate root water uptake in the layer to total root water uptake (TRWU, cm/day):

```
TRWU=TRWU+RWU(L)
```

2. Calculate a water use factor (WUF) to match plant evaporation (EP1, cm/day) to root water uptake (TRWU):

```
If EP1 < TRWU  then  WUF = EP1/TRWU

If EP1 > TRWU  then  WUF = 1
```

3. Adjust RWU for all layers in order to match total plant evaporation:

```
RWU(L) = RWU(L)*WUF    from L=1 to L=NLAYR
```

4. Reduce soil water content in all layers where water extraction ocurred.

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

5. Recalculate total soil water content (TSW, cm):

TSW = TSW+SW(L)*DLAYR(L) from L=1 to L=NLAYR

6. Calculate potential extractable soil water in the profile (PESW, cm):

PESW = TSW-TLL

7. Calculate soil water deficit factors:

7.1. Factor affecting photosynthesis (SWDF1):

SWDF1 = TRWU / EP1   if EP1 > TRWU

SWDF1 = 1   if EP1 < TRWU

7.2. Factor affecting expansion growth (SWDF2):

```
If ET0>0 RAT=10*PAW/ET0 else RAT=1

If SWDF1<1 and RAT> 0.5*SWDF1 then

   SWDF2=0.5*SWDF1

else         SWDF2=RAT
```

8. Reduce plant evaporation if it exceeded total root water uptake (note that EP and EP1 are both plant evaporation rates, but expressed in mm/day and cm/day, respectively):

If EP1 > TRWU   then EP = TRWU*10

- END of subroutine WATUP.

- RETURN to subroutine WATBAL.

SUBROUTINE GROSUB - OILCROP-SUN

Subroutine GROSUB calculates crop biomass accumulation, leaf appearance and frost damage senescence factor.

CALLED BY:
MAIN Program

CALLS:
NFACTO
NUPTAK
STAGE1
STAGE2
STAGE3
STAGE4
STAGE5

INPUT DATA:
SOLRAD
TEMPMX
TEMPMN
SWDF1
NDEF1
ISTAGE
XSTAGE
TLNO
CUMDTT
P9
PLANTS
SLAN

OUTPUT DATA:
CARBO
SLAMAX
SLAMIN
K1
K2
SLAMAX
SLAMIN

1. Assign values to Thermal Time to complete leaf Expansion (TTE), Phyllochron for leaves 1-6 (PHY1) and Phyllochron for leaves 7-N (PHY2):

```
TTE = 350.
PHY1 = 39.
PHY2 = 24.
```

2. Call subroutine NFACTO (to calculate the nitrogen deficit factors NDEF1, NDEF2 and NDEF3).

3. Calculate Photosynthetically Active Radiation (PAR, MJ/m2/day):

```
PAR = 0.5*SOLRAD
```

4. Assign value to Extinction Coefficient for PAR (K2) according to development stage (ISTAGE) and/or Leaf Area Index (LAI) and calculate intercepted PAR:

```
K2 = -LOG(1-QD)/LAI

where    QD = (2*QN)/(1+QN)
```

```
        and      QN = 1 - EXP(-0.86*LAI)

        If K2>3 then  K2=3

    RI=PAR*(1.-EXP(-K2*LAI))
```

5. Calculate RUE and potential biomass assimilation per plant (PCARB) (g biomass/plant/day):

```
        K1 = 1.40 + 1.8 * (1 -EXP (-.5*LAI))   if ISTAGE < 4


          GF1=.8-SUMDTT/140.*.2
For ISTAGE 4:
    IF GF1< 0.6 then GF1=0.6
           C1=0.8
           C2=GF1
For ISTAGE 5:
          GF1=.6-(SUMDTT-230.)/140.*.2
          If GF1<0.4 then GF1=0.4
           C1=0.8
           C2=GF1

    IF (ISTAGE .LT. 4) THEN
        PCARB = K1 * RI/PLANTS
    ELSE
        PCARB=(RI*RI1*C2/C1*K1-RM)/PLANTS
```

6. Estimate the average temperature for the daylight period (ELO):

```
        ELO = 0.25 * TEMPMN + 0.75 * TEMPMX
```

7. Calculate a temperature reduction factor (PRFT) for Carbon Assimilation:

```
        PRFT = 0.0              if ELO<4 or ELO>45

        PRFT = (ELO-4.0)/13.0  if  4 < ELO < 17

        PRFT = 1.0              if 17 < ELO < 31

        PRFT = (45-ELO)/14.0   if 31 < ELO < 45
```

8. Calculate actual biomass assimilation (CARBO) using the minimum of the three reduction factors: PRFT (temperature), SWDF1 (water stress) and NDEF1 (nitrogen stress):

```
        CARBO = PCARB*min(PRFT,SWDF1,NDEF1)
```

8b. Calculate a factor based on the red/far red ratio to reduce potential leaf area growth:

```
    RFR=1.2*EXP(-.5*k2*lai)
    If RFR> 0.5 then RFR=1.0 else RFR=1./0.5*RFR
```

9. Calculate the number of leaves that have appeared (LN):

```
        LN = LN+DTT/PHY,   LN < TLNO
```

where

```
PHY = PHY1   if LN < 6

PHY = PHY2   if LN > 6
```

10. Calculate the number of expanded leaves (CUMPH):

```
CUMPH = 0      if  (CUMDTT-P9) < (TTE+PH1)

CUMPH = CUMPH + DTT/QHY
```

where

```
QHY = PHY1   if CUMPH < 6

QHY = PHY2   if CUMPH > 6
```

11. Calculate maximum (SLAMAX) and minimum (SLAMIN) limits to Specific Leaf Area (cm2 leaf/ g leaf):

```
SLAMAX = 1.40 * SLAX

SLAMIN = 1.00 * SLAX
```

where

```
SLAX = 1./SQRT(2.778E-5-2.007E-7*LFWT)
```

12. Call the subroutine needed for the particular stage the plant is in:

```
CALL STAGE1      if ISTAGE = 1

CALL STAGE1                  2 ( see Note below)

CALL STAGE3                  3

CALL STAGE4                  4

CALL STAGE5                  5
```

NOTE: In OILCROP-SUN V5.1 biomass partitioning rules do not change between Stage 1 and Stage 2.

13. Assign values to potential growth of plant parts:

```
PDWI = CARBO -GRORT   (shoot)

PDWIL = GROLF         (leaves)

PDWIS = GROSTM        (stem)

PDWIH = GROHEAD       (head)

PGRORT = GRORT        (root)
```

14. Calculate the frost damage senescence factor (SLFT):

```
SLFT=  1.0                   if TEMPM > 2

SLFT = 1.0-(2.0-TEMPM)/2.0    if TEMPM < 2

SLFT = 0.0                   if TEMPMN<-3.0
```

15. Calculate the number of severe frost days (ICOLD):

```
ICOLD = 0                    if TEMPMN>-3.0

ICOLD = ICOLD + 1            if TEMPMN<-3.0
```

16. Calculate leaf area senesced by cold temperature (PLAS, cm2/day):

```
PLAS = (PLA-SENLA)*(1.0-SLFT)
```

17. Calculate cumulative leaf area senesced (SENLA, cm2):

```
SENLA = SENLA+PLAS
```

18. Calculate Leaf Area Index:

```
LAI = (PLA-SENLA)*PLANTS*0.0001
```

19. Terminate the program if one of the following conditions holds:

```
A) LN>3 and LAI=0 and ISTAGE<=4

B) ICOLD => 7
```

If the program is terminated, then print the following message:
'CROP FAILURE, GROWTH PROGRAM TERMINATED.'

20. Update root dry weight (RTWT, g/plant):

```
RTWT = RTWT + GRORT              if ISTAGE < 4

RTWT = RTWT+GRORT-0.005*RTWT     if ISTAGE > 4
```

NOTE: After anthesis 0.5 % of root weight is lost daily as a result of root senescence.

21. Calculate shoot biomass (BIOMAS, g/m2)

```
BIOMAS = (LFWT+STMWT+HEADWT+GRNWT+GRNWTE)*PLANTS
```

22. Calculate shoot biomass in Kg/ha (DM):

```
DM = BIOMAS*10.0
```

23. Calculate stover dry weight (STOVWT, g/plant):

```
STOVWT = LFWT+STMWT+HEADWT
```

24. Calculate the stover/(stover+root) dry weight ratio (PTF):

```
PTF = STOVWT/(RTWT+STOVWT)
```

25. Call Subroutine NUPTAK (plant nitrogen uptake).

- End of the GROSUB Subroutine.

- Return to Main Program.

SUBROUTINE NFACTO - OILCROP-SUN

Subroutine NFACTO calculates dynamics of critical and minimum N levels for each organ, and nitrogen deficit factors for photosynthesis, expansion and grain filling.

CALLED BY:
GROSUB

INPUT DATA:
XSTAGE
GLFWT
SLFWT
STMWT
HEADWT
RTWT
TANC
CNSD
CNSD

OUTPUT DATA:
NFAC
NDEF1
NDEF2
NDEF3
CNSD1
CNSD2

1. Calculate organ critical N concentrations as a function of XSTAGE:

Leaves:

XLCNP = (2.94 * EXP(-.326*XSTAGE) +3.26)/100.

Stem:

XSCNP = (3.29 * EXP(-.516*XSTAGE) + 1.25)/100.

Roots:

RCNP = (3.61 * EXP(-.521*XSTAGE) + 1.05)/100.

Head:

XHCNP = (21.37 * EXP(-.600*XSTAGE) + 1.60)/100.

2. Calculate organ minimum N concentrations:

Leaves:

XLMNC = XLCNP - 0.02

Stem:

XSMNC = XSCNP - 0.0112

Head:

XHMNC = XHCNP - 0.00895

Roots:

RMNC = RCNP - 0.0062

3. Calculate tops critical and minimum N concentrations:

TCNP=(XLCNP*GLFWT+XSCNP*STMWT+XHCNP*HEADWT)/(STOVWT-SLFWT)

TMNC=(XLMNC*GLFWT+XSMNC*STMWT+XHMNC*HEADWT)/(STOVWT-SLFWT)

4. Calculate nitrogen deficit factor (tops):

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

5. Calculate nitrogen deficit factor for leaves:

BRIAN =1.0 - (XLCNP-XLANC)/(XLCNP-XLMNC)

6. Calculate nitrogen deficit factor affecting photosynthesis:

NDEF1= BRIAN * 0.4+ 0.6 if BRIAN>0.5

NDEF1= BRIAN * 1.2+ 0.2 if BRIAN<0.5

7. Calculate nitrogen deficit factor affecting expansion:

NDEF2 = NFAC

8. Calculate nitrogen deficit factor affecting grain filling:

NDEF3 = 0.2 + NFAC   if NFAC<0.8

NDEF3 = 1.   if NFAC>0.8

9. Calculate cumulative N stress factor affecting photosynthesis:

CNSD1=CNSD1+1.0-NDEF1

10. Calculate cumulative N stress factor affecting expansion:

CNSD2=CNSD2+1.0-NDEF2

- End of subroutine NFACTO.

- RETURN to GROSUB subroutine.

SUBROUTINE STAGE1 - OILCROP - SUN

Subroutine STAGE1 calculates plant leaf area and organ growth rates for stages 1 and 2.

CALLED BY:
GROSUB

CALLS:
INCPLA

INPUT DATA:
LN
DTT
CUMPH
CARBO
SLAMIN
SLAMAX
PLA
LFWT
STMWT

OUTPUT DATA:
PLAG
GROLF
GROSTM
GRORT
PLA
LFWT

1. Calculate potential plant leaf area growth (PLAG, cm2/plant/day):

If LN<1 then assign PLAG=2 cm2/plant/day

If LN=>1 then call Function INCPLA (this function will return a value (INCPLA) which is the potential leaf area growth).

Then assign PLAG = RFR * INCPLA

2. If expansion is affected by water stress (SWDF2<1) specific leaf area adjustment is neutralized by setting the minimum value equal to the maximum one.

SLAMAX = SLAMIN

3. Calculate maximum (MAXGROLF) and minimum (MINGROLF) leaf weightincrease (g leaf/plant/day) limits:

MAXGROLF = PLAG / SLAMIN

MINGROLF = PLAG / SLAMAX

4. Assign a maximum of 57% of CARBO to leaf growth:

FRCARB = 0.57 * CARBO

5. Adjust plant leaf area expansion (PLAG, cm2/plant/day) and leaf weight increase (g leaf/plant/day) as a function of biomass partitioned to leaves and SLA limits:

If MAXGROLF<=FRCARB then GROLF = MAXGROLF

```
                                        PLAG = MAXGROLF * SLAMIN

            If MAXGROLF>FRCARB>MINGROLF then GROLF = FRCARB
                                             PLAG= PLAG

            If MINGROLF>FRCARB then GROLF = FRCARB
                                    PLAG= GROLF*SLAMAX
```

6. Reduce leaf growth (area and weight increase) if water or nitrogen stress is detected. Use the minimum of nitrogen stress(NDEF2) and water stress(SWDF2) factors:

```
GROLF= GROLF * AMIN1(SWDF2,NDEF2)

PLAG = PLAG * AMIN1(SWDF2,NDEF2)
```

7. Calculate stem growth (GROSTM, g/plant/day) as a fraction of carbohydrate supply (CARBO):

```
GROSTM = 0.245 * CARBO
```

8. Root weight increase (ROOTGR, g/plant/day) will be the amount of dry weight not allocated to leaves or stem:

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

9. Actualize leaf weight (LFWT, g/plant), stem weight (STMWT, g/plant) and plant leaf area (PLA, cm2/plant):

```
LFWT = LFWT+GROLF

STMWT = STMWT+GROSTM

PLA = PLA + PLAG
```

10. Assign leaf weight (LFWT) to green leaf weight (GLFWT):

```
GLFWT = LFWT
```

- END of subroutine STAGE1

- RETURN to subroutine GROSUB.

FUNCTION INCPLA - OILCROP-SUN

Function INCPLA calculates daily potential plant leaf area growth

CALLED BY:
STAGE1
STAGE2
STAGE3.

INPUT DATA:
LN
CUMPH
TEMPM
V1
TLNO

OUTPUT DATA:
INCPLA

1. Define duration of rapid expansion for any single leaf (C-day):

```
TTE = 350.
```

2. Calculate a temperature factor affecting leaf expansion rate (TFAC) as a function of mean temperature (TEMPM):

```
TFAC = 0                if TEMPM<4 or TEMPM>40

TFAC = (TEMPM-4) / 16   if 4 < TEMPM < 20

TFAC = (TEMPM-20) / 20  if 20< TEMPM < 40
```

3. Calculate leaf position where maximum individual leaf area occurs:

```
TLNOI = 1.54 + 0.61 * TLNO
```

4. Calculate maximum leaf area corresponding to position TLNOI:

```
YLNOI = 150 + (TLNOI-6) * 74
```

5. Calculate plant leaf expansion rate as the sum of expansion rates of leaves actually expanding.

5.1. Maximum leaf area for leaf position I is calculated:

```
If I<7 then MAXLA = 25 * I

If I>6 and I<TLNOI then

      MAXLA = 150 + (I-6) * 74

If I>6 and I>TLNOI then

      MAXLA = YLNOI - 117 * (I-TLNOI)
```

5.2. Leaf expansion rate for leaf position I (LER, cm2/day):

LER = MAXLA * TFAC / 18.

4.6. Sum LER to variable INCPLA for all leaf positions expanding:

INCPLA = INCPLA + LER

- End of Function INCPLA

- Return to Subroutine STAGE1, STAGE2 or STAGE3.

SUBROUTINE STAGE3 OILCROP-SUN

Subroutine STAGE3 calculates plant leaf area and organ growth for stage 3; and shade- and water-stress-driven leaf senescence.

CALLED BY:
GROSUB

CALLS:
INCPLA

INPUT DATA:
DTT
LN
CUMPH
CARBO
SLAMIN
SLAMAX
STMWT
LFWT
PLA
P3P
SWDF2
NDEF2
LAI
PLANTS
HEADWT
SUMP
IDURP

OUTPUT DATA:
PLAG
GROLF
GROSTM
GRORT
PLA
LFWT
SLAI
SLAN1
SLAN
HEADWT
SUMP
IDURP

1. Calculate potential plant leaf area growth (PLAG, cm2/plant/day):

Call Function INCPLA (this function will return a value (INCPLA) which is the potential leaf area growth).

Then assign PLAG = RFR * INCPLA

2. If expansion is affected by water stress (SWDF2<1), specific leaf area adjustment is neutralized by setting the minimum value equal to the maximum one:

SLAMAX = SLAMIN

3. Calculate maximum (MAXGROLF) and minimum (MINGROLF) leaf weight increase (g leaf/plant/day):

```
MAXGROLF = PLAG / SLAMIN

MINGROLF = PLAG / SLAMAX
```

4. Assign a maximum of 60.5% of CARBO to stem growth:

```
MAXGROSTM = 0.605 * CARBO
```

5. When thermal time from now to first anthesis is 180 C-day, the head starts to grow. When this condition applies, calculate head dry weight:

5.1- Initialize head weight (HEADWT) as a fraction of stem weight (STMWT):

```
HEADWT = 0.05 * STMWT
```

5.2- Define a potential head weight (POTHEADWT, g/plant):

```
POTHEADWT = 22.1
```

5.3- Correct stem weight for allocation of existing biomass to head:

```
STMWT = STMWT- HEADWT
```

6. Calculate a temperature reduction factor (RGFILL) for head and stem growth under non-optimum temperatures:

```
RGFILL = RGFILL + ELOFT(I)/8I=1 TO 8
```

where

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

and

```
ELOFT(I)=0.0   if TTMP(I)<4 or TTMP(I)>45

ELOFT(I)= (TTMP(I)-4.0)/13.0

               if 4 < TTMP(I) < 17

ELOFT(I)= 1.0  if 17 < TTMP(I) < 31

ELOFT(I)=(45-ELO)/14.0

               if 31 < TTMP(I) < 45
```

7. If head growth has started, then calculate head growth according to temperature (GROHEAD, g/plant/day), assuming that head growth under optimal conditions is 1.71 g head/plant/day:

```
GROHEAD = 1.71 * RGFILL
```

8. If head growth has not started, then calculate stem growth according to temperature:

```
MAXGROSTM = RGFILL * MAXGROSTM
```

Calculate the maximum amount of new biomass that can be assigned to leaf growth (assuming that a minimum of 10% of CARBO will be used for root growth):

```
FRCARB = 0.90 * CARBO - MAXGROSTM - GROHEAD
```

10. Limit the amount of CARBO for leaf growth to less than 29.5% of CARBO:

FRCARB = 0.295 * CARBO if FRCARB>0.295*CARBO

11. Calculate growth rates of leaves and stem according tobiomass availability:

11.1. If FRCARB<=0 then leaves do not grow:

MAXGROSTM = 0.90 * CARBO - GROHEAD

GROLF = 0.0

PLAG = 0.0

11.2. If MAXGROLF<=FRCARB then

GROLF = MAXGROLF

PLAG = MAXGROLF * SLAMIN

11.3. If MINGROLF>FRCARB then

GROLF = FRCARB

PLAG = GROLF * SLAMAX

11.4. If MINGROLF<FRCARBthen

GROLF = FRCARB

11.5. Stem growth rate:

GROSTM = MAXGROSTM

12. Reduce head, stem and leaf growth (area and weight increase) if water or nitrogen stress is detected. Use the minimum of nitrogen stress factor (NDEF2) and water stress factor (SWDF2) for leaves and head. Stem growth is reduced by stress factor SWDF1 or NDEF1 (By using these factors the model allows for carbohydrate accumulation in the stem under mild water stress. Stem growth is less affected than head growth because stem structure [and hence, storage space] has reached a substantial size by stage 3, while head structure may still be small by comparison).

GROLF= GROLF * AMIN1(SWDF2,NDEF2)

PLAG = PLAG * AMIN1(SWDF2,NDEF2)

GROHEAD = GROHEAD * AMIN1(SWDF2,NDEF2)

GROSTM = GROSTM * AMIN1(SWDF1,NDEF1)

13. Calculate new biomass available for root growth:

GRORT = CARBO - GROLF - GROSTM - GROHEAD

14. When LAI>1.2, commence counting time (SENTIME, days) from now to the start of leaf senescence driven by shade:

SENTIME = SENTIME + 1.

15. When SENTIME exceeds 13 days then calculate the rate of shade driven leaf senescence (SENRATE, m2/m2/day):

SENRATE = -0.0182 + 0.4147 * SGRO(1) * PLANTS/10000.

where SGRO(1) is Plant Leaf Area Growth (cm2/plant/day) which corresponds to 13 days ago.

16. Calculate the rate of leaf senescence (DSLAN1, cm2/plant/day) :

DSLAN1 = SENRATE / PLANTS * 10000.

17. After the last five leaves have begun to expand and if water stress is affecting expansion (SWDF2<0.8), then leaf senescence caused by water stress (DSLANW, cm2/plant/day) is calculated as 3% per day of green plant leaf area (GPLA):

DSLANW = 0.03 * GPLA

18. Daily leaf senescence rate is calculated as the largest of DSLAN1 and DSLANW.

DSLAN1 = DSLANW if DSLANW>DSLAN1

19. Cumulative senesced leaf area caused by light and/or water stress (SLAN1, cm2/plant):

SLAN1 = SLAN1 + DSLAN1

SLAN = SLAN1

20. Adjust nitrogen contents and weights of green and dead leaves:

20.1. Calculate specific leaf area of green leaves (SLAY, cm2/g):

SLAY = GPLA / GLFWT

20.2. Calculate plant leaf area (PLA, cm2/plant):

PLA = PLA + PLAG

20.3. Calculate green plant leaf area (GPLA, cm2/plant):

GPLA = GPLA - DSLAN1 + PLAG

20.4. Calculate senesced plant leaf area (SPLA, cm2/plant):

SPLA = SPLA + DSLAN1

20.5. Calculate nitrogen concentration of green leaves (XRAT, fraction):

XRAT = XNGLF/GLFWT

20.6. Calculate residual nitrogen concentration (YRAT, fraction) assuming that nitrogen content of senesced leaves is equal to 0.9%:

YRAT = (.009 - .0875 * XRAT) / .9125

20.7. Calculate the amount of nitrogen retranslocated from the senesced leaves to other organs (g N/plant):

SDN = DSLAN1/SLAY*(XRAT - YRAT)

20.8. Adjust the weight of senesced leaves (SLFWT, g/plant):

SLFWT = SLFWT + DSLAN1/SLAY - SDN * 6.25

20.9. Calculate residual nitrogen in senesced leaves (XNSLF, g N/plant):

XNSLF = XNSLF + DSLAN1/SLAY*YRAT

20.10. Calculate the weight of green leaves (GLFWT, g/plant):

GLFWT = GLFWT + GROLF + SDN * 6.25 - DSLAN1/SLAY

20.11. Calculate the amount of nitrogen in green leaves (XNGLF, g N/plant):

XNGLF = XNGLF - DSLAN1/SLAY*YRAT

20.12. Calculate maximum permissible amount of nitrogen in green leaves:

XXX = GLFWT * XLCNP

20.13. If the calculated amount of N in green leaves is greater than the maximum, then allocate the excess N to the stem and adjust organ weights accordingly:

YYY = XNGLF - XXX

XNGLF = XXX

GLFWT = GLFWT - YYY * 6.25

LFWT= LFWT- YYY * 6.25

STMWT = STMWT + YYY * 6.25

XSTEMN = XSTEMN + YYY

XLEAFN = XLEAFN - YYY

21. Actualize leaf weight (LFWT, g/plant), stem weight (STMWT, g/plant) and head weight (HEADWT, g/plant):

LFWT = LFWT + GROLF

STMWT = STMWT + GROSTM

HEADWT = HEADWT + GROHEAD

22. If thermal time from now to first anthesis is less than 130 C-day, then sum CARBO to variable SUMP and count time (IDURP):

SUMP = SUMP + CARBO

IDURP = IDURP + 1

NOTE: The ratio SUMP/IDURP at first anthesis will be the average dry matter accumulation rate (g/plant/day) during the 130 C-day period previous to first anthesis. This value will be used later to estimate grain number.

- END of subroutine STAGE3

- RETURN to subroutine GROSUB.

SUBROUTINE STAGE4 - OILCROP-SUN

Subroutine Stage 4 calculates plant leaf area, organ growth and water- and nitrogen-driven leaf senescence for stage 4.

CALLED BY:
GROSUB

CALLS:
NGRAIN

INPUT DATA:
DTT
LN
CUMPH
CARBO
SLAMIN
SLAMAX
STMWT
LFWT
PLA
P3P
SWDF2
NDEF2
LAI
PLANTS
HEADWT
SUMP
IDURP
POTGROPER
SWMAX
PLAMX
SLOPEPE
XLANC
XLMNC
SLAN2

OUTPUT VARIABLES:
PLAG
GROLF
GROSTM
GRORT
PLA
LFWT
SLAI
SLAN1
SLAN
HEADWT
SUMP
IDURP

1. Calculate the temperature reduction factor (RGFILL) for head and pericarp growth:

RGFILL = RGFILL + ELOFT(I)/8I=1 TO 8

where

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

and

```
ELOFT(I)=0.0                  if TTMP(I)<4 or TTMP(I)>45

ELOFT(I)= (TTMP(I)-4.0)/13.0  if 4 < TTMP(I) < 17

ELOFT(I)= 1.0                 if 17 < TTMP(I) < 31

ELOFT(I)=(45-ELO)/14.0        if 31 < TTMP(I) < 45
```

2. Calculate potential pericarp growth (GROPER, g/plant/day) as affected by temperature:

```
GROPER = POTGROPER * DTT * RGFILL
```

3. Calculate potential head growth as affected by temperature:

```
GROHEAD = 1.71 * RGFILL
```

4. Allocate daily biomass increase to growth:

4.1. If potential pericarp growth is greater than CARBO, then the head does not grow:

```
If GROPER >CARBO then GROPER = CARBO

                      GROHEAD = 0
```

4.2. If CARBO is insufficient for pericarp and head growth, then the pericarp grows at the potential rate and the head gets the excess carbon:

```
If GROPER+GROHEAD>CARBO then

GROHEAD = CARBO - GROPER
```

4.3. If CARBO is sufficient for pericarp and head growth then the excess biomass is allocated to stem (if stem weight is below its maximum) or roots:

```
EXCESS = CARBO - GROPER - GROHEAD

If STMWT<SWMAX then GROSTM = EXCESS

                    GRORT= 0.

If STMWT>SWMAX then GRORT = EXCESS

                    GROSTM = 0.
```

5.Reduce head and pericarp growth if water or nitrogen stress is detected. Use the minimum of these two stress factors (NDEF2 and SWDF2). Stem growth is reduced by stress factors NDEF1 and SWDF1:

```
GROHEAD = GROHEAD * AMIN1(SWDF2,NDEF2)

GROPER= GROPER* AMIN1(SWDF2,NDEF2)

GROSTM= GROSTM* AMIN1(SWDF1,NDEF1)
```

6. Calculate root growth:

```
GRORT = CARBO - GROHEAD - GROPER - GROSTM
```

7. Call Subroutine NGRAIN to calculate the amount of nitrogen demanded by grain (pericarp) growth:

```
CALL NGRAIN(CARBO,GROEMB,GROPER)
```

8. Calculate senescence due to N demand:

8.1. Calculate nitrogen concentration of green leaves (XRAT, fraction):

```
XRAT = XNGLF/GLFWT
```

8.2. Calculate residual nitrogen concentration of senesced leaves assuming they contain 0.9% (YRAT, fraction):

```
YRAT = ( .009 - .0875 * XRAT ) / .9125
```

8.3. Calculate amount of nitrogen available in green leaves:

```
XNGLF = XNGLF - YRAT*GLFWT
```

8.4. Calculate leaf area equivalent of the amount of N in green leaves:

```
LAEQ = ( XNGLF - YRAT*GLFWT) * SLOPEPE
```

8.5. Calculate senesced leaf area (ZZZ cm2) as the difference between the maximum plant leaf area(PLAMX) and (8.4).

```
ZZZ = PLAMX - LAEQ
```

8.6. Calculate increment in senesced leaf area attributable to N retranslocation (DSLAN2, cm2/day):

```
DSLAN2 = ZZZ - SLAN2
```

9.Calculate increment in senesced leaf area attributable to water stress (DSLANW, cm2/day):

```
DSLANW = 0.03 * GPLA if SWDF2<0.8
```

10. Calculate the effective senescence as the maximum attributable to either nitrogen or water stress:

```
If DSLANW > DSLAN2thenDSLAN2 = DSLANW
```

11. Actualize senesced plant leaf area:

```
SLAN2 = SLAN2 + DSLAN2
```

12. Calculate specific leaf area of green leaves (SLAY, cm2/g):

```
SLAY = GPLA / GLFWT
```

13. Reduce leaf weight according to the amount of N exported:

```
LFWT = LFWT- WLAN2 * (XRAT-YRAT)*6.25

where WLAN2 = DSLAN2/SLAY
```

14. Actualize green leaf weight (GLFWT) and senesced leaf weight (SLFWT):

```
GLFWT = GLFWT - WLAN2

SLFWT = SLFWT + WLAN2*(1-6.25*(XRAT-YRAT))
```

15. Actualize green plant leaf area (GPLA) and senesced plant leaf area (SPLA):

```
GPLA= GPLA - DSLAN2

SPLA= SPLA + DSLAN2
```

16. Calculate head weight (HEADWT), pericarp weight (PERWT) and grain weight (GRNWT):

```
HEADWT = HEADWT+GROHEAD

PERWT = PERWT + GROPER

GRNWT = PERWT
```

17. Calculate stem weight increases according to the amount of protein exported from senesced leaves:

```
STMWT = STMWT + WLAN2*(XRAT-YRAT)*6.25+GROSTM
```

18. Add CARBO to variable SUMP and count time (IDURP):

```
SUMP = SUMP + CARBO
```

IDURP = IDURP + 1

NOTE: The ratio SUMP/IDURP at the begining of oil accumulation will be the average dry matter accumulation rate (g/plant/day). This value will be used later to estimate filled grain number.

- END of subroutine STAGE4.

- RETURN to subroutine GROSUB.

SUBROUTINE NGRAIN -OILCROP-SUN

Subroutine NGRAIN calculates nitrogen source-sink balances during grain growth, and oil content of the grain.

CALLED BY:

STAGE4
STAGE5.

INPUT DATA:

P5
O1
GROEMB
GPP
EMBWT
OIL
EMBN
PERN
PERWT
RANC
RMNC
XNGLF
GLFWT
XSTEMN
STMWT
XHEADN
HEADWT
STOVN
STOVWT
XLMNC
XSMNC
XHMNC
XPEPE
RTWT

OUTPUT DATA:

OIL
XNGLF
XNSLF
XSTEMN
XHEADN
STOVN
VANC
PERN
EMBN
GRAINN

0. Calculate N concentration for new growth of kernel (ENP) and pericarp (PNP):

```
ENP = (0.0225+0.0200*NFAC)
PNP = (0.0050+0.0100*NFAC)
```

1. Calculate oil accumulation (OILINC, g/day) if oil deposition has begun. Oil accumulation starts 230 C-day after first anthesis.

```
PR=1000*GROEMB/GPP/G3
If PR< 0.7 then PO=O1 else PO=EXP(-1.4*(PR-0.8))*O1
OILINC =  PO/100. * GROEMB *(P5-170.)/(P5-230.)
```

2. Calculate total amount of oil in the grain (OIL, g/plant):

```
OIL = OIL + OILINC
```

3. Calculate nitrogen demand generated by grain N concentration for new growth (NSINK, g N/plant).

```
NSINK = NSINK1 + NSINK2
```

where

```
NSINK1 = GROEMB * ENP
```

and

```
NSINK2 = GROPER * PNP
```

4. Calculate fractions of grain N demand due to embryo(FSINK1) and pericarp (FSINK2):

```
FSINK1 = NSINK1 / NSINK

FSINK2 = NSINK2 / NSINK
```

5. Reset root N concentration to its minimum value if necessary:

```
If  RANC < RMNC  then  RANC=RMNC
```

6. Calculate actual N concentration for each organ:

```
XLANC = XNGLF/ GLFWT Green leaves

XSANC = XSTEMN / STMWT Stem

XHANC = XHEADN / HEADWTHead

VANC = STOVN/STOVWTStover
```

7. Calculate size of labile nitrogen pools (g N/plant). Two N pools are considered: NPOOL1 and NPOOL2. All labile N in stem and head and part of labile N in leaves belong to NPOOL1. Root labile N and the remainder of leaf labile N belong to NPOOL2. NPOOL2 is not used until NPOOL1 is exhausted.

8.1. Calculate leaf contributions to the two pools (NPL1L is part of NPOOL1, and NPL2L is part of NPOOL2):

```
NPL1L =GLFWT * ( XLANC - XLMNC)
```

It is assumed that a fixed amount of leaf labile N is not exported until all labile N in the above ground parts is exhausted. This amount is called XPEPE (g N/plant) and is equivalent to 50% of labile N in leaves at first anthesis.

```
If NPL1L > XPEPE  then  NPL1L=NPL1L-XPEPE
                        NPL2L=XPEPE

If NPL1L < XPEPE  then  NPL2L = NPL1L
                        NPL1L = 0
```

8.2. Calculate stem contribution to NPOOL1:

```
NPL1S = STMWT * ( XSANC - XSMNC)
```

8.3. Calculate head contribution to NPOOL1:

NPL1H = HEADWT * (XHANC - XHMNC)

9. Calculate the size of the first labile N pool in above ground parts (NPOOL1, g N/plant):

NPOOL1 = NPL1L + NPL1S + NPL1H

10. Calculate root contribution to NPOOL2 (NPL2R, g N/plant):

NPL2R = RTWT * (RANC-RMNC)

11. Calculate the size of the second labile nitrogen pool (NPOOL2, g N/plant):

NPOOL2 = NPL2R + NPL2L

12. Calculate total labile nitrogen pool (NPOOL, g N/plant):

NPOOL = NPOOL1 + NPOOL2

13. Calculate Nitrogen Supply/Nitrogen Demand Ratio (NSDR):

NSDR = NPOOL/NSINK

14. Adjust demand if it exceeds supply:

If NSDR<1   then NSINK=NSINK*NSDR

15. Calculate limiting N concentration for green leaves that have lost all available nitrogen:

YRAT = (0.009-0.0875*XLANC)/0.9125

16. If there is not enough N in NPOOL1 to satisfy the demand then deplete NPOOL1 completely and use part of NPOOL2 :

17.1. Reduce stem, head and stover N content:

XSTEMN = XSTEMN - NPL1S

XHEADN = XHEADN - NPL1H

STOVN = STOVN-NPOOL1

17.2. The amount of N that will be extracted from each organ contributing to NPOOL2 will be proportional to its labile N content. The amount of N extracted from NPOOL2 is:

RNOUT = NSINK-NPOOL1

17.3. Reduce root N content:

ROOTN = ROOTN-RNOUT*NPL2R/NPOOL2

17.4. Actualize root N concentration:

RANC = ROOTN/RTWT

17.5. Calculate amount of N exported from leaves (RONL, g N/plant):

RONL = RNOUT*NPL2L/NPOOL2+NPL1L

17.6. Actualize leaf N content:

XLEAFN = XLEAFN - RONL

17.7. Actualize N content of green leaves:

XNGLF=XNGLF-RONL-RONL*YRAT/(XNGLF/GLFWT-YRAT)

17.8. Actualize N content of senesced leaves:

XNSLF= XLEAFN - XNGLF

18. If there is enough N in NPOOL1 to satisfy the demand:

18.1. Calculate the fraction of NPOOL1 contributed by each organ:

FACLN = NPL1L/NPOOL1(leaves)

FACSN = NPL1S/NPOOL1(stem)

FACHN = NPL1H/NPOOL1(head)

18.2. Reduce the labile N of each organ in proportion to its labile N content:

XLEAFN = XLEAFN - FACLN * NSINK

XNGLF= XNGLF-FACLN*NSINK*(1+YRAT/(XNGLF/GLFWT-YRAT))

XNSLF= XLEAFN - XNGLF

XSTEMN = XSTEMN - FACSN * NSINK

XHEADN = XHEADN - FACHN * NSINK

STOVN = STOVN-NSINK

VANC = STOVN/STOVWT

19. Actualize pericarp, embryo and grain N contents:

PERN = PERN + NSINK * FSINK2

EMBN = EMBN + NSINK * FSINK1

GRAINN = GRAINN+NSINK

- END of subroutine NGRAIN.

- RETURN to subroutine STAGE4 or STAGE5.

SUBROUTINE STAGE5 - OILCROP-SUN

Subroutine STAGE5 calculates leaf area and organ biomass balance during stage 5.

CALLED BY:
GROSUB

CALLS :
NGRAIN

INPUT VARIABLES :
SUMDTT
POTGROPER
PPP
TEMPMN
TEMPMX
G3
SWDF1
HEADWT
GPP
HVMAX
DTT
NDEF2
SWDF2
P5
DOY
CARBO
STMWT

OUTPUT VARIABLES :
EMBWT
PERWT
GRNWT
OILPERC
PLAG
GPLA
SPLA
GLFWT
SLFWT
GROLF
GROSTM
GRORT
PLA
LFWT
SLAI
SLAN1
SLAN
HEADWT
SUMP
IDURP

1. Calculate senescence due to N demand:

1.1. Calculate nitrogen concentration of green leaves (XRAT, fraction):

XRAT = XNGLF/GLFWT

1.2. Calculate residual nitrogen concentration (YRAT, fraction), assuming that senesced leaves contain 0.9% nitrogen.:

YRAT = (.009 - .0875 * XRAT) / .9125

1.3. Calculate labile nitrogen content of green leaves:

XNGLF - YRAT*GLFWT

1.4. Calculate leaf area equivalent to the amount of N in green leaves:

LAEQ = (XNGLF - YRAT*GLFWT) * SLOPEPE

1.5. Calculate senesced leaf area (ZZZ, cm2) as the difference between the maximum plant leaf area (PLAMX) and (8.4).

ZZZ = PLAMX - LAEQ

1.6. Calculate increment in senesced leaf area (DSLAN2, cm2/day):

DSLAN2 = ZZZ - SLAN2

2. Calculate senescence due to water stress (DSLANW, cm2/day):

DSLANW = 0.03 * GPLA   if SWDF2<0.8

3. Compare senescence due to nitrogen and to water stress and select the greater:

If DSLANW > DSLAN2   then DSLAN2 = DSLANW

4. Actualize senesced plant leaf area:

SLAN2 = SLAN2 + DSLAN2

5. Calculate the temperature control factor (RGFILL) for head, embryo and pericarp growth:

RGFILL = RGFILL + ELOFT(I)/8I=1 TO 8

where

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

and

ELOFT(I)=0.0   if TTMP(I)<4 or TTMP(I)>45

ELOFT(I)= (TTMP(I)-4.0)/13.0

if 4 < TTMP(I) < 17

ELOFT(I)= 1.0   if 17 < TTMP(I) < 31

ELOFT(I)=(45-ELO)/14.0

if 31 < TTMP(I) < 45

6. Calculate pericarp growth (GROPER, g/plant/day) as affected by temperature. Pericarp growth continues until 180 GDD from the beginning of STAGE 5:

GROPER = POTGROPER * DTT * RGFILL   if SUMDTT<180

7. Calculate head growth as affected by temperature. Head growth continues

until maximum head weight (HWMAX) is achieved:

```
GROHEAD = 1.71 * RGFILL            if HEADWT<HWMAX
```

8. Calculate embryo growth rate (g/embryo/d) as affected by temperature (through RGFILL), a genetic constant (G3), water deficit (SWDF1) and the growth factor (GRFACTOR) based on head weight which seeks to allow potential grain size reflect head size:

```
PEPE = RGFILL*G3*0.001*(0.70+0.30*SWDF1)*GRFACTOR
```

9. Calculate embryo growth (GROEMB, g/plant). Embryo growth takes place in all grains until grain number is determined(GPP=0). Thereafter (GPP>0) embryo growth takes place only in GPP filling grains:

```
GROEMB = GPP * PEPE     if GPP>0

GROEMB = PPP * PEPE     if GPP=0
```

10. Allocate available carbohydrates to growth:

10.1. Calculate total carbohydrate demand for growth:

```
CDEMAND = GROEMB + GROPER + GROHEAD
```

10.2. Calculate carbohydrate demand for grain growth:

```
CDGR = GROPER + GROEMB
```

10.3. If grain growth (CDGR) is greater than CARBO,then the head does not grow and biomass is imported from the stem+head pool:

```
If CDGR > CARBO

GROHEAD = 0
```

10.3.1. Calculate translocatable biomass pool size (CPOOL, g/pl/d):

```
    FCP=(STMWT-SWMIN)/(SWMAX-SWMIN)
IF FCP> 0.3 then FCP2=1 else FCP2=0

    CPOOL1=0.79*FCP2 (pool of stem)

    FCP=(HEADWT-HWMIN)/(HWMAX-HWMIN)
IF FCP> 0.3 then FCP2=1 else FCP2=0

    CPOOL2=0.42*FCP2 (pool of the head)

    CPOOL=CPOOL1+CPOOL2
```

10.3.2. If CPOOL is enough to satisfy the demand for biomass for use in growth (CDGR-CARBO), calculate export requirements from head and stem and resulting organ biomass changes assuming that 100 units of biomass in CPOOL are equivalent to 44 units of biomass in the grain. The amount of biomass exported from each organ is taken to be proportional to organ dry weight. To do this, the fractions of CPOOL in stem (FPOOL1) and the head (FPOOL2) are calculated, and then stem and head weights are recalculated:

```
If CPOOL>(CDGR-CARBO)/.44     then
```

FPOOL1 = (STMWT - SWMIN) / CPOOL

FPOOL2 = (HEADWT - HWMIN) / CPOOL

STMWT = STMWT - (GROEMB+GROPER-CARBO)/0.44*FPOOL1

HEADWT = HEADWT - (GROEMB+GROPER-CARBO)/0.44*FPOOL2

10.3.3. If CPOOL is not enough to satisfy the biomass requirement for growth (CDGR - CARBO), calculate the effects of exporting all available labile biomass on organ dry weight and grain growth. Stem and head weight will then be left at their minimum values. Embryo and pericarp will grow below their potential rates in proportion to the reduction in supply. This reduction is mediated by the reduction factor, FACPOOL :

FACPOOL = CPOOL * 0.44 / (CDGR - CARBO)

GROEMB = GROEMB * FACPOOL

GROPER = GROPER * FACPOOL

STMWT = SWMIN

HEADWT = HWMIN

10.3.4. If CARBO exceeds the biomass required for grain growth but is insufficient for both grain and head growth, then the pericarp and the embryo grow potentially and the head gets the excess biomass up to the maximum limits of head growth:

If CDEMAND>CARBO and CARBO>CDGR then

GROHEAD = CARBO - CDGR

10.3.5. If CARBO exceeds the biomass requirements for both grain and head growth then the excess biomass is allocated to the stem (if stem weight is below its maximum) or roots:

```
EXCESS = CARBO - CDEMAND

If STMWT<SWMAX    then

If SWMAX-STMWT>CARBO-CDEMAND  then

GROSTM = EXCESS

else

GROSTM = SWMAX - STMWT

GRORT= EXCESS - GROSTM

If STMWT>SWMAX    then

      GRORT = EXCESS

and   GROSTM = 0.
```

12.Reduce pericarp growth if water or nitrogen stress is detected. Use the minimum of nitrogen stress factor (NDEF2) and water stress factor (SWDF2).

GROPER= GROPER* AMIN1(SWDF2,NDEF2)

13. Calculate any root growth derived from excess biomass:

```
GRORT = CARBO - GROHEAD - GROPER - GROEMB - GROSTM
```

14. Call Subroutine NGRAIN to calculate the amount of nitrogen demanded by grain (pericarp and embryo) growth:

```
CALL NGRAIN(CARBO,GROEMB,GROPER)
```

15. Calculate head weight (HEADWT), pericarp weight (PERWT), embryo weight (EMBWT) and grain weight (GRNWT):

```
HEADWT = HEADWT + GROHEAD

EMBWT = EMBWT + GROEMB

PERWT = PERWT + GROPER

GRNWT = EMBWT + PERWT
```

16. Calculate specific leaf area of green leaves (SLAY, cm2/g):

```
SLAY = GPLA / GLFWT
```

17. Calculate total senesced leaf area:

```
SLAN = SLAN1 + SLAN2
```

18. Reduce leaf weight according to the amount of N exported:

```
LFWT = LFWT- WLAN2 * (XRAT-YRAT)*6.25

where WLAN2 = DSLAN2/SLAY
```

19. Actualize green leaf weight (GLFWT) and senesced leaf weight (SLFWT):

```
GLFWT = GLFWT - WLAN2

SLFWT = SLFWT + WLAN2*(1-6.25*(XRAT-YRAT))
```

20. Actualize green plant leaf area (GPLA) and senesced plant leaf area (SPLA):

```
GPLA= GPLA - DSLAN2

SPLA= SPLA + DSLAN2
```

21. Calculate oil percent in the grain (OILPERC):

```
OILPERC = OIL / GRNWT * 100.
```

22. Add CARBO to variable SUMP and count time (IDURP):

```
SUMP = SUMP + CARBO

IDURP = IDURP + 1
```

NOTE: The ratio SUMP/IDURP at the begining of oil accumulation will be the average dry matter accumulation rate (g/plant/day) for the interval from first-anthesis to the start of oil accumulation. This value will be used later to estimate the number of grains which continue filling.

- END of subroutine STAGE5.
- RETURN to subroutine GROSUB.

SUBROUTINE NUPTAK - OILCROP-SUN

Subroutine NUPTAK calculates soil N content, crop N uptake and organ N concentration and content.

CALLED BY:
MAIN Program

INPUT DATA:
HEADWT
XSTEMN
GROPER
GROEMB
PERWT
EMBWT
ROOTN
XSTEMN
XNGLF
XHEADN
RTWT
STMWT
HEADWT
NO3(I)
NH4(I)
RLV(I)

OUTPUT DATA:
XLEAFN
XNGLF
XNSLF
XSTEMN
XHEADN
EMBN
PERN
STOVN
ROOTN
NO3(I)
NH4(I)
FON(I)
TNO3
TNH4

1. Reset head and stem N contents when head rapid growth starts.

XHEADN = 0.042 * HEADWT

XSTEMN = XSTEMN - XHEADN

2. Calculate actual N concentrations in plant parts

RANC=ROOTN/RTWT Roots

XSANC = XSTEMN / STMWT Stem

XLANC = XNGLF/ GLFWT Green leaves

XHANC = XHEADN / HEADWT Head

and Shoot (excluding senesced leaves):

```
TANC = ( XSTEMN + XNGLF + XHEADN )/ ( STMWT+GLFWT+HEADWT)
```

3. Calculate nitrate and ammonimum concentrations (mg N/kg soil) for all layers in the soil profile (from L=1 to L=NLAYR):

```
NO3(L)=SNO3(L)*FAC(L)

NH4(L)=SNH4(L)*FAC(L)
```

where SNO3(L) and SNH4(L) are nitrate and ammonimum concentrations in kg N/ha, and FAC(L) converts kg N/ha to mg N/kg soil.

4. Calculate total amount (kg N/ha) of NO3 (ANO3) and NH4 (ANH4) in the soil profile:

```
ANO3=ANO3+SNO3(L) from L=1 to L=NLAYR

ANH4=ANH4+SNH4(L) from L=1 to L=NLAYR
```

5. Calculate total N content (kg N/ha) of the soil profile:

```
TOTN=TOTN+NO3(L)+NH4(L)from L=1 to L=NLAYR
```

6. Calculate total root length in the soil profile:

```
TRLV=TRLV+RLV(L) from L=1 to L=NLAYR
```

7. Calculate demand of N for new growth of the plant parts:

```
DNGL = PDWIL * XLCNP (leaves)

DNGS = PDWIS * XSCNP (stem)

DNGH = PDWIH * XHCNP (head)
```

8.Calculate N demand to cover existing deficits:

```
DNSL = GLFWT * ( XLCNP - XLANC)(leaves)

DNSS = STMWT * ( XSCNP - XSANC)(stem)

DNSH = HEADWT * ( XHCNP - XHANC) (head)
```

9. Calculate total N demand of the plant parts:

```
XLNDEM = DNGL + DNSL (leaves)

XSNDEM = DNGS + DNSS (stem)

XHNDEM = DNGH + DNSH (head)
```

10. Calculate total tops N demand:

```
TNDEM = XLNDEM + XSNDEM + XHNDEM
```

11. Calculate root N demand:

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

12. Calculate total N demand for the whole plant (NDEM, g N/plant):

NDEM=TNDEM+RNDEM

13. Calculate total N demand for crop (ANDEM, kg N/ha):

ANDEM=NDEM*PLANTS*10.0

14. Reset daily uptake description and control variables to zero.

DROOTN=DSTOVN=DLEAFN=DSTEMN=DHEADN=0

TRNU=TNUP=0.0

NUF=0.

15. Calculate for each layer in the soil the supply factors for NO3 (FNO3) and NH4 (FNH4).

FNH4=1.0-EXP(-0.030*(NH4(L)-0.5))

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

where NO3(L) and NH4(L) are nitrate and ammonium concentration in layer L (mg N/kg soil).

16. Reset FNO3 and FNH4 if they are outside the 0-1 range.

FNO3=0.0   if FNO3<0.04

FNO3=1.0   if FNO3> 1

FNH4=0.0   if FNH4<0.04

FNH4=1.0   if FNH4> 1

17. Calculate soil water deficit factor for N uptake:

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

if SMDFR>1

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

18. Calculate root N uptake factor in layer L:

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

19. Calculate potential root NO3 uptake in layer L (kg N/ha):

RNO3U(L)=RFAC*FNO3*0.006

20. Calculate potential root NH4 uptake in layer L (kg N/ha):

RNH4U(L)=RFAC*FNH4*0.006

21. Calculate potential root N uptake in the soil profile (kg N/ha):

TRNU=TRNU+RNO3U(L)+RNH4U(L)for L=1 to L=NLAYR

22. Reset potential N uptake to zero if N demand is zero.

TRNU=0   if ANDEM=0

23. Calculate a N use factor (NUF) if N demand exceeds potential root N uptake.

```
NUF=ANDEM/TRNU
```

24. Calculate actual root NO3 uptake for each layer (kg N/ha):

```
UNO3=RNO3U(L)*NUF
```

25. Calculate actual root NH4 uptake for each layer (kg N/ha):

```
UNH4=RNH4U(L)*NUF
```

26. Set the minimum value for NO3 in the layer (XMIN, kg N/ha) equivalent to 0.25 mg N/kg soil.

```
XMIN=0.25/FAC(L)
```

27. Reduce NO3 uptake if neccesary, to avoid depleting NO3 below its minimum value (XMIN):

```
UNO3=SNO3-XMIN if UNO3>SNO3-XMIN
```

where SNO3 is NO3 concentration in the layer (kg N/ha).

28. Actualize NO3 concentration in the layer:

```
SNO3(L)=SNO3(L)-UNO3
```

29. Set a minimum value for NH4 in the layer (XMIN, kg N/ha) equivalent to 0.50 mg N/kg soil.

```
XMIN=0.50/FAC(L)
```

30. Reduce NH4 uptake if neccesary, to avoid depleting NH4 below its minimum value (XMIN):

```
UNH4=SNH4-XMIN if UNH4>SNH4-XMIN
```

where SNH4 is NH4 concentration in the layer (kg N/ha).

31. Actualize NH4 concentration in the layer:

```
SNH4(L)=SNH4(L)-UNH4
```

32. Reset NO3 and NH4 concentrations in the layer (mg N/kg soil):

```
NO3(L)=SNO3(L)*FAC(L)

NH4(L)=SNH4(L)*FAC(L)
```

33. Add root N loss to the layer to the organic N pool in the layer:

```
FON(L)=FON(L)+RNLOSS
```

34. Add potential NO3 and NH4 uptake from the layer to total N uptake from the profile:

```
TRNU=TRNU+UNO3+UNH4
```

35. Calculate individual plant potential uptake in units of g N/plant:

TRNU=TRNU/(PLANTS*10.0)

36. If N demand exceeds potential N uptake, then reduce plant N demand to potential N uptake and calculate a supply/demand factor (FACTOR):

if NDEM>TRNU

FACTOR = TRNU / NDEM

and NDEM = TRNU

37. Adjust N demand of the plant parts to potential N supply:

XLNDEM = XLNDEM * FACTOR (leaves)

XSNDEM = XSNDEM * FACTOR (stem)

XHNDEM = XHNDEM * FACTOR (head)

TNDEM = TNDEM * FACTOR (above ground parts)

RNDEM = RNDEM * FACTOR (roots)

38.Calculate weights of the plant parts as fractions of whole plant weight:

PTFL = PTF * GLFWT / (STOVWT-SLFWT)(leaves)

PTFS = PTF * STMWT / (STOVWT-SLFWT)(stem)

PTFH = PTF * HEADWT /(STOVWT-SLFWT)(head)

39. Increment in N content for each plant part as a function of plant gain or loss of N:

DLEAFN=XLNDEM/NDEM*TRNU(leaves)

DSTEMN = XSNDEM/NDEM*TRNU (stem)

DHEADN = XHNDEM/NDEM*TRNU (head)

40. Increment the N content of the above ground plant parts (DSTOVN) and the roots (DROOTN) as a function of plant gain of N:

DSTOVN = DLEAFN + DSTEMN + DHEADN

DROOTN=RNDEM/NDEM*TRNU

41. Calculate N content of the plant parts (g N/plant):

XLEAFN = XLEAFN + DLEAFN(leaves)

XNGLF= XNGLF+ DLEAFN(green leaves)

XNSLF= XLEAFN - XNGLF (senesced leaves)

XSTEMN = XSTEMN + DSTEMN(stem)

XHEADN = XHEADN + DHEADN(head)

42. Calculate N content of aerial plant parts(STOVN, g N/plant) and roots (ROOTN, g N/g):

STOVN= XNGLF + XSTEMN + XHEADN + XNSLF

ROOTN=ROOTN+DROOTN

43. Calculate N concentration of roots (RANC, g N/g):

RANC=ROOTN/(RTWT-0.01*RTWT)

44. Reset NO3 and NH4 concentrations (kg N/ha) in the soil profile:

TNO3=TNO3+SNO3(L) for L=1 to L=NLAYR

TNH4=TNH4+SNH4(L) FOR L=1 to L=NLAYR

- END of subroutine NUPTAK.

- Return to subroutine GROSUB.

SUBROUTINE PHENOL-OILCROP-SUN

Subroutine PHENOL establishes the progress of crop development and calculates rooting depth. In addition, the numbers of filled and empty grains (both strongly affected by environment/phenology interactions) are also calculated. This subroutine also prepares a summary report of the values of several crop variables at harvest.

CALLED BY:

MAIN Program

CALLS:

PHASEI
CALDAT [1]
CALCSI [1]

[1] CALDAT, and CALCSI6 are auxiliary subroutines needed for data handling, and data input/output. They are common to OILCROP-SUN and CERES models and are not described here.

INPUT DATA :

TEMPMX
TEMPMN
TBASE
TMFAC(I)
PLANTS
TANC
STOVN
SUMDTT
CUMDTT
SW(I)
LL(I)
RTDEP
P9
ISTAGE
XSTAGE
P1
DOY
S1
C1
P2
SIND
SUMP
IDURP
G2
HEADWT
POTHEADWT
G3
P5
GRAINN
GRNWT
PERWT
EMBWT

OUTPUT DATA :

DTT
SUMDTT
CUMDTT
RTDEP
ISTAGE
XSTAGE

SIND
ABIOMS
ISDATE
PPP
PERWT
POTGROPER
GPP
PERWTE
EMBWTE
GRNWTE
GRAINN1
GRAINNE
PERN
EMBN
GPSM
EMBWT
YIELD
SKERWT

1. Initialize variables:

XANC = TANC * 100.0

APTNUP = STOVN * 10. * PLANTS

IRET = 0

2. Calculate daily average temperature (TEMPM):

TEMPM= (TEMPMX + TEMPMN) / 2.

3. Calculate growing degree-days for current day (DTT):

DTT= TEMPM - TBASE

4. Recalculate DTT if the weather is outside the normal range:

4.1. DTT = 0   if TEMPMX < TBASE

4.2. When TEMPMN<=TBASE or TEMPMX=>28.0 :

DTT = DTT + F(I)   from I=1 to 8

F(I)=(TTMP-TBASE)/8   if TBASE< TTMP <=28

F(I)=(28-TBASE)*(1-.007*(TTMP-28)**2)/8

if 28 < TTMP < 40

where

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

5. Calculate cumulative growing degree-days:

SUMDTT = SUMDTT + DTT

6. If ISTAGE=7 then determine sowing date:

CALL CALDAT

and initialize variables

```
            CALL PHASEI

            NDAS = 0

            CUMDEP = 0.

            L = 1

            and find the layer where sowing took place (L0).

7. If ISTAGE=8 then determine germination date:

7.1. If SW(L0)<=LL(L0)) then

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

            NDAS = NDAS + 1

            If NDAS=>40 then - GERMINATION FAILURE -

                  - Terminate program :

                        ISTAGE = 6
                        PLANTS = 0.
                        GPP= 1.
                        GRNWT= 0.

7.2. If SW(L0)>LL(L0) then germination occurrs, so initialize variables:

            CALL CALDAT

            CALL PHASEI

8. If ISTAGE=9 then determine seedling emergence rate:

8.1. Calculate rooting depth:

            RTDEP = RTDEP + 0.15 * DTT

8.2. Check if emergence occurred:

            If SUMDTT=>P9 then - EMERGENCE -

            and initialize variables:

            CALL CALDAT

            CALL PHASEI

            Make ISTAGE = 1

9. If ISTAGE=1 then determine the end of the juvenile phase:

9.1. Real variable to quantify development (XSTAGE):

            XSTAGE = SUMDTT / P1

9.2. Check if the juvenile phase has terminated:

            If SUMDTT=>P1 then - END OF JUVENILE PHASE -

            and initialize variables:
```

CALL CALDAT

CALL CALCSI

CALL PHASEI

Make ISTAGE = 2

10. If ISTAGE=2 then determine the date of inflorescence initiation:

10.1. Calculate photoperiod (HRLT):

HRLT = PHOTOP(DOY,S1,C1)

if HRLT>15 then make HRLT=15

10.2. Calculate rate of development (RATEIN):

RATEIN = 1 / (3 + P2 * (15 - HRLT))

10.3. Calculate cumulative development:

SIND = SIND + RATEIN

10.4. Calculate XSTAGE:

XSTAGE = 1.0 + 0.5 * SIND

10.5. Check if inflorescence initiation has started:

If SIND=>1 then - START OF INFLORESCENCE INITIATION -

Make ISTAGE = 3

Calculate when first anthesis will take place: P3P in Cday will be the thermal time required to reach first anthesis.

P3P = 2 *P1

Call subroutine CALDAT to determine the date and call subroutine PHASEI to initialize variables:

11. If ISTAGE=3 then determine the begining of anthesis:

11.1. XSTAGE:

XSTAGE = 1.5 + 3.0 * SUMDTT / P3P

11.2. Check if anthesis has started:

If SUMDTT=>P3P then - ANTHESIS STARTED -

Make ISTAGE = 4

Assign values to variables:

CALL CALDAT

ISDATE = DOY

ABIOMS = BIOMAS

11.3. INCLUDE CALCULATIONS TO CORRECT RUE AFTER ANTHESIS

```
     MANTAINANCE RESPIRATION
      RM = (BIOMAS+RTWT*PLANTS)*0.008*.729
      RI1=1.+RM/PSKER/PLANTS
```

12. Calculate pericarp number and fix limits to growth of grains.

12.1. Calculate average rate of dry matter accumulation in the period prior to anthesis (PSKER, g/plant/day):

PSKER = SUMP / IDURP

12.2. Calculate number of pericarps per plant:

```
PPP = 430 + G2 * PSKER / 14.5       if PSKER>5

PPP = PSKER * (430+G2*5/14.5)/5     if PSKER<5

make PPP=G2                         if PPP>G2
```

12.3. Calculate factor for grain growth (GRFACTOR) as a function of head weight (HEADWT):

GRFACTOR = 0.6 + 0.4 * ZZZ < 1

where ZZZ=HEADWT/POTHEADWT   and ZZZ<=1

12.4. Initialize pericarp weight (PERWT, g/plant):

PERWT = PPP * 0.002

(each pericarp starts with 2 mg)

12.5.Adjust head weight by substracting the weight assigned to pericarps:

HEADWT = HEADWT - PERWT

12.6. Calculate potential pericarp growth rate (POTGROPER, g/plant/day):

POTGROPER = 24.* ALF1 * PPP / 1000.

where

ALF1=(0.22*G3/24*(P5-170)-2*0.78)/270/0.78

Call subroutine CALDAT to determine the date and call subroutine PHASEI to initialize variables:

13. If ISTAGE=4 then determine the beginning of effective embryo growth:

13.1. Calculate XSTAGE:

XSTAGE = 4.5 + 5.5 * SUMDTT / (P5 * .95)

13.2. Check if embryo filling has started:

If SUMDTT=>90 then - EMBRYO FILLING PERIOD STARTED -

Call subroutine CALDAT to determine the date and call subroutine PHASEI to initialize variables :

```
13.3. INCLUDE CALCULATIONS TO CORRECT RUE AFTER ANTHESIS
C     MANTAINANCE RESPIRATION
      PS=RM/(RI1-1.)
      RM = (BIOMAS+RTWT*PLANTS)*0.008*.729
      RI1=1.+RM/PS
```

14. If ISTAGE=5 then determine the end of the effective embryofilling period:

14.1.Calculate XSTAGE:

XSTAGE = 4.5 + 5.5 * SUMDTT/P5

14.2. Check if oil has started to accumulate:

If SUMDTT=>230 then- OIL STARTED TO ACCUMULATE -

15. Calculate number of embryos that continue to fill and determine effects of incomplete embryo setting on biomass and N partitioning.

15.1. Calculate average rate of dry matter accumulation in the period after anthesis (PSKER, g/plant/day):

PSKER = SUMP / IDURP

15.2. Calculate number of filled grains per plant (GPP):

GPP = 430 + G2 * PSKER / 14.5 if PSKER>5

GPP = PSKER * (430+G2*5/14.5)/5 if PSKER<5

make GPP=PPP if PPP>G2

15.3. Calculate pericarp weight of empty grains (PERWTE, g/plant):

PERWTE = (PPP - GPP) * PERWT / PPP

15.4. Calculate embryo weight of empty grains (EMBWTE, g/plant):

EMBWTE = (PPP - GPP) * EMBWT / PPP

15.5. Calculate grain weight of empty grains (GRNWTE, g/plant):

GRNWTE = PERWTE + EMBWTE

15.6. Calculate nitrogen content of the grains that continue to fill (GRAINN1, g/plant):

GRAINN1 = GRAINN * (1. - GRNWTE / GRNWT)

15.7. Calculate nitrogen content of empty grains (GRAINNE, g/plant):

GRAINNE = GRAINN - GRAINN1

15.8. Calculate nitrogen content of pericarps (PERN, g/plant):

PERN = PERN * GRAINN1 / GRAINN

15.9. Calculate nitrogen content of embryos (EMBN, g/plant):

EMBN = EMBN * GRAINN1 / GRAINN

15.10. Adjust grain N content to N content of grains that continue to fill:

GRAINN = GRAINN1

15.11. Adjust grain weight (GRNWT), embryo weight (EMBWT) and pericarp weight (PERWT) to account for the weight of empty grains:

GRNWT = GRNWT - GRNWTE

PERWT = PERWT - PERWTE

EMBWT = EMBWT -EMBWTE

16. Check if the embryo filling period has ended:

If SUMDTT=> P5*0.95 then - END OF EMBRYO FILLING PERIOD -

Initialize variables:

Make ISTAGE = 6

Call subroutine CALDAT to determine date and call subroutine PHASEI to initialize variables:

17. If ISTAGE=6 then determine physiological maturity:

17.1. Check if conditions for physiological maturity are met:

If DTT<2then SUMDTT=P5 (very cold conditions)

If SUMDTT=>P5then - PHYSIOLOGICAL MATURITY -

17.2 Assign values to variables:

17.2.1. Grain yield (YIELD, kg/ha with 9% moisture):

YIELD = GRNWT * 10. * PLANTS / 0.91

17.2.2. Calculate individual grain weight (SKERWT, g/grain):

SKERWT = GRNWT / GPP

17.2.3. Calculate individual grain weight (PGRNWT, mg/grain):

PGRNWT = SKERWT * 1000.0

17.2.4. Calculate number of filled grains per square meter (GPSM):

GPSM = GPP* PLANTS

17.2.5. Calculate stover weight (kg/ha):

STOVER = BIOMAS * 10. - YIELD*0.91

17.2.6. Calculate grain nitrogen concentration (XGNP, percent):

XGNP = (GRAINN / GRNWT) * 100.0

17.2.7. Calculate grain protein concentration(XPTN, percent):

XPTN = XGNP * 6.25

17.2.8. Calculate grain nitrogen uptake(GNUP, kg/ha):

GNUP = GRAINN * PLANTS * 10.

17.2.9. Calculate total nitrogen uptake(TOTNUP, kg/ha):

TOTNUP = GNUP + APTNUP

Call subroutine CALDAT to determine the date and call subroutine PHASEI to initialize variables.:

- END of subroutine PHENOL.

- RETURN to MAIN program.

SUBROUTINE PHASEI - OILCROP-SUN

Subroutine PHASEI initializes variables at the start of each development stage, fixes limits to head and stem growth and labile and non-labile biomass fractions in the stem and receptacle, Nmin levels and labile-N contents of leaves.

CALLED BY:
PHENOL

INPUT DATA:
ISTAGE
PLA
LFWT
XLEAFN
SUMDTT
STMWT
P3P
XNGLF
GLFWT
LAI
PLANTS
SDEPTH
P1
P2

OUTPUT DATA (Many variables are initialized in this subroutine. Only those that are calculated have been listed):

SLOPEPE
XPEPE
SWMIN
SWMAX
XLEAFNMIN
HWMAX
HWMIN
P9
TBASE

1- Set cumulative variables for stress to zero:

```
CNSD1=CNSD2=CSD1=CSD2=0.
```

2- Stage 2 : End of juvenile phase to flower initiation.

```
SIND=0.
```

3- Stage 3 : Flower initiation to first anthesis.

3.1- Time variable to calculate senescence due to shading.

```
SENTIME = 0.
```

3.2- Senescence rate due to shading.

```
SENRATE = 0.
```

3.3- Green plant leaf area is set equal to total plant leaf area.

GPLA = PLA

3.4- Senesced plant leaf area.

SPLA = 0.

3.5- Senesced plant leaf weight.

SLFWT = 0.

3.6- Nitrogen amount in senesced leaves.

XNSLF = 0.

3.7- Green plant leaf weight is set equal to total plant leaf weight.

GLFWT = LFWT

3.8- Nitrogen amount in green leaves is set equal to N amount in leaves.

XNGLF = XLEAFN

3.9- Head weight.

HEADWT=0.

3.10- Total leaf number is assumed to be a function of thermal time from emergence and the rate of leaf primordia initiation (14 GDD/leaf).Two leaf primordia are present in the seed.

TLNO=SUMDTT/14+2

3.11- Initialize cumulative thermal time from the beginning of the stage.

SUMDTT=0.

3.12- Initialize cumulative biomass for period:

SUMP=0.

3.13- Initialize duration (days) of the period for which SUMP is computed.

IDURP=0

4- Stage 4 : First anthesis to beginning of embryo filling.

4.1- Initialize cumulative biomass for the period:

SUMP=0.

4.2- Initialize duration (days) of the period for which SUMP is computed.

IDURP=0

4.3- Fix minimum stem weight which is set equal to 80% of stem weight at first anthesis. This assumption implies that 20% of stem biomass is labile.

SWMIN=STMWT*.80

4.4- Fix maximum limit to stem weight. The stem is assumed not to grow more than a further 80% of its current weight. Maximum stem weight is calculated.

```
SWMAX=1.80*STMWT
```

4.5- Initialize top fraction.

```
PTF=1.0
```

4.6- Reset cumulative thermal time to zero or about zero.

```
SUMDTT=SUMDTT-P3P
```

4.7- Fix minimum N amount in leaves at 0.9% of the current amount at first anthesis.

```
XLEAFNMIN = 0.009*LFWT
```

4.8- Determine nitrogen concentration in green leaves.

```
XRAT = XNGLF / GLFWT
```

4.9- Determine nitrogen concentration in senesced leaves.

```
YRAT = (0.009-0.0875*XRAT)/0.9125
```

4.10- Determine the plant leaf area/available N in leaves ratio. This variable is used to calculate the senescence rate driven by N demand.

```
SLOPEPE = LAI*10**3/PLANTS/ ( XNGLF - YRAT*GLFWT)
```

4.12- Determine the amount of N in leaves that can be rapidly exported. This is assumed to equal 50% of labile N.

```
XPEPE = 0.50 * ( XNGLF - YRAT*GLFWT)
```

4.13- Initialize rate of leaf senescence driven by N demand.

```
DSLAN2= 0.
```

5- Stage 5 : Beginning of embryo filling to physiological maturity.

5.1- Initialize number of grains per plant.

```
GPP = 0.
```

5.2- Fix limit to maximum head weight. This is set at 220% of its current weight.

```
HWMAX = 2.20 * HEADWT
```

5.3 - Fix limit to minimum head weight. This is set equal to head weight at the start of STAGE 5.

```
HWMIN =HEADWT
```

5.4 - Initialize individual grain weight.

```
SKERWT=0.0
```

6 - Stage 6 : No variables are initialized.

7 - Stage 7 : Start of the simulation to sowing.

7.1- Initialize cumulative thermal time.

```
CUMDTT=0.
```

7.2- Initialize cumulative rainfall, soil evaporation,plant evaporation and evapotranspiration.

```
CRAIN=CES=CEP=CET=0.
```

8 - Stage 8 : Sowing to germination.

8.1- Set initial rooting depth equal to sowing depth.

```
RTDEP=SDEPTH
```

8.2- Initialize cumulative thermal time from sowing.

```
SUMDTT = 0.
```

9 - Stage 9 : Germination to emergence.

9.1- Initialize cumulative rainfall, soil evaporation, plant evaporation and evapotranspiration.

```
CRAIN=CES=CEP=CET=0.
```

9.2- Thermal time (base 4C) from germination to emergence is calculated according to sowing depth.

```
P9=66.+11.9*SDEPTH
```

9.3- Initialize cumulative thermal time.

```
CUMDTT=0.
```

9.4- Initialize nitrogen stress factors affecting photosynthesis, expansion growth and grain filling:

```
NDEF1=NDEF2=NDEF3=1.0
```

9.5 - Initialize thermal time from germination.

```
SUMDTT=0.
```

9.6- Fix base temperature.

```
TBASE=6
```

10 - Stage 1 : Emergence to end of the juvenile phase.

10.1 - Set thermal time from emergence to zero or about zero.

```
SUMDTT=SUMDTT-P9
```

10.2 - Initial plant leaf area which is equal to initial green plant leaf area is set to 3 cm2/plant and leaf number is set to 1:

```
PLA = GPLA = 3.0
```

LN= 1

10.3 - Initial plant leaf weight which is equal to initial green plant leaf weight is set to 0.03 g/plant:

LFWT = GLFWT = 0.03

10.4 - Initial senesced leaf weight is set equal to zero.

SLFWT = 0.

10.5 - Set initial root and stem weight:

RTWT=0.02

STMWT=0.01

10.6 - Calculate LAI at emergence:

LAI=PLANTS*PLA*0.0001

10.7 - Set head, pericarp, embryo, grain and empty grain weights to zero:

HEADWT= PERWT = EMBWT = GRNWT = GRNWTE = 0

10.8 - Assign an initial value to stover weight, which is equal to biomass at emergence:

STOVWT=0.04

BIOMAS=STOVWT

10.9 - Set growth rates to zero for all the plant parts:

GROSTM= GROLF = GROHEAD = GROPER = GROEMB = GRORT = 0.

10.10 - Oil content and pericarp number are set to zero:

OIL = 0.

PPP = 0.

10.11 - Calculate an initial estimate of final leaf number by assuming photoperiod of 12h and 10 C-d per day:

TLNO = 2 + (P1 + 30 + 30*P2)/14

10.12 - Cumulative senesced leaf areas are set to zero:

SENLA=SLAN=SLAN1=SLAN2 = 0.

10.13 - The number of expanded leaves is zero:

CUMPH = 0

10.14 - Actualize base temperature:

TBASE=4.0

10.15 -Set N concentrations for roots, leaves, stem, head and aerial biomass (tops):

RANC=0.0466

XLANC = 0.062

XSANC = 0.0444

XHANC = 0.042

TANC=0.0576

10.16-Calculate N contents in leaves, stem, roots and tops:

XLEAFN = XNGLF = XLANC * LFWT

XSTEMN = XSANC * STMWT

ROOTN=RANC*RTWT

STOVN=STOVWT*TANC

10.17 - Calculate initial root length density for all layers where roots are present:

RLV(L) = 0.20*PLANTS/DLAYR(L)

- END of subroutine PHASEI.

- Return to MAIN program.

FUNCTION PHOTOP - OILCROP-SUN

Function PHOTOP calculates photoperiod as a function of latitude and day of the year.

CALLED BY:
PHENOL.

INPUT DATA:
S1
C1
DOY

OUTPUT DATA:
PHOTOP

1. Calculate solar declination (radians):

```
DEC = 0.4093* SIN(0.0172 * (DOY - 82.2))
```

2. Calculate daylength with photoperiodic activity (radians):

```
DLV = (-S1 * SIN(DEC) - 0.1047) / (C1 * COS(DEC))
```

3. Set a minimum value for DLV:

```
If DLV<-0.87 then set DLV=-0.87
```

4. Photoperiod (hours):

```
PHOTOP = 7.639 * ACOS(DLV)
```

where ACOS is the Fortran arc-cosine function.

- End of PHOTOP function.

- RETURN to subroutine PHENOL.

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GLOSSARY

A - Zero to unity factor for relative nitrification rate (unitless)
ABD - Average soil bulk density (g/cm3)
ABIOMS - Shoot biomass at first anthesis (g/m2).
ADD - Temporary variable used in the calculation of crop residue
AFERT(J) - Amount of nitrogen added as fertilizer on JFDAY(J) (kg N/ha)
AIRR(J) - Amount of irrigation added on JDAY(J) (mm)
ALBEDO - Integrated crop and soil albedo - unitless
ALF1 - Variable used to calculate potential pericarp growth rate.
ALX - Current Julian date as a radian fraction of 1 year for soil temperature calculations
AMP - Annual amplitude in annual average temperature
ANDEM - Crop N demand (kg N/ha)
ANH4 - Total extractable ammonium N in soil profile (kgN/ha)
ANO3 - Total extractable nitrate N in soil profile (kgN/ha)
APTNUP - Vegetative N uptake (kg N/ha)
ATOT - Accumulator used to calculate moving average soil surface temperatures
AVEARG(10) - Array used to store variables for soil water output calculations
AW - Available water used in soil temperature calculations (cm)
AWR - Assimilate area to weight ratio (square cm/g)
B - Interim variable used in the Gamma function to predict soil temperature
BD - Bulk density of soil (g/cm3)
BDATE - Character variable indicating the beginning date of weather contained within a weather file
BIOMAS - The accumulated dry weight biomass of above ground plant material following seedling emergence - g/m2 = Shoot biomass.
BRIAN - N deficit factor for leaves.
C1 - Cosine of the latitude
CARBO - Rate of dry matter accumulation (g /plant/day).
CDEMAND - Total biomass demand for growth (g/plant/day).
CDGR - Biomass demand for grain growth (g/plant/day).
CEP - Cumulative plant evaporation (mm).
CES - Cumulative soil evaporation (mm).
CET - Cumulative evapotranspiration (mm).
CN1 - Intermediate quantity used to calculate daily runoff
CN2 - Curve number input used to calculate daily runoff
CN3 - Intermediate variable used to calculate runoff.
CNI(L) - Capacity for nitrification index in layer L.This is a zero to unity number indicating the relative capability for nitrification to proceed.
CNR - C:N ratio calculated as (kg C in FOM)/(kg N in FOM + kg mineral N)
CNRF - Zero to unity C:N ratio factor for decomposition rate
CNSD1 - Accumulates nitrogen deficit factor (NDEF1) in each stage and is printed at the end of each stage as a daily average
CNSD2 - Accumulates nitrogen deficit factor (NDEF2) in each stage and is printed at the end of each stage as a daily average
CPOOL - Carbohydrate pool in stem and head (g/plant).
CRAIN - Cumulative precipitation (mm).
CSD1 - Accumulates soil water deficit factor 1 (SWDF1) in each stage and is printed at the end of each stage as a daily average
CSD2 - Accumulates soil water deficit factor 2 (SWDF2) in each stage and is printed at the end of each stage as a daily average
CTNUP - Cumulative tops N uptake (kg N/ha)
CUMDEP - Cumulative depth of the soil profile - cm
CUMDTT - Cumulative thermal time after germination (C-day).

CUMPH - Number of expanded leaves.
CW - Water extractable carbon concentration of soil (ppm)
DAGR - Floating variable for the integer IOUTGR
DAUP - Floating variable for the integer IOUTNU
DAWA - Floating variable for the integer IOUTWA
DBAR - Average soil water diffusivity used to calculate upward water flow in top layers
DD - Soil temperature damping depth (mm)
DEC - Declination of the sun - radians
DEF - Interim variable used to ensure soil nitrogen pools remain positive
DEMBN - Increment in embryo N.
DEPMAX - Maximum soil depth where soil water concentration changes - mm
DEPTH - Depth to the bottom of a layer from the surface (cm)
DFERT(J) - Depth of incorporation of fertilizer applicationon Julian date(JFD)
DHEADN - Daily change in head N content.
DL1 - Upper depth of a soil layer - cm
DL2 - Lower depth of a soil layer - cm
DLAYR(L) - Depth increment of soil layer L - cm
DLEAFN - Daily change in leaf N content.
DLL - Intermediate variable used in soil water initialization
DLV - Temporary variable used in the determination of day length
DM - Shoot biomass (kg/ha).
DMINR - Humic fraction decay rate (1/days)
DMOD - Zero to unity dimensionless factor used to decrease to rate of mineralization in soils with chemically protected organic matter
DNG - N demand of potential new growth of tops (gN/plant)
DNGL - N demand of potential new growth of leaves (gN/plant)
DNGS - N demand of potential new growth of stem (g/plant)
DNGH - N demand of potential new growth of head (gN/plant)
DNGP - N demand of potential new growth of pericarps (gN/plant)
DNGE - N demand of potential new growth of embryos (gN/plant)
DNRATE - Denitrification rate (kg N/ha/day)
DNSL - N deficit demand of leaves.
DNSS - N deficit demand of stems.
DNSH - N deficit demand of heads.
DNSP - N deficit demand of pericarps.
DNSE - N deficit demand of embryos.
DOY - Day of the year (1-365).
DP - Maximum damping depth for the soil layer (mm)
DPERN - Increment in pericarp N.
DRAIN - Drainage rate - cm/day
DROOTN - Daily change in plant root nitrogen content (gN/plant)
DSLAN1 - Leaf senescence rate (m2/plant/day).
DSLAN2 - Rate of leaf senescence caused by nitrogen (cm2/day).
DSLANW - Rate of senescence caused by water stress (cm2/plant/day).
DSTEMN - Daily increment in stem N content.
DT - Difference between moving average soil surface temperature and long-term daily average ambient temperature
DTOPSN - Daily change in plant tops nitrogen content (gN/plant)
DTT - Daily thermal time (C-day).
DUL(L) - Drained upper limit soil water for soil layer L -volume fraction
EDATE - Character variable indicating the ending date of weather contained within a weather file
EEQ - Equilibrium evaporation used to calculate potential evapotranspiration - mm/day
ELNC - Environmental limit on nitrification capacity (zero to unity unitless factor)
ELO - Average temperature for the daylight period (C).
ELOFT(I) - Intermediate variable to calculate the effect of temperature

on growth.

EMBN - Nitrogen amount in embryos (g/plant).
EMBWT - Embryo weight (g/plant).
EMBWTE - Embryo weight of empty grains (g/plant).
EO - Potential evapotranspiration - mm/day
EOS - Potential soil evaporation - mm/day
EP - Actual plant evaporation (transpiration) -mm/day
EP1 - Actual transpiration - cm/day
ES - Actual soil evaporation - mm/day
ES1 - Actual soil evaporation - cm/day
ESW(L) - Extractable soil water content for soil Layer L (the difference between DUL and LL - volume fraction)
ESX - Temporary soil evaporation variable - mm/day
ET - Actual soil and plant evaporation - mm/day
EXCESS - Variable used to calculate partitioning.
EXPTNO - Experiment number (used in DSSAT I/O)
F - Interim variable used to calculate soil temperature
FAC(L) - Conversion factor for PPM N to kg N/ha for Layer L
FACLN - Fraction of exported N taken from leaves.
FACSN - Fraction of exported N taken from the stem.
FACHN - Fraction of exported N taken from the head.
FACPOOL - Reduction factor for embryo and pericarp growth.
FACTOR - Relative weighting to distribute crop root residues at the beginning of a simulation
FACTOR - Factor to adjust N uptake to soil available N.
FILE0 - Character variable with file name for crop specific coefficients
FILE1 - Character variable with file name for daily weather data
FILE2 - Character variable with file name for soil profile properties
FILE3 - Character variable with file name for unused at present time
FILE4 - Character variable with file name for soil nitrogen dynamics properties
FILE5 - Character variable with file name for soil profile initial conditions
FILE6 - Character variable with file name for irrigation management data
FILE7 - Character variable with file name for nitrogen fertilizer management data
FILE8 - Character variable with file name for crop management data
FILE9 - Character variable with file name for genetic coefficients
FILEA - Character variable with file name for measured summary data
FILEB - Character variable with file name for measured seasonal data for graphics
FLOW(L) - Volume of water moving from Layer L due to unsaturated flow (cm) positive indicates upward movement and negative value indicates downward movement
FLUX(L) - Water moving downward from Layer L with drainage(cm)
FNH4 - Unitless soil ammonium supply index
FNO3 - Unitless soil nitrate supply index
FOM(L) - Fresh organic matter (residue) in Layer L (kg/ha)
FON(L) - N in fresh organic matter in Layer L (kg N/ha)
FPOOL(L,J) - Fresh organic matter in layer L kg/O.M./ha.J=1 indicates pool is assumed to be carbohydrates,if J=2 pool is assumed to be cellulose, and if J=3pool is assumed to be lignin
FPOOL1 - Fraction of CPOOL in the stem.
FPOOL2 - Fraction of CPOOL in the head.
FR - Unitless value used to distribute crop residue
FRCARB - Fraction of CARBO available for leaf growth.
FSINK1 - Fraction of N demand due to the embryo.
FSINK2 - Fraction of N demand due to the pericarp.
FT - Temperature factor affecting denitrification rate
FTYPE(M) - Fertilizer type code
FW - Unitless soil moisture factor affecting denitrification rate
G2. - Potential grain number (seeds/plant). Genetic coefficient.

G3 - Potential embryo growth rate (mg/day). Genetic coefficient.
GLFWT - Weight of green leaves (g/plant).
GN - Amount of N in the grains (g N/plant).
GNP - N concentration in daily increment of grain growth (g N/g dry matter)
GNUP - Grain nitrogen uptake (kg N/ha).
GPLA - Green plant leaf area (cm2/plant).
GPP - Number of filled grains per plant.
GPSM - Number of grains per square meter.
GRAINN - Grain N content (g N/plant)
GRAINN1 - Amount of nitrogen in filling grains (gN/plant).
GRAINNE - Amount of nitrogen in empty grains (gN/plant).
GRCOM - Gross release of carbon from organic matter decomposition (kg C/ha)
GRFACTOR - Factor affecting grain growth (a function of head weight).
GRNOM - Gross release of N from organic matter decomposition (kg N/ha/day)
GRNWT - Grain weight (g/plant).
GRNWTE - Grain weight of empty grains (g/plant).
GROEMB - Embryo growth rate (g/plant/day).
GROGRN - Daily growth of the grain - g
GROHEAD - Head growth rate (g/plant/day).
GROLF - Leaf growth rate (g/plant/day).
GROPER - Pericarp growth rate (g/plant/day).
GRORT - Root growth rate (g/plant/day).
GROSTM - Stem growth rate (g/plant/day).
GRPCTN - Observed grain N% at maturity
HDAY - Day of the year of the hottest day (200 <-northern hemisphere, 20 <- southern hemisphere)
HEADWT - Head weight (g/plant).
HOLD - Temporary variable in calculations for distribution of organic matter
HOLDW - The amount of water a soil layer will hold above its present level, used to calculate downward flow (cm)
HRLT - Photoperiod (hours).
HUM(L) - Stable humic fraction material in Layer L (kg/ha)
HWMAX - Maximum head weight (g/plant).
HWMIN - Minimum head weight (g/plant).
IANTJD - Observed Julian date of anthesis
ICOLD - Number of severe frost days.
ICSDUR - Accumulates days of each growth stage for calculating mean soil water deficit factor CSD1 and CSD2
IDIM(I) - Days in month I
IDRSW - An integer containing information about downward flowing soil water, = 0 no downward flow, = 1 downward flow
IDUMSL - Number of layers in soils file (used in DSSAT I/O but not model calculations)
IDURP - Duration (days) of the period when SUMP is computed.
IECHON - Logical variable to indicate whether inputs are to be echoed to the screen
IFLAG - Switch variable used to direct control to either the leaching component or the upward flux component of subroutine NFLUX
IFTYPE - Code number for fertilizer type
IHVON - Logical variable to indicate that post-harvest comparisons of predicted and observed data are to be displayed on the screen
IIRR - Switch variable to indicate type of irrigation (may be none)
INCPLA - Potential plant leaf area growth (cm2/plant/day).
INSTE - Institute ID code (DSSAT I/O)
IOFF - Switch variable to disable runoff during irrigation
IOUT - Switch variable used in the distribution of organic matter
IOUTGR - Number of days since growth conditions were last written

```
IOUTNU      - Number of days since N output was last written
IOUTWA      - Number of days since water conditions were last written
IRET        - Variable to specify an alternate return from subroutine PHENOL
when             growth stage 6 is reached
ISDATE      - Date of first-anthesis (DOY).
ISIM        - Day when the simulation starts (day of the year)
ISOW        - Julian date of sowing
IST         - Variable to determine number of layers considered in unsaturated
                 flow
ISTAGE      - Phenological stage
ISTAGE 1    - Emergence to end of the juvenile phase.
ISTAGE 2    - End of the juvenile phase to start of flower initiation.
ISTAGE 3    - Flower initiation to first anthesis.
ISTAGE 4    - First anthesis to beggining of embryo filling.
ISTAGE 5    - Beginning of embryo filling to physiological maturity.
ISTAGE 6    - Physiological maturity to harvest.
ISTAGE 7    - Start of the simulation (fallow) to sowing.
ISTAGE 8    - Sowing to germination.
ISTAGE 9    - Germination to emergence.
ISWNIT      - A switch parameter specified as input that determines whether
                 nitrogen calculators are performed (Not operative in
OILCROP-               SUN).
ISWSWB      - A switch parameter specified as input that determines whether
the              model calculates the soil water balance parts of the model
(Not             operative in OILCROP-SUN).
IVARTY      - Number assigned to a variety in the variety file
IYR         - Last two digits of year
JANTH       - Predicted Julian date of anthesis
JDATE       - Julian date
JDATEX      - A switch used for establishing days/month and printing the
starting               date
JDAY(I)     - Julian date of Ith irrigation
JFDAY(J)    - Julian date of fertilizer application J
JHEAD       - Used to write table heading for water use table
JPHMA       - Predicted Julian date of maturity
K           - Reverse loop variable for upflux calculations and day indicator
in               moving average soil surface temperature calculations
K1          - Radiation Use Efficiency (g biomass/MJ PAR).
K2          - Extinction Coefficient for PAR.
KHEAD       - Used to write table heading for growth table
KOUTGR      - Frequency in days for printing growth output
KOUTNU      - Frequency in days for printing nitrogen output
KOUTWA      - Frequency in days for printing water use output
KSOIL       - The number assigned to a soil in the soils file
KVARTY      - The number assigned to a crop variety in the variety file
L0          - Number of layer where sowing took place.
L1          - The number of soil layers to the bottom of the root zone
LAEQ        - Leaf area equivalent to N content of leaves.
LAI         - Leaf area index
LAT         - Latitude - degrees (use negative for southern hemisphere)
LER         - Leaf expansion rate for leaf position I (cm2/day).
LFWT        - Leaf weight (g/plant).
LL(L)       - Lower limit soil water content for soil Layer L (volume
fraction)
LN          - Number of leaves that have appeared.
MATJD       - Observed Julian date of maturity
MAXGROLF    - Maximum leaf growth rate (g/plant/day).
MAXGROSTM   - Maximum stem growth rate (g/plant/day).
MAXLA       - Maximum area for each leaf position.
MAXLAI      - Maximum LAI.
MF          - Zero to unity moisture factor for residue decomposition rate
MINGROLF    - Minimum leaf growth rate (g/plant/day).
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MO - Number of month of year
MU - Loop variable to indicate layer below the current layer
ND - Day of the month
NDAS - Number of days after sowing
NDEF1 - Zero to unity N deficiency factor for photosynthetic rate
NDEF2 - Zero to unity N deficiency factor for expansion growth
NDEF3 - Nitrogen stress factor affecting grain filling.
NDEM - Plant nitrogen demand (g/plant)
NFAC - Zero to unity factor based on actual and critical N concentrations
NFERT - Number of fertilizer applications made
NFEXP - Variable to indicate whether or not to open a new experiment file (DSSAT I/O)
NH4(L) - Soil ammonium (ppm-N) in Layer L
NHDUP - Used to write table headings for plant N output
NHUM(I) - N associated with the stable humic fraction in Layer I (kg N/ha)
NIND - Variable to indicate second from bottom layer
NIRR - Number of irrigations
NLAYR - Number of layers in soil
NNOM - Net N released from all organic sources in a layer(kg N/ha)
NO3(L) - Soil nitrate (ppm-N) in Layer L
NOUT(L) - Nitrate N leaching from layer (kg N/ha)
NOUT1 - Logical unit number for output to file OUT1
NOUT2 - Logical unit number for output to file OUT2
NOUT3 - Logical unit number for output to file OUT3
NOUT4 - Logical unit number for output to file OUT4
NOUTO - Logical unit number for output to file OUT0
NPL1L - Contribution of leaves to NPOOL1.
NPL1H - Contribution of the head to NPOOL1.
NPL1S - Contribution of the stem to NPOOL1.
NPL2L - Contribution of leaves to NPOOL2.
NPL2R - Contribution of roots to NPOOL2.
NPOOL - Total plant labile N available for translocation to grain (g/plant)
NPOOL1 - N pool available for translocation to grain (g/plant) that includes N in stem and head, and 50% of N in leaves.
NPOOL2 - N pool available for translocation to grain (g/plant) that includes N in the roots and 50% of N in leaves.
NSDR - Plant N supply/demand ratio used to modify grain N concentration
NSENS - Switch variable to indicate whether changes to management variables are to be interactively made or not (DSSAT I/O)
NSFILE - Variable to indicate whether or not to open a new soils file (DSSAT I/O)
NSINK - Demand for N associated with grain filling (g/plant/day)
NSINK1 - Demand for N associated with embryo growth.
NSINK2 - Demand for N associated with pericarp growth.
NSOIL - Number assigned to the soil to be used from the soils file, it should correspond to KSOIL in the soil file
NUF - Plant N supply/demand ratio used to modifyuptake
NUP(L) - Nitrate N moving from Layer L with unsaturated flow (kg N/ha)
NWFILE - Variable to indicate whether or not to open a new weather file (DSSAT I/O)
O1 - Maximum embryo oil concentration. Genetic coefficient.
OBSOL - Long-term annual average solar radiation (Langleys)
OBTMN - Long-term annual average minimum temperature -degrees C
OBTMX - Long-term annual average maximum temperature -degrees C
OC(L) - Organic carbon in Layer L (%)
OIL - Oil weight (g/plant)
OILFRAC - Fraction of oil in new grain growth.
OILINC - Rate of oil deposition (g/plant/day).
OILPERC - Oil percent in the grain (%).
OUT1 - Character variable with file name for output record of crop

model inputs: Simulated biomass and water balance components at selected phenological stages. Harvest summary (simulated and observed).

OUT2 - Character variable with file name for simulated crop variables vs time
OUT3 - Character variable with file name for weather variables and simulated soil water balance vs time
OUT4 - Character variable with file name for simulated soil nitrogen variables vs time
OUTN - Nitrate N leaching from a layer (kg N/ha)
P1 - Duration of the juvenile phase (C-day, base: 4 C). Genetic coefficient.
P2 - Photoperiod sensitivity coefficient.
P3P - Thermal time between flower initiation and anthesis (C-day, base: 4 C).
P5 - Thermal time from first anthesis to physiological maturity (C-day, base:4C).
P9 - Thermal time (C-day, base 4C) from germination to emergence.
PAR - Photosynthetic Active Radiation (MJ/m2/day).
PARFAC - Factor to convert solar radiation to PAR
PARDAT - Switch to indicate if PAR data are available.
PB - Intermediate quantity for calculating daily runoff (cm)
PBIOMS - Predicted crop biomass at maturity (kg/ha)
PCARB - Potential Carbon Assimilation rate (gbiomass/plant/day).
PDWI - Potential shoot growth rate (g/plant/day).
PDWIH - Potential head growth rate (g/plant/day).
PDWIL - Potential leaf growth rate (g/plant/day).
PDWIS - Potential stem growth rate (g/plant/day).
PEDON - Soil Pedon number (used in DSSAT I/O but not model calculations)
PEPE - Embryo growth rate (g/embryo/day).
PERN - Nitrogen amount in pericarps (g/plant).
PERWT - Pericarp weight (g/plant).
PERWTE - Pericarp weight of empty grains (g/plant).
PERWTMAX - Maximum pericarp weight (g/plant).
PESW - Potentially extractable soil water in the profile equal to total soil water in the profile equal to total soil water (TSW) minus total water at the lower limit (TLL) - cm
PGNP - Predicted grain N% at maturity
PGRNWT - Individual grain weight (mg/grain).
PGRORT - Potential root growth rate (g/plant/day).
PH(L) - Soil pH in layer L
PHN(L) - Zero to unity factor describing the effect of soil pH on nitrification rate in layer L
PHOTOP - Photoperiod (hours).
PHY - Phyllochron (C day per leaf).
PHY1 - Phyllochron for leaves 1-6.
PHY2 - Phyllochron for leaves 7-N.
PINF - The precipitation that infiltrates into the soil (cm/day)
PLA - Plant leaf area (cm2/plant).
PLAG - Plant leaf area expansion rate (cm2/plant/day).
PLAGMS - Plant leaf area growth rate on the main stem (sq.cm/day)
PLAMX - Maximum plant leaf area (cm2/plant).
PLANTS - Plant population (plants/m2).
PLAS - Leaf area senescence rate driven by cold temperature (cm2/plant/day).
PLAY - Intermediate variable to calculate N driven senescence.
PNUP - Plant N uptake from layer (kg N/ha)
POTGROPER - Potential pericarp growth rate (g/plant/day).
POTHEADWT - Potential head weight (g/plant).
PPP - Number of pericarps per plant.
PRECIP - Temporary variable used for rain
PRFT - Temperature reduction factor for Biomass Accumulation.

PSKER - Average rate of dry matter accumulation in the period previous to anthesis (g/plant/day).
PTF - Stover/(stover+root) dry weight ratio.
PTFL - Fraction of plant weight in leaves.
PTFH - Fraction of plant weight in the head.
PTFS - Fraction of plant weight in the stem.
QN - Fraction of PAR intercepted at noon.
QD - Daily fraction of PAR intercepted.
QHY - Variable used to calculate leaf number.
R2 - Intermediate quantity used to calculate daily runoff
RAIN - Precipitation (mm/day)
RANC - Root N concentration (g N/g).
RATEIN - Rate of development during stage 2.
RCN - C:N ratio of root residue of previous crop
RCNP - Root critical nitrogen concentration (g N/g root dry weight)
RDECR(J) - The maximum rate constant for decay of residue components (1/days)
RFAC - Interim variable describing the effects of root length density on potential N uptake from a layer
RGFILL - Temperature reduction factor for head and stem growth.
RGNFIL - Rate of daily grain N accumulation -(micrograms/grain/day)
RHMIN - N mineralized from humus in a layer (kg N/ha)
RLDF(L) - A root length density factor for soil layer L used to calculate new root growth distribution (unitless)
RLNEW - New root length to be added to the total root system length (cm root per sq. cm. ground)
RLV(L) - Root length per unit soil volume for soil Layer L (cm/cm3)
RLVF - Factor to constrain root growth at depth (unitless)
RMNC - Root minimum nitrogen concentration (g N/g root dry weight)
RNAC - Immobilization rate of N associated with the decay of residues (kg N/ha/day)
RNDEM - Plant root demand for nitrogen (g/plant)
RNFAC(L) - Zero to unity factor describing mineral N availability effect on root growth in Layer L
RNH4U(L) - Potential ammonium uptake from Layer L (kg N/ha)
RNKG - Amount of N added to soil profile as root residue kg N/ha
RNLF - Intermediate factor used to calculate distribution of new root growth in the soil - unitless value between 0 and 1
RNLOSS - Loss of N from the plant via root exudation in one layer (g N/plant)
RNO3U(L) - Potential nitrate uptake from Layer L (kg N/ha)
RNOUT - Nitrogen exported from the roots.
RNTRF - Amount of ammonium nitrified in a layer (kg N/ha/day)
RONL - Nitrogen exported from the leaves.
ROOT - Mass of root residue of previous crop (kg/ha)
ROOTGR - Root growth rate (g/plant/day).
ROOTN - Plant root N content (g N/plant)
ROOTN - Amount of N in roots (g N/plant).
RP2 - Temporary variable used in nitrification calculations
RTDEP - Rooting depth (cm).
RTWT - Root weight (g/plant).
RUNOFF - Daily runoff(cm)
RWU(L) - Root water uptake from soil Layer L (cm)
RWUMX - Maximum daily root water uptake per unit root length (cm3/cm root)
S1 - Sine of latitude
SALB - Bare soil albedo - unitless
SANC - Supply of ammonium effect on nitrification capacity
SARNC - Supply of ammonium effect on the reduction of nitrification capacity (zero to unity, unitless)
SAT(L) - Field saturated soil water content in Layer L -volume fraction(cm water/cm3 soil)

SCN - C:N ratio of surface residue of previous crop
SDEP - Depth of incorporation of residue (CM)
SDEPTH - Sowing depth (cm).
SDN - Incremental loss of nitrogen by leaves that senesce (gN/plant/day).
SEEDRV - Reserve carbohydrates in seed for use by plant in seedling stage(g)
SENLA - Cumulative senesced leaf area (cm2/plant).
SENRATE - Rate of shade driven leaf senescence (m2/m2/day).
SENTIME - Time (days) to start leaf senescence driven by shading.
SGRO(I) - Variable used to calculate shade driven senescence.
SI1(I) - Accumulates SWDF1 for growth stage I
SI2(I) - Accumulates SWDF2 for growth stage I
SI3(I) - Accumulates NFAC for growth stage I
SI4(I) - Accumulates NDEF2 for growth stage I
SIND - Cumulative development during stage 2.
SITEE - Codes for site ID (used in DSSAT I/O but not model calculations)
SITES - Codes for site ID (used in DSSAT I/O but not model calculations)
SITEW - Codes for site ID (used in DSSAT I/O but not model calculations)
SKERWT - Individual grain weight (g/grain).
SLAI - LAI of senesced leaves.
SLAMAX - Maximum Specific Leaf Area (cm2 leaf/g leaf).
SLAMIN - Minimum Specific Leaf Area (cm2 leaf/g leaf).
SLAN - Total senesced leaf area (cm2/plant).
SLAN1 - Cumulative senesced leaf area caused by shade and/or water stress (cm2/plant).
SLAN2 - Senesced plant leaf area (cm2/plant).
SLAX - Variable used to calculate Specific Leaf Area.
SLAY - Specific leaf area of green leaves (cm2/g).
SLFT - Cold temperature senescence factor.
SLFWT - Weight of senesced leaves (g/plant).
SLOPEPE - Ratio plant leaf area/available N in leaves.
SMDFR - Soil moisture deficit factor affecting N uptake
SMIN - Interim variable to prevent soil N pools from becoming less than 1 ppm
SMLT - Amount of snow melt (mm)
SMX - Intermediate quantity used to calculate daily runoff
SNH4(L) - Soil ammonium in Layer L (kg N/ha)
SNKG - Amount of N added to soil profile as fresh residue kg N/ha
SNO3(L) - Soil nitrate in Layer L (kg N/ha)
SNOW - Precipitation in the form of snow - mm
SNOWMLT - Daily rate of snow melting (mm)
SOILC - Soil carbon concentration (kg C/ha)
SOILN - Variable used to modify initial soil water status
SOLRAD - Solar radiation - (MJ/m2/day)
SPLA - Senesced plant leaf area (cm2/plant).
ST(L) - Soil temperature in Layer L (degrees C)
STMWT - Stem weight (g/plant).
STOVER - Stover weight (kg/ha).
STOVN - Amount of N in the stover (g N/plant).
STOVWT - Stover dry weight (g/plant).
STRAW - Mass of surface residue of previous crop (kg/ha)
SUM - Intermediate quantity used to calculate runoff
SUMDTT - Cumulative thermal time from the beginning of the stage (C-day).
SUMES1 - Accumulative soil evaporation in stage 1 (mm)
SUMES2 - Accumulative soil evaporation in stage 2 (mm)
SUMP - Cumulative biomass for period of seed number determination.
SW(L) - Actual soil water content in Layer L - volume fraction
SWCON - Constant for calculating drainage rate
SWDEF - Soil water deficit for irrigation scheduling.
SWDF - Soil water deficit factor for Layer L used to calculate root growth and water uptake - unitless value between 0 and 1

SWDF1 - Soil water deficit factor affecting photosynthesis and transpiration.
SWDF2 - Soil water deficit factor affecting extension growth.
SWDF3 - Available water in the layers colonized by roots.
SWDFR - Soil water deficit factor for root growth on distribution
SWEF - Soil water evaporation fraction.The fraction of the lower limit water content that determines the lowest possible value the top soil layer can reach through soil evaporation. The value depends on the depth of the first layer.
SWINIT(L) - Default initial water content for each soil layer (cm/cm)
SWMAX - Maximum stem weight (g/plant).
SWMIN - Minimum stem weight (g/plant).
SWR - Unitless value used to calculate initial value of soil evaporation.
SUMES2 - Cumulative soil evaporation during the soil-limited stage (mm).
SWSD - An approximation of the soil water content above the lower limit at the seeding depth used to determine whether the seed can germinate
SWX(L) - Temporary array for soil water in layers (volume fraction)
SY - Interim variable used in soil temperature calculation
T - Time after 2nd stage soil evaporation is reached-days
TANC - Tops nitrogen concentration (g N/g).
TAV - Annual average ambient temperature (degrees C)
TAXON - Soil classification name (used in DSSAT I/O but not in model calculations)
TBASE - Base temperature (C).
TBD - Accumulator used to calculate average bulk density
TCNP - Tops critical N concentration (g N/g dry weight)
TD - Weighted temperature used to calculate potential evaporation (degrees C)
TDUL - Total soil water held in the soil at the drained upper limit (cm)
TEMPM - Average temperature (C).
TEMPMN - Minimum temperature - degrees C
TEMPMX - Maximum temperature - degrees C
TF - Temperature factor used to adjust nitrification effect on mineralization
TFAC - Temperature factor for leaf growth.
TFY(L) - Factor to account for the effect of the temperature previous day on nitrification in Layer L
THET1 - The soil water content above the lower limit (LL) for the upper layer of soil for water flow from a lower layer-volume fraction
THET2 - The soil water content above the lower, limit (LL) for the lower layer of soil for water flow into an upper layer-volume fraction
TIFOM - Total initial fresh organic matter (kg/ha)
TIFON - Total initial fresh organic matter (kg N/ha)
TITLEE - Experiment title (DSSAT I/O)
TITLER - Experiment title (DSSAT I/O)
TITLES - Experiment title (DSSAT I/O)
TITLET - Treatment title (DSSAT I/O)
TITLEW - Weather station title (DSSAT I/O)
TLL - Total soil water in the soil profile at the lower limit (cm)
TLNO - Total leaf number (leaves/plant).
TLNOI - Leaf position where maximum leaf area occurs.
TMA(K) - 5 Day moving average soil surface temperature for day K
TMFAC(I) - Factor to calculate the evolution of temperature through the day (I=1 to 8)
TMINH - Total N released by mineralization of stable humic fraction in the profile on 1 day (kg N/ha)
TMN - Mean temperature (degrees C)

TMNC - Plant tops minimum nitrogen concentration (g N/g dry weight)
TNDEM - Plant tops demand for nitrogen (g N/plant)
TNH4 - Total NH4 in the soil profile (kg N/ha).
TNO3 - Total NO3 in the soil profile (kg N/ha).
TNUP - Total N uptake from the profile on 1 day (kg N/ha)
TNUP - Total plant N uptake from the profile (kg N/ha)
TOPSN - N contained in plant tops excluding grain (gN/plant)
TOPWT - Weight of plant tops excluding grain (g)
TOTN - Total mineral N in a layer (kg N/ha)
TOTNUP - Predicted total shoot N uptake at maturity (kg N/ha)
TOTNUP - Total nitrogen uptake(kg N/ha):
TPESW - Total potential extractable soil water in the soil profile (cm)
TPRECP - Total precipitation (mm)
TRLDF - An intermediate calculation used to calculate distribution of new root growth in soil
TRLV - Total root length density variable
TRNLOS - Total plant N lost by root exudation (g N/plant)
TRNU - Total potential root nitrogen uptake from the soil (kg N/ha)
TRWU - Total potential daily root water uptake from the soil-plant system (cm)
TSAT - Total soil water in profile at field saturation(cm)
TST(L) - Soil temperature accumulator for calculation of period mean soil temperature
TSW - Total soil water in the profile (cm)
TTE - Thermal Time to complete leaf expansion of each individual leaf (C-day).
TTMP(I) - Temperature at eight three-hour periods.
U - Upper limit of stage 1 soil evaporation (mm)
UNH4 - Plant uptake of ammonium from a layer (kg N/ha)
UNO3 - Plant uptake of nitrate from a layer (kg N/ha)
UP1 - Interim variable used to prevent soil N pools from being reduced below 1 ppm
V1 - Maximum plant leaf area (cm2). Genetic coefficient.Not used by the present version.
VANC - Plant vegetative actual N content (g N/plant)
VARTY - Variety name
VMNC - Plant vegetative minimum N concentration (g N/g dry weight)
WAT1 - Temporary variable used in upward flow calculations
WC - Moisture content effect on soil temperature
WF(L) - Weighting factor for soil depth L to determining runoff.
WFD - Today's water factor for nitrification
WFY(L) - Yesterday's water factor for nitrification in layer L
WINF - Amount of water infiltrating into the soil as used in the soil evaporation routine (mm)
WLAN2 - Leaf senescence rate (weight equivalent).
WR(L) - Weighting factor for soil depth L to determine new root growth distribution (unitless)
WRN(L) - Temporary variable used to calculate distribution of residues in the soil
WSUM - Variable used to calculate distribution of organic residues
WUF - An intermediate factor used to calculate root water uptake (unitless)
WW - Soil porosity
WX - Intermediate value used to calculate runoff
XANC - Tops actual N concentration (%)
XAPTNP - Observed total straw N uptake at maturity (kg N/ha)
XBIOM - Observed biomass at maturity (kg/ha)
XENDEM - Total N demand for embryos.
XGNP - Grain nitrogen concentration (%).
XGNUP - Observed grain N uptake (kg grain N/ha)
XGPSM - Observed number of grain per square metre
XGRNWT - Observed weight of individual grains (mg)

XHANC - Head nitrogen concentration (g N/g)
XHCNP - Head critical N concentration (g N/g)
XHEADN - Amount of N in the head (g N/g).
XHMNC - Minimum head N concentration (g N/g).
XHNDEM - Total N demand for the head.
XI - Non-integer Julian date
XL - Temporary variables used to determine N transformations in the soil.
XL2 - Moisture effect on mineralization rate
XLAI - Observed maximum leaf area index
XLANC - Leaf nitrogen concentration (g N/g).
XLCNP - Critical leaf N concentration (g N/g).
XLEAFN - Amount of N in leaves (g N/plant).
XLEAFNMIN - Minimum N amount in leaves (1.4% of the N amount at first anthesis).
XLMNC - Minimum leaf N concentration (g N/g).
XLNDEM - Total N demand for leaves.
XLONG - Longitude of the experimental site (degrees)
XMIN - Minimum N concentration in the layer.
XNGLF - Amount of nitrogen in green leaves (g N/plant).
XNSLF - Amount of nitrogen in senesced leaves (g N/plant).
XPEPE - Amount of N in leaves that can be rapidly exported (50% of labile N).
XPLANT - Temporary variable to transfer the value of the numbers of plants/sq.metre
XPNDEM - Total N demand for pericarps.
XPTN - Grain protein concentration (%).
XRAT - Nitrogen concentration of green leaves (g N/g).
XSANC - Stem nitrogen concentration (g N/g).
XSCNP - Stem critical N concentration (g N/g).
XSMNC - Minimum stem N concentration (g N/g).
XSNDEM - Total N demand for the stem.
XSTAGE - Non-integer growth stage indicator ranging from zero to ten.
XSTAGE - Real variable to quantify development.
XSTEMN - Amount of N in the stem (g N/plant).
XSTRAW - Observed straw biomass at harvest (kg/ha)
XT - Temperature effect on nitrification capacity
XTOTNP - Observed total shoot N uptake at maturity (kg N/ha)
XW - Moisture effect on nitrification capacity
XX - Intermediate value used to calculate runoff
XXX - Maximum amount of nitrogen in green leaves (gN/plant).
XYIELD - Observed grain yield (kg/ha)
YEAR - Year number (last two digits)
YIELD - Grain yield (kg/ha with 9% moisture).
YIELDB - Yield (bushels/acre)
YLNOI - Maximum area of an individual leaf.
YRAT - Residual leaf nitrogen concentration (g N/g).
YYY - Intermediate variable in the plant N balance.
Z(L) - Depth to midpoint of soil layer L (mm)
ZD - Variable used in the calculation of soil temperature
ZZZ - Variable used to calculate senescence.