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1973/74 PROGRESS REPORT

# A SIMPLIFIED VERSION OF THE DESERT BIOME GENERAL-PURPOSE MODEL TO SIMULATE THE PRODUCTION OF DRY MATTER IN PLANTS

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# INTRODUCTION

The model explained here is in a preliminary stage and is subject to improvement. Ameliorations will surely result from dialogue with the field scientists for whom the model was built (scientists of the FAO/CNRS project "Parcours Sud de la Tunisie" in Gabès). Because of the distance between Gabès and Logan, good communication between personnel was difficult during the author's stay in Logan.

Because of close association with the Desert Biome modelling team and the availability of data, this first version model based on dry matter (and not on the chemical constituents of dry matter) was able to be built in a relatively short time (Fig. 1).

We hope that this attempt at a simplified model will be useful to others working with simple data (dry matter) from the field.

# OBJECTIVES

The most important objective of this model was the prediction of primary production for one or two years in one given type of production.

It was proposed at first to use the general existing model used in the Desert Biome. Two reasons militated against this proposal: (1) the lack of detailed Tunisian data for the chemical composition of plants; and (2) the goal of having an easily modified simple program which could be used with the available data.

In fact, the first attempt at simplification of the existing model, in order to simulate primary production for total dry matter only, was abandoned because of the inability to adopt several features of the model (e.g., ratio of protein carbon to total carbon, etc.). It was necessary to add "parallel" subroutines to the existing model. Once accomplished, it was easier to build a new model which fits more closely to the objectives and data.

# GENERAL CHARACTERISTICS

This model was patterned after the "Multi-purpose Desert Biome Model" and shares its principal characteristics, the three most notable being: (1) modular structure; (2) submodels differing in degree of sophistication; and (3) ability to specify state variables at execution time, etc.

Whenever possible the general structural design and processes used in the Desert Biome models were preserved, and for this reason detailed descriptions of items explained in the 1973 modelling report (Goodall, 1973) and other Desert Biome reports are limited. In fact, processes come from the different existing version levels, including Version IV of the plant submodel (Valentine, 1974).

Submodels related to the plants and soil are given here as examples. Due to the lack of time and the lack of data for animals and other processes, we prefer to add this at a later time.

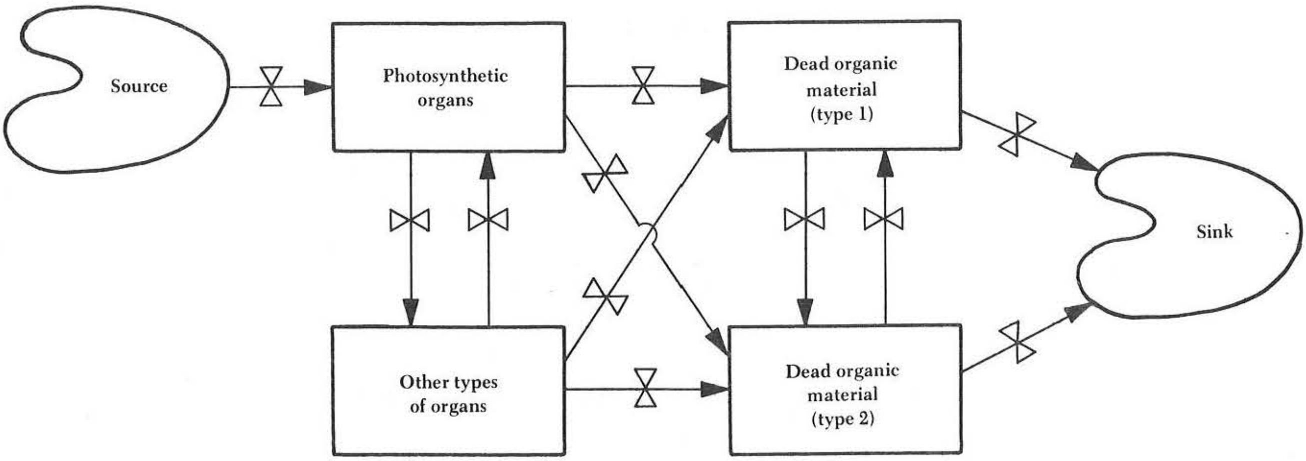

**Figure 1.** Simplified diagram for the dry matter model. Each valve is controlled by one or more parameters, including exogenous data, soil conditions, etc.

# SHORT DESCRIPTION OF THE PROGRAM

## MAIN PROGRAM

At this stage of development, the state variables are the dry weight of each organ of each plant species and of each type of dead organic material.

The time step is one day, although the subroutine SOWAT and one part of the main program can run for lesser time increments.

The most important role of the main program is the calling of the subroutines, which can be modified if necessary (Fig. 2).

### STEPS IN THE OPERATION OF THE PROGRAM

1. Read parameters and initial data with the help of the subroutines.
2. The subroutines will determine the conditions for vegetation in the current day (date, season, rain, soil condition, etc.)
3. For each species, the subroutines will determine the phenological stage, the net daily increment of dry matter, allocation of this increment among the photosynthetic organs, transfers between organs, and the death of each organ.
4. Subroutines will be called to determine the transfer of dead organic material. A sink can simulate the loss to the ecosystem or the decomposition which is not included in this version.
5. Increments (whether negative or positive) are "tested to ensure that none of them would cause state variables to become negative where this constraint is appropriate (which is true of most state variables in ecological systems). If some of the negative increments are 'too large' in this sense, all increments are scaled down in such proportion as the most limiting constraint requires, the increments are applied to all state variables, and the subroutines are called again for recalculation of increments. These increments are then multiplied by the complement of the proportion already applied to the state variables, and the test of their magnitude is repeated. The process continues until a set of increments can be applied *in toto*. Briefly, this is equivalent to dividing the time unit over which the difference equations approximate the underlying differentials into arbitrary portions such that the constraints can be met." (Goodall, 1973, pp. 2.1.3.1.-17 and 18.)
6. The main program fills a storage array with all state variables.
7. Subroutines are called to plot specified variables and the program terminates. A listing of the program appears in Appendix 1.

## SUBROUTINES
(in alphabetical order)

**DATE** -- Computes the date (day, month, year) from the date of the initial day, and the number of days after the initial day.

**DEGREE** -- Deals with the soil temperatures. The processes proposed by Griffin et al. (1974) are used in this model. The differential equation describes soil temperature, T, as a function of depth, z, and time t:

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}[\sigma \frac{\partial T}{\partial z}]$$

where T is the thermal diffusivity (generally a function of time and depth), which is equal to thermal conductivity at the specific heat.

**DLIGHT** -- Computes the number of daylight hours in the current day and the fraction of the total number of daylight hours in one year in the current day. This fraction is used in subroutine EVAPO.

If

$$A = 730 + 274 \cdot 10^{-3} \cdot RLAT + 793 \cdot 10^{-5} (RLAT)^2$$
$$B = 342 \cdot 10^{-1} + 78 \cdot 10^{-2} \cdot RLAT + 10^{-1} \cdot (RLAT)^2$$

$$Z = 2 \cdot \pi \cdot (\frac{I + 285}{365})$$

DAPHOT = Number of daylight hours the first day of the calendar year (January 1, I = 1; December 31, I = 365 or 366).

$$= \frac{A + B + \sin(Z)}{60}$$

where

RLAT is latitude in degrees.
DALITE is for the first day of the calendar year the portion of illumination relative to the illumination occurring in an entire year.

**DMDM (provisional version)** -- Computes, with given rates, the translocations between the different types of dead organic material. To simulate the losses, it is possible to create an "artificial" compartment of dead material which is a "sink." For each season (IS) a rate of daily transfer, RTLI (IS, LD, LR), is given between the different compartments of dead material. The amount transferred to the receptor compartment (LR) is proportional to the amount of dry matter in the donor compartment (LD).

Under these conditions the daily variation (DCLIT) in dry matter for compartment p is equal to

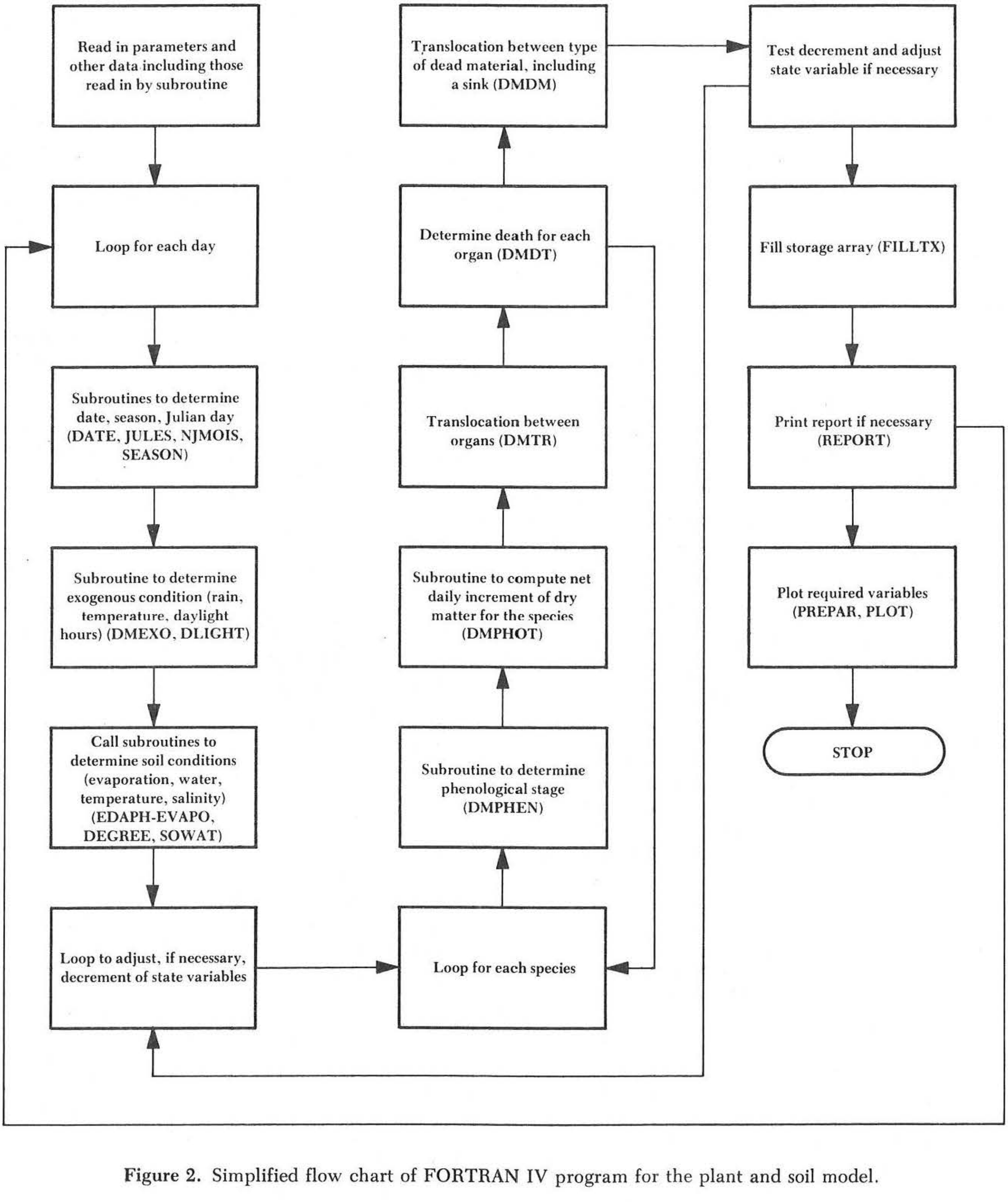

**Figure 2.** Simplified flow chart of FORTRAN IV program for the plant and soil model.

DCLIT (p) =

$$\underbrace{\sum_{\substack{i=1\\ i\neq p}}^{NLIT} CLIT(i)\cdot RTLI(IS,i,p)}_{\text{received}} \qquad \underbrace{\sum_{\substack{i=1\\ i\neq p}}^{NLIT} CLIT(P)-RTLI(IS,p,i)}_{\text{lost}}$$

by compartment p

where

CLIT (p) = quantity of organic matter in compartment p at the beginning of the daily time step.

NLIT = total number of compartments containing dead organic matter.

**DMDT** -- Deals with the death of the living material and lists the class of dead organic material to which the new dead organic material will be transferred. For each organ (J) of each species (I) a mortality rate (DRATE) is calculated depending on phenological status. The subroutine contains two parts:

1. Dormancy stage: where the rate of death is an exponential function of the time since the beginning of the dormancy (cf. provisional version IV of the Desert Biome model). It is possible to give different parameters for each organ of each species.

$$DRATE = a + b\cdot e^{ct}$$

where

a, b, c = parameters provided for each organ of each species.

t = time in days since the onset of dormancy.

The amount of material passing into a dead status for organ J of species I, for one day, is now equal to

$$DDMSP\,(I,J) = DMSP\,(I,J)\cdot DRATE$$

where

DMSP (I, J) = the quantity of dry matter in organ I of species J at the beginning of the daily time step.

This function has been made exponential in form in order to eventually cause a total disappearance of biomass of the organ concerned.

2. Phenological states other than dormancy: the rates of death are read in, for each organ of each species in each phenological stage.

**DMEXO** -- Reads in the exogenous data (rain, temperature and total daily irradiation) and provides this data each day. For the rain, the dates (and the amount of water in millimeters) are used, for the days where rain occurs. For the temperature, the dates of change of temperature are read in, and the temperature is assumed to be the same between successive changes.

**DMPHEN** -- Determines the phenological stage for each species. This version is based on the provisional Version IV of the Desert Biome model. The possibilities are:

1. A jump from germination (or leafing-out) to vegetative stage is possible if X is greater than a coefficient which is an exponential function of the moisture in the soil. For the annual species, X is the ratio of the total dry matter in this species to the dry matter in seeds of this species; for other species, X is the ratio of the dry matter in new shoots of this species to the total dry matter in this species. The duration of germination is not allowed to exceed a specified value.

   A threshold value (CRATLO) is calculated in the following manner:

$$CRATLO = a + b\cdot e^{cw}$$

where

w is the water potential (WATER [LSOIL]) of a given horizon LSOIL with

$$LSOIL = LCOUCH\,(ISP)$$

a, b, c are parameters provided for each species (respectively, PARPH1 [ISP], PARPH2 [ISP], PARPH3 [ISP]).

The species will change its phenological state if

$$X > CRATLO$$

$$X = \frac{\text{total dry matter contained in a species}}{\text{dry matter in grains of same species}} \text{ for annuals}$$

$$X = \frac{\text{dry matter contained in the shoots}}{\text{total dry matter for the species}} \text{ for perennials}$$

Moreover, the germination period cannot be more than a given time (NDGERM).

2. A jump from vegetative to fruiting stage occurs if the soil moisture and temperature are above the given thresholds, and if the value of daylight hours is between two thresholds; i.e.,

Soil temperature by horizon (LCOUCH [ISP]) above a threshold (THTPVG [ISP]),

Water potential of a given horizon (LCOUCH [ISP]) above a threshold (THWTVG [ISP]),

Daily illumination between two values (PHOVMN [ISP] and PHOVMX[ISP]).

3. A jump from vegetative to dormant stage occurs when either the soil moisture or soil temperature falls below a specified threshold.

Water potential of a given horizon (LCOUCH [ISP]) below a threshold (THTPVD [ISP]).

Temperature of a given horizon (LCOUCH [ISP]) below a threshold (THTPVD[ISP]).

4. Test for return from fruiting stage to vegetative stage: the fruiting stage is finished if X is greater than a one-parameter function of the soil moisture, where X is the ratio of the dry matter accumulated in fruits to the total dry matter in the species. The duration of the fruiting stage is not allowed to exceed a specified value.

A threshold value CRATFT (ISP) is calculated for each species in the following manner:

$$\text{CRATFT (ISP)} = a + b \cdot e^{cw}$$

where

w is the water potential (WATER[LSOIL]) of a given horizon LSOIL with:

$$\text{LSOIL} = \text{LCOUCH (ISP)}$$

a, b, c are parameters provided for each species (respectively, PARPH4 [ISP], PARPH5 [ISP], PARPH6 [ISP]).

There will be transfer from fruiting to a vegetative stage if a quantity X is above CRATFT (ISP).

where

$$X = \frac{\text{DMNEW (ISP)}}{\text{DMT (ISP)}} = \frac{\text{year's addition to dry matter; organs}}{\text{total dry matter of the species}}$$

The fruiting period (IPFRUT [ISP]) cannot be above a given threshold (NDFRUT [ISP]).

5. Jump from dormant to germination (or leafing-out) stage begins if temperature and soil moisture are above given thresholds and if the number of daylight hours is between two given thresholds; i.e.,

Temperature (SOILTE [LSOIL]) in a given horizon of LSOIL (with LSOIL = LCOUCH) above a threshold (THTPLO [ISP]),

Water potential (WATER [LSOIL]) in a given horizon (LSOIL), above a threshold (THWTLO [ISP]),

Daily illumination between two values (PHOTMN[ISP]) and (PHOTMX [ISP]).

**DMPHOT** -- This subroutine computes for each species (each day) a total daily increment for the dry matter. This increment is proportional to the biomass of photosynthetic organs. The rate is determined from a maximum rate which is depressed when air temperature, the soil moisture, or the radiation is not optimum.

The actual rate, LIGHTF, of radiation is given thus:

$$\text{LIGHTF} = \frac{\text{DAYRAD}}{\text{KMLITE (ISP)} + \text{DAYARAD}}$$

where

DAYRAD is total daily radiation in $\text{cal/m}^2$ of leaf area.

The actual rate, TEMPF of the temperature (here is equal to ambient), is calculated in two different ways depending on whether the temperature is above or below a given threshold TEMPUM (ISP).

If the temperature (TLEAF) > TEMPUM (ISP), the function is linear:

$$\text{TEMPF} = \frac{\text{TEMPUT (ISP)} - \text{TLEAF}}{\text{TEMPUT (ISP)} - \text{TEMPUM (ISP)}}$$

where

TEMPUT and TEMPUM are parameters.

If TLEAF $\leqslant$ TEMPUM (ISP) one has a sigmoid function.

$$\text{TEMPF} = \frac{1}{1 + \text{CCPS (ISP)} \cdot e^{(-\text{RRPS x TLEAF})}}$$

where

CCPS and RRPS are the parameters.

The actual rate, PMSF, of soil moisture is obtained as follows:

If soil moisture in a given layer for each species LAYCH (ISP) is above a given threshold WMAC (ISP) PMSF = 1.

If this soil moisture is below a given threshold WMIN (ISP), PMSF = 0.

If the soil moisture, WBID, is between these two thresholds, PMSF is a linear function of soil moisture.

$$\mathrm{PMSF} = \frac{\mathrm{WBID} - \mathrm{WMIN\,(ISP)}}{\mathrm{WMAX\,(ISP)} - \mathrm{W\,(ISP)}}$$

The daily increment of dry matter per g of dry photosynthetic material is then given by:

$$\mathrm{PSRATE} = \mathrm{DDMMAX\,(ISP).\ LIGHTF.\ TEMPF.\ PMSF}$$

where

DDMMAX (ISP) is the maximum possible (ideal conditions) daily increment per g of photosynthetic dry matter.

**DMTR** -- There are two parts in this subroutine:

1. One to allocate the total net daily increment of dry matter to the photosynthetic organs.
2. One to simulate the translocation of dry matter between organs. This translocation is assumed to be proportional to the amount of dry material present in the donor compartment at the beginning of the day. This subroutine provides also the amount of new dry matter accumulated during the germination, leafing-out, or fruiting stage.

**EDAPH** -- In this version only those subroutines dealing with soil processes are called:

DEGREE for the soil temperature
EVAPO for the evapotranspiration and evaporation
SOWAT for the water movements in the soil

**EVAPO** -- To compute evaporation and evapotranspiration with the model proposed by Griffin et al. (1974).

**FILLTX** -- This subroutine deals with the storage of the state variables for the plotting of results at the need of the simulation.

**INVDAT** -- Computes the number of days (+ 1) after the initial day from the current date (day, month, year).

**JULES** -- Computes the number of days after the first of January of the current year (in Julian days) from the current date (day, month, year).

**NJMOIS** -- For a given year computes the number of days in one month.

**PLOT** -- Plots the results at the end of the simulation.

**PREPAR** -- Prepares the data for the subroutine PLOT from the storage array which is in the subroutine FILLTX.

**REPORT** -- To write a report of the principal variables, if this report is required.

**SEASON** -- To determine the season on the basis of the Julian day.

**SOWAT** -- This subroutine predicts soil water content and potential as a function of time and depth, and also the salt content (Griffin et al., 1974; Hanks et al., 1969; Jurinak and Griffin, 1972; Nimah and Hanks, 1973). The differences between this model and the model proposed by Griffin et al. (1974) involve only the input/output statements.

The theoretical aspects of the model can be described by the following relations.

The model performs the solution of the general equation in one-dimensional flows with an extraction term for roots, A (z):

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial Z}\left[K(\theta)\,\frac{\partial H}{\partial z}\right] + A(z)$$

with

$$A(z) = \frac{[\mathrm{Hroot} + (\mathrm{PRES} \times z) - h(z)s(z)] \times \mathrm{RDF}(z) \times K(\theta)}{\Delta z}$$

where

$\theta$ = water content by volume
t = time
z = depth
K = hydraulic conductivity
H = hydraulic head at the surface (z = o)
PRES = $R_c + 1$
$R_c$ = flow coefficient
$h_{(z)}$ = pressure at depth z
$S_{(z)}$ = osmotic pressure at depth z
$\mathrm{RDF}_{(z)}$ = fraction of roots active in the layer of soil $\partial$ z.

This subroutine permits equally the description of a process for salt:

$$\frac{\partial}{\partial t}[Q + Oc] = \frac{\partial}{\partial z}\left[D(V,O)\frac{\partial c}{\partial z}\right] - \frac{\partial (qc)}{\partial z} + S$$

where

Q = local concentration (positive or negative) of solute in the absorbent phase (meq/cm$^3$).

C = concentration in the solution phase (meq/cm$^3$ of soil solution).

S = a "well" or a "source" for the efflux or influx of salt in the soil.

z = depth (positive down below).

D = coefficient (cm$^2$ sec$^{-1}$ combining diffusion and dispersion.

q = flux in volume of solution ($cm^3\ cm^{-2}\ sec^{-1}$) and V is the average speed of capillary flow.

We note, however, that the use of this model poses some problems since it presumes the soil has certain characteristics identical throughout the profile.

# INPUT ORGANIZATION

Remark: Columns 61 to 80 are for explanations and are not read, except in some specified cases. An example of input/output is given in Appendix 2.

## CARDS READ BY MAIN PROGRAM

### Comments and Table Headings

Any comments which are to be associated with the output may be printed out before the rest of the output by inserting cards bearing the comment information at the beginning of the input deck. These cards should finish with a blank card, or be replaced by a blank card if no comments are needed. The blank ending the comments is followed by a single card providing a heading (STATE(20)) for tabular output. (The 80 columns are read in for this card.)

### Instruction Cards

*One card* with the starting date (IND, INM, INY) of the run and the date of the last day of the run (ILD, ILM, ILY) are read in (6I5) format. The components of the dates are given in the following order: day, month, year.

*One card* with the number of species (NSP), the number of types of dead organic material (NLIT), the number of horizons (NHOR) in (12I5) format.

*One card* (*or two*) with the number of organs (NORG(I)) for each species in (1215) format.

*One card* (*or two*) for each species, containing the function (IFUN(I,J)) of each organ J of species I, in (12I5) format. Provisional classification: 1=seed, 2=fruit, 3=photosynthetic organs, 4=root, 5=stem.

*One card* (*or two*) with the life forms (LIF(I)) of each species I, in (12I5) format. Provisional classification: 1=annual, 2=shrub, 3=perennial herbaceous.

*One card* (*or two*) with the name (NAMSP(I)) of each species, in (10A8) format. (Explanations in columns 61 to 80 are not possible.)

*One card* (*or more*) for each species, containing the name (NAMORG(I,J)) of each organ J of species I, in (10A8) format. (Explanations in columns 61 to 80 are not possible.)

*One card* with the name (NAMLIT(I)) of each type of dead material in (10A8) format. (Explanations in columns 61 to 80 are not possible.)

*One card* (*or more*) for each species, containing the dry weight (DMSP(I,J)) in g/ha of each organ J of species I, in (6F10.0) format.

*One card* (*or two*) with the dry weight (CLIT(I)) of each type of dead organic material, in (6F10.0) format.

## CARDS READ IN THE SUBROUTINES

### Subroutine REPORT (ENTRY INDMRP)

*One card*, serving as a check on the proper order of the cards, which reads in a character string, in (20A4) format. Hereafter this will be called a read-check card.

*One card* with the number (NREP) of tabulated reports required, including the report for the initial day in (12I5) format.

*One card* for each report, containing the date (ID=(day), IM=(month), IY=(year)) of the required report, in (3I5) format.

### Subroutine DMEXO (ENTRY INDMEX)

*One read-check card.*

*One card* with the number of days (NDR) with rain, and the number of days (NDT) where the temperature changes (including the initial day) in (12I5) format.

*One card* for each day of rain containing the date (day, month, year) when the rain occurs and the amount of rain (in mm), in (3I5, F10.0) format.

*One card* for each day of temperature change, containing the date of the change and the new temperature (in degrees centigrade), in (3I5, F10.0) format.

### Subroutine DMPHEN (ENTRY INDMPN)

*One read-check card.*

*One card* (*or two*) with the phenological stage (IPHENO(I)) of each species, in (12I5) format. 1=germination, 2=leafing-out, 3=vegetative stage, 4=fruiting stage, 5=dormancy.

*One card* for each species, in (12I5) format, containing the following:

The maximum number of days (NDGERM(I)) for the germination.
The maximum number of days (NDFRUT(I)) for the fruiting stage.
If the species is in germination, the number of days (IPGERM(I)) since the beginning of this stage (0 if not).
If the species is in the fruiting stage the number of days (IPFRUT(I)) since the beginning of this stage (0 if not).

*One card (or two)* for each species specifying the horizon (LCOUCH(I)) whose water content and temperature are used as an environmental trigger, in (12I5) format.

*A group of three cards* for each species containing parameters used in this subroutine, in (6F10.0) format:

*First card:* PARPH1(I), PARPH2(I), PARPH3(I). PARPH4(I), PARPH5(I), PARPH6(I).

*Second card:* THTPVG(I), THWTVG(I), PHOVMX(I), PHOVMN(I), THRTVG(I), THTPVD(I).

*Third card:* THWTVD(I), THRTVD(I), THTPLO(I), THWTLO(I), PHOTMN(I), PHOTMX(I).

The meaning of these parameters is given in the comments of the program.

### SUBROUTINE DMPHOT (ENTRY INDMFO)

*One read-check card.*

*Two cards* for each species containing parameters used in this subroutine, in (6F10.0) format:

*First card:* KMLITE(I), CCPS(I), RRPS(I), TEMPUT(I), TEMPUM(I), DDMMAX(I).

*Second card:* WMIN(I), WMAX(I).

The meaning of these parameters is given in the comments of the program.

*One card (or two)* for each species, specifying the horizon whose water content (LAYCH(I)) is used as an environmental trigger, in (12I5) format.

### SUBROUTINE DMTR (ENTRY INDMTR)

*One read-check card.*

*One card ( or two)* for each species I, containing the rate of transfer of the daily increment of dry matter for each organ J, (RTPH(I,J)), in (6F10.0) format.

*One card (or two)* for each species I, and each donor organ JD, specifying the rate of transfer from the donor organ JD to the receptor organs JR (including the donor organ itself) during the germination (RTGR(I,JD,JR)), in (6F10.0) format.

*A similar group of cards* for the leafing-out stage (RTLO(I,JD,JR)); for the vegetative stage (RTVG(I,JD, JR)); for the fruiting stage (RTFR(I,JD,JR)).

### SUBROUTINE DMDT (ENTRY INDMDT)

*One read-check card.*

*One card (or more)* for each species I, specifying the number of days (WTIME(I)) since the beginning of dormancy if species I is in the dormant stage at the start of the simulation (0 if not), in (6F10.0) format.

*One card* for each species I, containing pointers (LREP(I,J)), which indicates the type of dead organic material to which the dead organic material of the organ "J" will be transferred, in (6F10.0) format.

*One card* for each organ J of each species I (organs nested inside species), containing the three parameters (PDDT1(I,J) PDDT2(I,J), PDDT3(I,J)) in the exponential function which computes the rate of death during dormancy.

*One card (or more)* for each species J, giving the rate of death (PDT(I,J,K)) of each organ K during germination (I = 1).

*A similar group of cards* for: the leafing-out stage (I = 2); the vegetative stage (I = 3); the fruiting stage (I = 4).

### SUBROUTINE DMDM (ENTRY INDMDM)

*One read-check card*

*One card (or two)* for each season I and each donor type JD of dead organic material (donor type nested in season) giving the rates of transfer RTLI(I,JD,JR) for the season I from the donor compartment JD to the receptor compartment JR (including the donor compartment itself) in (6F10.0) format.

### SUBROUTINE DLIGHT (ENTRY INDMDL)

*One read-check card.*

*One card* to read in the latitude (RLAT, in degrees) of the site, in (6F10.0) format.

### SUBROUTINE EDAPH (ENTRY INDMED)

*One read-check card.*

*One card* with the depth in centimeters, of the bottom of each soil horizon in (6F10.0) format.

### SUBROUTINE EVAPO (ENTRY INDMEV)

*One read-check card.*

*One card* to read in the number of temperature thresholds plus one (NT), used to compute evaporation in (12I5) format.

*One card* to read the (NT-1) temperature threshold values (TARTUF(I)), in °C, in (6F10.0) format.

*One card* to read NT values for FACTOR (I), the parameter used to compute the evaporation, in (6F10.0) format.

### SUBROUTINE SOWAT (ENTRY INDMWT)

*One read-check card.*

*One card* with the parameters MM, NB, ND, in (12I5) format.

*One card* with the parameters ALAMBA, CB, CONQ, CUMT, DETT, DELW, in (6F10.0) format.

*One card* with the parameters DELX, DIFA, DIFB, DIFO, SYSTD, in (6F10.0) format.

*One card* with the parameters HDRY, HWET, HLOW HHI, RRES, SOCON, in (6F10.0) format.

*One card* with the parameters SOURCE, TAA, TIME, TT, in (6F10.0) format.

*One group of cards* with the value of D(I) in (6E10.0) format.

*One group of cards* with the value of P(I) in (6E10.0) format.

*One card (or two)* with the value of W(I) in (6F10.0) format.

*One card (or two)* with the value of WATL(I) in (6F10.0) format.

*One card (or two)* with the value of WATH(I) in (6F10.0) format.

*One card (or two)* with the value of RDF(I) in (6F10.0) format.

*One card (or two)* with the value of SE(I) in (6F10.0) format.

*One card* assigning a value to the logical variable IWRITE, in (L5) format.

### SUBROUTINE FILLTX (ENTRY INFILL)

*One read-check card.*

### SUBROUTINE PREPAR

*One read-check card.*

*One card* with KSUP=1, if the tables of the superposed symbols in diagrams are required (=0 if not) in (12I5) format.

**For one required diagram:**

*One card* for each variable containing the following, in (3I5, 11A4) format: (see comments in PREPAR) IGEN, IND1, IND2, LEG(11).

*One card* with nothing in columns 1 to 5.

**To terminate:**

*One card* with 100 (or more) in columns 1 to 5.

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## APPENDIX 1

### PROGRAM LISTING

Storage and time requirements (after compilation and storage of the program) on a Burroughs 6700 for a simulation of 36 days: process time, 0.38 min; virtual memory, 5.78 kwords-mins.

### *Explanations for Variables*

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C          PROGRAMME    MODELE MATIERE SECHE
C1              .....................................
C2              .           EXPLANATIONS            .
C3              .   FOR THE VARIABLES IN COMMONS    .
C4              .....................................
C5         ...............................................................
C1 A      (I)     NEGATIVES VALUES SHOW THE SOIL HORIZON ROOTS ARE
C2 A      (I)     EXTRACTING WATER FROM.
C1 ALAMBA         CONSTANT USED IN SALT CALCULATION.
C1 ARAIN  (I)     STORAGE ARRAY FOR THE AMOUNT OF RAIN.
C1 ARTE   (I)     STORAGE ARRAY FOR THE TEMPERATURES.
C1 B      (I)     VARIABLE USED IN 'SOWAT' .
C1 BEGTEM(I)      INITIAL SOIL TEMPERATURE(DEGREE C.) IN HORIZON 'I'.
C1 C      (I)     WATER CAPACITY OF THE SOIL INCREMENTS IN CM FOR THE
C2 C      (I)     HORIZON 'I' .
C1 CB             CONSTANT TO MULTIPLY  D ARRAY BY,USUALLY 1.0 .
C1 CCPS   (I)     CONSTANT FOR THE SPECIES 'I' IN THE INTEGRATED FORM OF
C2 CCPS   (I)     THE LOGISTIC EQUATION RELATING NET DAILY INCREMENT OF
C3 CCPS   (I)     DRY MATTER TO TEMPERATURE.
C1 CHECK  (I)     TEMPORARY STORAGE VARIABLE FOR READ CHECK CARD.
C1 CLIGHT         NAME OF A COMMON FOR THE SUBROUTINE DLIGHT.
C1 CLIT   (I)     AMOUNT OF DRY MATTER OF THE TYP 'I' OF DEAD ORGANIC
C2 CLIT   (I)     MATERIAL.
C1 CONDUC(I)      SOIL THERMAL CONDUCTIVITY (CAL/CM-HR-DEG) IN HORIZON I.
C1 CONN           LARGEST WATER CONTENT CHANGE ALLOWED EACH COMPUTATION,
C2 CONN           THE SMALLER THE NUMBER THE MORE ACCURATE THE COMPUTA-
C3 CONN           TION BUT THE LONGER THE RUN TIME,USUALLY 0.03 TO 0.05 .
C1 CRATFT(I)      RATIO OF DRY MATTER IN NEW FRUTS  TO CARBON IN PLANT
C2 CRATFT(I)      THAT MUST BE ATTAINED FOR THE PLANT TO PROGRESS FROM
C3 CRATFT(I)      CURRENT PHENOLOGICAL STAGE (FRUITING) TO THE NEXT(VEG.)
C1 CRATLO(I)      RATIO OF DRY MATTER IN NEW GROWTH TO DRY MATTER IN PLANT
C2 CRATLO(I)      THAT MUST BE ATTAINED FOR THE PLANT TO PROGRESS FROM
C3 CRATLO(I)      CURRENT PHENOLOGICAL STAGE (LEAFING-OUT OR GERMINATION)
C4 CRATLO(I)      TO THE NEXT (VEGETATIVE).
C1 CUMT
C1 CV     (I)     SOIL HEAT CAPACITY(CAL/G) IN HORIZON 'I'.
C1 CWFLX          VARIABLE USED IN 'SOWAT' .
C1 D      (I)     CM/HR HYDRAULIC CONDUCTIVITY-WATER CONTENT ARRAY IN
C2 D      (I)     'DELW' INCREMENTS AT THE BEGINNING. AFTER  CONTAINS
C3 D      (I)     THE DIFFUSIVITY.
C1 DALITE         FRACTION OF  THE TOTAL DAYLIGHT HOURS IN ONE YEAR FOR
C2 DALITE         THE CURRENT DAY.
C1 DAPHOT         NB. OF DAYLIGHT HOURS FOR THE CURRENT DAY.
C1 DARAIN         RAIN (MM) OF THE CURRENT  DAY.
C1 DATE           NAME OF A SUBROUTINE
C1 DATUM          NAME OF THE COMMON FOR THE DATE.
C1 DAYMIN(I)      STORAGE VARIABLE USED FOR THE COMPUTATION OF DAPHOT AND
C2 DAYMIN(I)      DALITE.
C1 DAYRAD         TOTAL IRRADIATION IN CAL/M*M/DAY
C1 DCLIT  (I)     VARIATION OF DRY MATTER FOR THE CURRENT DAY IN THE TYP
C2 DCLIT  (I)     'I' OF DEAD ORGANIC MATERIAL.
C1 DDMSP  (I,J)   VARIATION OF DRY MATTER FOR THE CURRENT DAY IN ORGAN
C2 DDMSP  (I,J)   'J' OF SPECIES 'I'.
C1 DD     (I)     DEPTH OF LAYERS USED IN THE SUBROUTINE 'SOWAT'.
C2 DD     (I)     THEY ARE DIFFERENT OF THE DEPTH  (DEPTH(I)) OF THE
C3 DD     (I)     BOTTOM  OF EACH HORIZON(CF. EXPLANATIONS  IN 'EDAPH'.
C4 DD     (I)     IN CENTIMETERS.
C1 DDMMAX(I)      MAXIMUM, FOR THE SPECIES 'I', NET DAYLY INCREMENT FOR
C2 DDMMAX(I)      DRY MATTER UNDER OPTIMAL CONDITIONS OF SOIL WATER POT-
C3 DDMMAX(I)      ENTIAL, AIR TEMPERATURE AND SUNLIGHT.(G D.M./G OF
C4 DDMMAX(I)      PHOTOSYNTHETIC ORGANS/DAY)
C1 DEGREE         NAME OF A SUBROUTINE
C1 DELT           VARIABLE USED IN 'SOWAT' .
C1 DELW           WATER CONTENT DIFFERENCE OF THE P(I),D(I) ARRAYS .
C2 DELW           USUALLY  0.01  .
C1 DELX           CONSTANT EQUAL TO 7.6  .
C1 DETI           SMALLEST TIME INCREMENT ALLOWED, USUALLY  0.0024 HR 9
C1 DIAGR          NAME OF A COMMON
C1 DIFA           CONSTANT USED IN SALT CALCULATIONS.
C1 DIFB           CONSTANT USED IN SALT CALCULATIONS.
C1 DIFC           CONSTANT USED IN SALT CALCULATIONS.
C1 DLIGHT         NAME OF A SUBROUTINE
C1 DMDM           NAME OF A SUBROUTINE
C1 DMOT           NAME OF A SUBROUTINE
C1 DMEXD          NAME OF A SUBROUTINE
C1 DMNEW  (I)     DRY MATTER ACUMULATED IN  SPECIES 'I' DURING THE
C2 DMNEW  (I)     GERMINATION (OR LEAFING-OUT)  OR FRUITING STAGE.
C1 DMPHEN         NAME OF A SUBROUTINE
C1 DMPHOT         NAME OF A SUBROUTINE
C1 DMSP   (I,J)   AMOUNT OF DRY MATTER IN THE ORGAN 'J' OF THE SPECIES I.
C1 DMT    (I)     AMOUNT OF DRY MATTER IN SPECIES 'I'.
C1 DMTR           NAME OF A SUBROUTINE
C1 DTIME          SIZE OF THE TIME INTERVAL FOR SOIL TEMPERATURE CALCULA-
C2 DTIME          TIONS IN HOURS.
C1 E      (I)     VARIABLE USED IN 'SOWAT' .
C1 EDAFON         NAME OF A COMMON
C1 EDAPH          NAME OF A SUBROUTINE
C1 EOR            EVAPORATION(CM) OR RAIN(CM) FOR 1 HOUR.
C1 ERAIN          NAME  OF A COMMON
C1 ET             POTENTIAL EVAPO TRANSPIRATION (CM/HR)
C1 ETIME          VARIABLE TO CONTROL THE NUMBER OF RUNS FOR THE SUBROU-
C2 ETIME          TINE 'SOWAT' .
C1 ETOUT          TRANSPIRED WATER.
C1 EVAP           CF. EOR.
C1 EVTP           NAME OF A COMMON
C1 EVAPO          NAME OF A SUBROUTINE
C1 EXO            NAME OF A COMMON
C1 F      (I)     VARIABLE USED IN 'SOWAT' .
C1 FACTOR(I)      DIFFERENT VALUES (ACCORDING WITH THE VALUES OF TARTUF)
C2 FACTOR(I)      OF A PARAMETER USED  TO COMPUTE ET AND EVAP IN 'EVAPO'.
C1 FILL           NAME OF A COMMON
C1 FILLIX         NAME OF A SUBROUTINE
C1 FORCE          RAINFALL INTENSITY (MM/HOUR).
C1 G      (I)     VARIABLE USED IN 'SOWAT' .
C1 GRADE          NAME OF A COMMON
C1 H      (I)     WATER POTENTIAL IN SOIL HORIZON 'I' IN CM .
C1 HDRY           CM PRESSURE OF AIR DRY SOIL WATER CONTENT.
C1 HEAD           NAME OF THE COMMON FOR THE TITLE.
C1 HHT            MAXIMUM ROOT POTENTIAL ALLOWED,USUALLY 0.0  .
C1 HLOW           MINIMUM ROOT POTENTIAL ALLOWED,USUALLY -15000. TO
C2 HLOW           -40000. CM  .
C1 HROOT          ROOT WATER POTENTIAL IN CM.
C1 HWET           CM PRESSURE OF SATURATION SOIL  WATER CONTENT.
C1 IANUAL         (=1)  NUMBER FOR THE ANNUAL LIFE FORM.
C1 IBIS            NOT USED.
C1 ICD            THE DAY FOR THE CURRENT DATE.
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C1 ICM            THE MONTH FOR THE CURRENT DATE.
C1 ICY            THE YEAR FOR THE CURRENT DATE.
C1 IDATR (I)      DATE OF THE I-TH REPORT.
C1 IDAY           CURRENT DAY (INITIAL DAY=1).
C1 IERAIN         TEST IF RAIN IS FINISHED FOR A DAY WITH RAIN/IN 'EVAPO.
C1 IFON   (I,J)   FUNCTION OF THE ORGAN J IN THE SPECIES I.
C2 IFON   (I,J)   SEE ALSO  NOSEED,NOFRUT,NOPHOT,NOROOT,NOSTEM.
C1 IMP            PRINTING MACHINE.
C1 IND            DAY OF THE INITIL DATE. (EXCEPT IN 'PLOT')
C1 INM            MONTH OF THE INITIAL DATE.
C1 INOU           NAME OF THE COMMON FOR THE INPUT-OUTPUT.
C1 INVDAT         NAME OF A SUBROUTINE
C1 INY            YEAR OF THE INITIAL DATE.
C1 IPDAY          CURRENT DAY(IDAY) -1.
C1 IPFRUT(I)      IF THE SPECIES I IS IN FRUITING STAE
C2 IPFRUT(I)      NUMBER OF DAYS OF FRUITING STAGE
C3 IPFRUT(I)      THE BEGINNING OF THIS STAGE.
C1 IPGERM(I)      IF THE SPECIES I IS IN GERMINATION, OR LEAFING-OUT.
C2 IPGERM(I)      NUMBER OF DAYS OF GERMINATION,OR LEAFING-OUT, SINCE
C3 IPGERM(I)      THE BEGINNING OF THIS STAGE.
C1 IPHENN(I)      PHENOLOGICAL STAGE OF THE SPECIES 'I' DURING THE PRE-
C2 IPHENN(I)      VIOUS DAY.
C1 IPHENO(I)      PHENOLOGICAL STAGE OF THE SPECIES 'I'.
C1 IPU            PUNCH CARD.
C1 IREP           NUMBER OF THE CURRENT REPORT.
C1 IS             THE SEASON.
C2 IS                  =1 FOR WINTER
C3 IS                  =2 FOR SPRING
C4 IS                  =3 FOR SUMMER
C5 IS                  =4 FOR AUTUMN
C1 ISHRB          (=2)  NUMBER FOR THE SHRUB  LIFE FORM.
C1 ISP            NUMBER OF THE CURRENT SPECIES.
C1 IWRITE         LOGICAL VARIABLE .IF TRUE WRITE INFORMATIONS FOR THE
C2 IWRITE         SOIL THE DAYS WITH A REPORT.
C1 JDR    (I)     STORAGE ARRAY FOR THE DATES OF DAYS WITH RAIN.
C1 JDTC   (I)     STORAGE ARRAY FOR THE DATES OF DAYS WHOSE THE TEMPERA-
C2 JDTC   (I)     TURE CHANGES.
C1 JOURS          NUMBER OF DAYS IN THE CALLED MONTH (SUBROUTINE NJMOIS).
C1 JULDAY         THE CURRENT JULIAN DAY.
C1 JULES          NAME OF A SUBROUTINE
C1 K              = NHOR .
C1 K1     (TO K15)PARAMETERS USED BETWEEN 'FILLIX' AND 'PREPAR'.
C1 KAS            NAME OF A COMMON
C1 KCK            VARIABLE USED IN 'SOWAT' .
C1 KK             =K+1   .
C1 KMLITE(I)      THE IRRADIATION WHICH CAUSES THE CARBON FIXATION RATE
C2 KMLITE(I)      TO BE HALF ITS MAXIMUM WHEN OTHER FACTORS ARE OPTIMAL
C3 KMLITE(I)      FOR THE SPECIES 'I'.
C1 LAYCH (I)      THE  SOIL HORIZON WHOSE TEMPERATURE AND/OR SOIL WATER
C2 LAYCH (I)      POTENTIAL IS USED A TRIGGER  IN THE  DETERMINATION OF
C3 LAYCH (I)      DAYLY  RATE INCREMENT FOR DRY MATTER.
C1 LEC            CARD READER.
C1 LCOUCH(I)      THE  SOIL HORIZON WHOSE TEMPERATURE AND/OR SOIL WATER
C2 LCOUCH(I)      POTENTIAL IS USED A TRIGGER FOR GERMINATION  AND LEAFING
C3 LCOUCH(I)      -OUT FOR THE SPECIES 'I'.
C1 LEG    (I,J)   IDEM IV
C1 LIF    (I)     LIFE FORM OF THE SPECIES I.
C2 LIF    (I)     1= ANNUAL
C3 LIF    (I)     2= SHRUB
C4 LIF    (I)     3= PERENNIAL HERBACEOUS
C1 LITPAR         NAME OF A COMMON
C1 LITTER         NAME OF A COMMON
C1 LL             VARIABLE USED IN 'SOWAT' .
C1 LREP   (I,J)   POINTERS TO INDICATE IN WHICH COMPARTMENT OF DEAD
C2 LREP   (I,J)   MATERIAL WILL BE TRANSFERRED THE DEAD MATTER OF
C3 LREP   (I,J)   ORGAN 'J' IN THE SPECIES 'I'.
C1 MM             NOT USED IN THIS VERSION .
C1 N              VARIABLE USED IN 'SOWAT' .
C1 NAME           NAME OF THE COMMON FOR THE ALPHABETICAL NAMES.
C1 NAMLIT(I)      ALPHABETICAL NAME OF THE DEAD MATERIAL CATEGORY I.
C1 NAMORG(I,J)    ALPHABETICAL NAME OF THE ORGAN J IN THE SPECIES I.
C1 NAMSP (I)      ALPHABETICAL NAME OF THE SPECIES I.
C1 NB             EQUAL TO N OR LESS, USED WHEN COMPUTATION OVER ONLY A
C2 NB             PORTION  OF THE PROFILE IS DESIRED .
C1 ND             SIZE OF THE POTENTIAL-WATER CONTENT TABLE .
C1 NDAY           NUMBER OF DAYS TO SIMULATE +1.
C1 NDFRUT(I)      MAXIMUM NUMBER OF DAYS FOR THE FRUITING STAGE OF THE
C2 NDFRUT(I)      SPECIES I.
C1 NDGERM(I)      MAXIMUM NUMBER OF DAYS FOR THE GERMINATION, OR LEAFING-
C2 NDGERM         OUT, OF THE SPECIES I.
C1 NDR            NUMBER OF DAYS WITH RAIN.
C1 NDTC           NUMBER OF DAYS WHOSE THE TEMPERATURE CHANGES(INCLUDING
C2 NDTC           THE INITIAL DAY).
C1 NHOR           NUMBER OF SOIL HORIZONS.
C1 NLIT           NB. OF TYPS OF DEAD ORGANIC MATERIAL.
C1 NODOR          (=5) NUMBER FOR DORMANCY.
C1 NOFR           (=4) NUMBER FOR FRUITING STAGE.
C1 NOFRUT         (=2) NUMBER OF THE FROT FUNCTION.
C1 NOGER          (=1) NUMBER FOR GERMINATION.
C1 NOLO           (=2) NUMBER FOR LEAFING-OUT.
C1 NOPHOT         (=3)  NUMBER OF THE PHOTOSYNTHETIC FUNCTION.
C1 NORG   (I)     NUMBER OF ORGANS OF THE SPECIES I.
C1 NOROOT         (=4) NUMBER OF THE ROOT FUNCTION.
C1 NOSEED         ( =1) NUMBER OF THE SEED FUNCTION.
C1 NOSTEM         (=5) NUMBER OF THE   STEM FUNCTION.
C1 NOVEG          (=3) NUMBER FOR VEGETATIVE STAGE.
C1 NREP           NUMBER OF REPORTS (INCLUDED FOR THE INITIAL DAY IF
C2 NREP           DESIRED)  ,MAXIMUM=20.
C1 NSP            NUMBER OF SPECIES.
C1 NT             NUMBER OF THRESHOLDS (+1) USED  IN 'EVAPO' FOR THE
C2 NT             TEMPERATURE.
C1 P      (I)     CM OF PRESSURE HEAD-WATER CONTENT ARRAY IN 'DELW'
C2 P      (I)     INCREMENTS.
C1 PARPH1(I)      PARAMETER USED IN THE SUBROUTINE 'DMPHEN' IN EXPONEN-
C2 PARPH1(I)      TIAL FUNCTION RELATING  THE MAXIMUM VALUE OF THE RATIO
C3 PARPH1(I)      (DRY MATTER IN NEW TISSUE TO TOTAL DRY MATTER IN PLANT
C4 PARPH1(I)      OR IN SEED POOL),AT END OF LEAFING-OUT OR GERMINATION
C5 PARPH1(I)      TO THE SOIL WATER POTENTIAL.
C1 PARPH2(I)      CF. PARPH1(I).
C1 PARPH3(I)      CF. PARPH1(I).
C1 PARPH4(I)      PARAMETER USED IN THE SUBROUTINE 'DMPHEN' IN EXPONEN-
C2 PARPH4(I)      TIAL FUNCTION RELATING THE MAXIMUM VALUE OF THE RATIO
C3 PARPH4(I)      (DRY  MATTER IN FROTS TO DRY MATTER IN PLANT) AT END
C4 PARPH4(I)      OF FRUITING STAGE TO THE SOIL WATER POTENTIAL.
C1 PARPH5(I)      CF  PARPH4(I).
C1 PARPH6(I)      CF  PARPH4(I).
C1 PODT1  (I,J)   PARAMETER FOR THE ORGAN 'J' OF THE SPECIES 'I' ,USED TO
C2 PODT1  (I,J)   COMPUTE THE RATE OF DEATH DURING THE DORMANCY.
C1 PODT2  (I,J)   CF. PODT1(I,J)
C1 PODT3  (I,J)   CF. PODT1(I,J)
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C1 PDT    (I,J,K) RATE OF DEATH DURING THE SEASON 'I' FOR THE ORGAN 'K'
C2 PDT            OF THE SPECIES 'J'.
C1 PHENO          NAME OF A COMMON
C1 PHOTMN(I)      MINIMUM PHOTOPERIOD TO GO FROM LEAFING-OUT OR GERMINA-
C2 PHOTMN(I)      TION  TO VEGETATIVE STAGE FOR THE SPECIES 'I'.
C1 PHOTMX(I)      MAXIMUM PHOTOPERIOD TO GO FROM LEAFING-OUT OR GERMINA-
C2 PHOTMX(I)      TION  TO VEGETATIVE STAGE FOR THE SPECIES 'I'.
C1 PHOTO          NAME OF A COMMON
C1 PHOVMN(I)      MINIMUM PHOTOPERIOD FOR THE SPECIES 'I' TO JUMP FROM
C2 PHOVMN(I)      VEGETATIVE TO REPRODUCTIVE STAGE.
C1 PHOVMX(I)      MAXIMUM PHOTOPERIOD FOR THE SPECIES 'I' TO JUMP FROM
C2 PHOVMX(I)      VEGETATIVE TO REPRODUCTIVE STAGE.
C1 PHSATE         NET DAYLY DRY MATTER FOR THE CURRENT SPECIES.
C1 PIT            VARIABLE USED IN 'SOWAT' .
C1 PLOT           NAME OF A SUBROUTINE
C1 PREPAR         NAME OF A SUBROUTINE
C1 PRFACT(I)      STORAGE ARRAY FOR THE REPORT OF THE VALUE 'PSRATE' IN
C2 PRFACT(I)      SUBROUTINE 'DMPHOT'.
C1 PRLITE(I)      STORAGE ARRAY FOR THE REPORT OF THE VALUE 'LIGHTF' IN
C2 PRLITE(I)      SUBROUTINE 'DMPHOT'.
C1 PRMOIS(I)      STORAGE ARRAY FOR THE REPORT OF THE VALUE 'PMSF  ' IN
C2 PRMOIS(I)      SUBROUTINE 'DMPHOT'.
C1 PROVIS         NAME OF A COMMON
C1 PRSATE(I)      STORAGE ARRAY FOR THE REPORT OF THE VALUE 'PHSATE' IN
C2 PRSATE(I)      SUBROUTINE 'DMPHOT'.
C1 PRTEMP(I)      STORAGE ARRAY FOR THE REPORT OF THE VALUE 'TEMPF ' IN
C2 PRTEMP(I)      'SUBROUTINE 'DMPHOT'.
C1 PCHECK         NAME OF A COMMON
C1 ROF    (I)     FRACTION OF ROOTS IN EACH DEPTH INCREMENT(HORIZON 'I')
C1 REP            NAME OF A COMMON
C1 REPORT         NAME OF A SUBROUTINE
C1 RRES           ROOT RESISTANCE, 1.05    .
C1 RRPS   (I)     CONSTANT FOR THE SPECIES 'I' IN THE INTEGRATED FORM OF
C2 RRPS   (I)     THE LOGISTIC EQUATION RELATING NET DAILY INCREMENT OF
C3 RRPS   (I)     DRY MATTER TO TEMPERATURE.
C1 RT             NAME OF A COMMON
C1 RTFR   (I,J,K) THE SAME AS RTGR(I,J,K) BUT FOR FRUITING STAGE.
C1 RTGR   (I,J,K) RATE OF TRANSFER DURING THE GERMINATION FOR THE SPECIES
C2 RTGR   (I,J,K) 'I' BETWEEN THE DONOR ORGAN 'J' AND THE RECEPTOR ORGAN
C3 RTGR   (I,J,K) 'K'.
C1 RTLT   (I,J,K) RATE OF TRANSFER FOR THE SEASON 'I' BETWEEN THE TYP 'J'
C2 RTLT   (I,J,K) (DONOR) AND THE TYP 'K' (RECEPTOR) OF DEAD ORGANIC MATERIAL.
C1 RTLO   (I,J,K) THE SAME AS RTGR(I,J,K) BUT FOR LEAFING-OUT.
C1 RTPH   (I,J)   RATE TO ALLOCATE THE  NET DAYLY INCREMENT  FOR THE
C2 RTPH   (I,J)   SPECIES 'I' TO THE  ORGAN 'J'.
C1 RTVG   (I,J,K) THE SAME AS RTGR(I,J,K) BUT FOR VEGETATIVE STAGE.
C1 RUNOF          CUMULATIVE CM OF RUNOFF WATER (FOR THE CURRENT DAY).
C1 SALNTY(I)      AMOUNT OF SALT IN HORIZON 'I' IN M(=SO(I))
C1 SO     (I)     AMOUNT OF SALT IN HORIZON 'I' IN MEQ.
C1 SE     (I)     CONCENTRATION OF SALT IN HORIZON 'I' ,E.C. READINGS IN
C2 SE     (I)     MMHOS/CM.
C1 SEASON         NAME OF A SUBROUTINE
C1 SMAX           VARIABLE USED IN 'SOWAT' .
C1 SUCON          CONSTANT USED IN SALT CALCULATIONS.
C1 SOIL           NAME OF A COMMON
C1 SOILTE(I)      SOIL TEMPERATURE IN HORIZON 'I'(IN DEGREE C.)/=STEMP(I)
C1 SOURCE         CONSTANT USED IN SALT CALCULATIONS.
C1 SOWAT          NAME OF A SUBROUTINE
C1 SS     (I)     VARIABLE USED IN 'SOWAT' .
C1 STATE  (I)     VARIABLE WITH THE TITLE
C1 STEMP  (I)     SOIL TEMPERATURE IN HORIZON 'I', (=SOILTE(I)).
C1 SYSTO          TEMPORARY PARAMETER TO SHIFT THE HYDRAULIC CONDUCTIVITY
C1 T      (I)     WATER CONTENT TABLE, HAS EVEEN INCREMENTS 'DELW' IN
C2 T      (I)     SIZE .
C1 TAA            ZERO IF THE BOTTOM BOUNDARY IS A WATER TABLE, OTHERWISE
C2 TAA            EQUAL TO 1.0   .
C1 TARTOF(I)      DIFFERENT  THRESHOLDS TEMPERATURE (IN DEGREE C.) USED
C2 TARTOF(I)      IN 'EVAPO'
C1 TBB            VARIABLE USED IN 'SOWAT' .
C1 TCOVER         FRACTION OF THE GROUND SURFACE COVERED BY VEGETATION.
C1 TDAY           AIR TEMPERATURE  (DEGREE C.) OF THE CURRENT DAY.
C1 TEMPUM(I)      THE 'UPPER OPTIMUM TEMPERATURE' FOR MAIMUM DAYLY INCRE-
C2 TEMPUM(I)      MENT.
C1 TEMPUT(I)      THE UPPER TEMPERATURE THRESHOLD ABOVE WHICH THERE IS NO
C2 TEMPUT(I)      DAYLY INCREMENT FOR DRY MATTER.
C1 TIME           TIME THE COMPUTATION STARTS , USUALLY 0. - AND THE
C2 TIME           CUMULATIVE HOURS OF THE SIMULATION RUN FOR EACH DAY.
C1 THRTVG(I)      NOT USED IN THIS VERSION.
C1 THRTVD(I)      NOT USED IN THIS VERSION.
C1 THTPLO(I)      MINIMUM TEMPERATURE              TO GO FROM LEAFING-OUT
C2 THTPLO(I)      OR GERMINATION TO VEGETATIVE STAGE FOR THE SPECIES 'I'.
C1 THTPVD(I)      THRESHOLD TEMPERATURE            TO GO FROM VEGETATIVE
C2 THTPVD(I)      TO DORMANT STAGE FOR THE SPECIES 'I'.
C1 THTPVG(I)      MINIMUM TEMPERATURE FOR THE SPECIES 'I' TO JUMP FROM
C2 THTPVG(I)      VEGETATIVE TO REPRODUCTIVE STAGE.
C1 THWTLO(I)      MINIMUM SOIL  WATER POTENTIAL TO GO FROM LEAFING-OUT
C2 THWTLO(I)      OR GERMINATION TO VEGETATIVE STAGE FOR THE SPECIES 'I'.
C1 THWTVD(I)      THRESHOLD SOIL WATER POTENTIAL TO GO FROM VEGETATIVE
C2 THWTVD(I)      TO DORMANT STAGE FOR THE SPECIES'I'.
C1 THWTVG(I)      MINIMUM SOIL WAT.POT.  FOR THE SPECIES 'I' TO JUMP FROM
C2 THWTVG(I)      VEGETATIVE TO REPRODUCTIVE STAGE.
C1 TIME   (I)     NB. OF DORMANT DAYS SINCE THE BEGINNING OF THIS STAGE,
C2 TIME   (I)     IF THE SPECIES 'I' IS IN DORMANCY(IN OTHER CASES=0.)
C1 TM             VARIABLE USED IN 'SOWAT' .
C1 TOTMIN         STORAGE VARIABLE USED IN THE COMPUTATION  OF DAPHOT AND
C2 TOTMIN         DALITE
C1 TRAIN          LENGTH OF THE  RAIN FOR ONE DAY(IN HOURS).
C1 TRANS          NAME OF A COMMON
C1 TRMAT  (I,J)   STORAGE ARRAY USED IN THE SUBROUTINE 'DMTR'.
C1 TT             IS 1.0 FOR BAASONEN OR 0.5 FOR CRANK-NICHOLSON COMPUTA-
C2 TT             TIONAL PROCEDURE .
C1 TV     (I,J)   STORAGE ARRAY USED BETWEEN THE SUBROUTINES 'PREPAR'
C2 TV     (I,J)   AND 'PLOT'.
C1 TX     (I,J)   STORAGE ARRAY FOR THE VARIABLES WHICH WILL BE PLOTTED.
C1 VEG            NAME OF A COMMON
C1 W      (I)     INITIAL VOLUMETRIC FRACTIONAL WATER CONTENT IN HORIZON
C2 W      (I)     'I' .
C1 WAT            NAME OF A COMMON
C1 WATABS(I)      TOTAL AMOUNT OF WATER (MM) IN THE HORIZON 'I'.
C1 WATER  (I)     SOIL WATER POTENTIAL OF THE HORIZON 'I' (IN BARS).
C1 WATH   (I)     SATURATION SOIL WATER CONTENT OF HORIZON 'I'.
C1 WATL   (I)     VOLUMETRIC FRACTIONAL AIR DRY SOIL WATER CONTENT
C2 WATL   (I)     (HORIZON 'I') .
C1 WFOD           VARIABLE USED IN 'SOWAT' .
C1 WMAX   (I)     SOIL WATER POTENTIAL THRESHOLD ABOVE WICH  THIS PARAME-
C2 WMAX   (I)     TER  HAS NO INHIBITING EFFECT.
C1 WMIN   (I)     SOIL WATER POTENTIAL THRESHOLD BELOW WHICH PHOTOSYN-
C2 WMIN   (I)     THESIS CANNOT OCCUR
C1 WTIME  (I)     THE NUMBER OF DAYS SINCE THE BEGINNING OF  DORMANCY
C2 WTIME  (I)     FOR THE SPECIES  'I' IN DORMANT STAGE (0. FOR OTHERS)
C1 Y      (I)     VARIABLE USED IN 'SOWAT' .
C1 YORO           NAME OF A COMMON
```

## *Main Program*

```
C*****************************************************************
C                         M A I N   P R O G R A M               *
C                         ************************              *
C.................................................................
      COMMON /CLIGHT/ DAYMIN(366),TOTMIN
      COMMON /DATUM/ IND,INM,INY,IDAY,JULDAY,ICD,ICM,ICY,IS,IBIS,JOURS,
     1              NDAY,IPDAY
      COMMON /DEATH/WTIME(20),LREP(20,10),PDOT1(20,10),PDOT2(20,10),
     1              PDOT3(20,10),PDT(4,20,10)
      COMMON /DIAGR/ TV(10,100),LEG(10,11)
      COMMON /EDAFON/  DD(11),DTIME
      COMMON /ERAIN/ IERAIN,FORCE
      COMMON /EVTP/ ET,EVAP,FACTOR(4),TARTOF(4),NT
      COMMON /EXO/ DARAIN,TDAY,DAPHOT,DAYRAD,DALITE,TRAIN
      COMMON /FILL/ TX(50,100)
      COMMON /GRADE/ STEMP(11),CV(11),CONDUC(11),REGTEM(11)
      COMMON /HEAD/ STATE(20)
      COMMON /INOU/ LEC,IMP,IPU
      COMMON /KAS/ K1,K2,K3,K4,K5,K6,K7,K8,K9,K10,K11,K12,K13,K14,K15
      COMMON /LITPAR/ RTLT(5,10,10)
      COMMON /LITTER/ CLIT(10),DCLIT(10),NLIT
      COMMON /NAME/ NAMSP(20),NAMORG(20,10),NAMLIT(10)
      COMMON /PHENO/ PARPH1(20),PARPH2(20),PARPH3(20),PARPH4(20),
     1              PARPH5(20),PARPH6(20),CRATLO(20),CRATFT(20),
     2              THTPVG(20),THWTVG(20),PHOVMN(20),PHOVMX(20),
     3              THRTVG(20),THTPVD(20),
     4              THWTVD(20),THRTVD(20),THTPLO(20),THWTLO(20),
     5              PHOTMN(20),PHOTMX(20),
     6              IPGERM(20),IPFRUT(20),NDGERM(20),NDFRUT(20),
     7              LCOUCH(10)
      COMMON /PHOTO/ KMLITE(20),CCPS(20),RRPS(20),TEMPUT(20),TEMPUM(20),
     1              DUMMAX(20),WMIN(20),WMAX(20),LAYCH(20)
      COMMON /PROVIS/ PRLITE(20), PRTEMP(20),PRMOIS(20),PRFACT(20),
     1               PRSATE(20)
      COMMON /RCHECK/ CHECK(20)
      COMMON /REP/ IDATR(20),NREP ,IREP
      COMMON /RT/ NDR,JDR(100),ARAIN(100),NDTC,JDTC(100),ARTE(100)
      COMMON /SOIL/  WATER(10),SOILTE(10),       NHOR
      COMMON /TRANS/ RTPH(20,10),RTGR(20,10,10),RTLO(20,10,10),
     1              RTVG(20,10,10),RTFR(20,10,10),TRMAT(10,10)
      COMMON /VEG/ ISP,NSP,IANUAL,ISHRB,NOSEED,NOPHOT,
     1          NORG(20),LIF(20),IPHENO(20),IPHENN(20),IFUN(20,10),
     2          DMSP(20,10),DDMSP(20,10),DMT(20),DMNEW(20),PHSATE,
     3           NOGER,NOLO,NOVEG,NOFR,NODOR,ICOVER
      COMMON /WAT/ WATABS(10),RUNOF,     SALNTY(10),EOR,ETIME,ETOUT,
     1             RROUT
      COMMON /ZORO/ ALAMBA,CB    ,CONQ  ,COMT  ,DETT  ,DELW  ,
     1             DELX  ,DIFA  ,DIFB  ,DIFO  ,
     2             HDRY  ,HWET  ,HLOW  ,HHI   ,RRES  ,SUCON ,
     3             SOURCE,TAA   ,TIME  ,TT,ND ,WFOD  ,LL,MM ,DELT  ,NH,
     4             TM    ,TBB   ,PIT   ,SMAX  ,CWFLX ,N,K,KK,KCK   ,
     5             D(60),P(60),T(60),
     6             C(11),G(11),H(11),ROF(11),SO(11),SE(11),SS(11),
     7          W(11),WATH(11),WATL(11),Y(11),A(11),B(11),E(11),F(11),
     8             IWRITE
      LOGICAL IWRITE
      DOUBLE PRECISION NAMSP,NAMORG,NAMLIT
      DATA IMP/6/,LEC/5/
      DATA TCOVER/0.2/,DAYRAD/275./
      DATA BLANK/' '/
C........ALL DATA ARE READ IN COLUMNS 1 TO 60,EXCEPT THE NAMES.(C. 1 TO
C          40).
C...................................................................
C          COMMENTS ARE READ IN AND PRINTED OUT UNTIL A BLANK CARD IS    .
C          ENCONTERED.                                                   .
C...................................................................
   19 READ(LEC,1) (STATE(I),I=1,20)
      WRITE(IMP,2)(STATE(I),I=1,20)
      DO 20 I=1,20
      IF (STATE(I).NE. BLANK) GO TO 19
   20 CONTINUE
C.........A HEADING IS READ IN FOR TABULAR OUTPUT.
      READ(LEC,1)(STATE(I),I=1,20)
C.....READ THE DATE OF THE INITIAL DAY. THE SIMULATION BEGIN THE SECOND
C          DAY.
      READ(LEC,3) IND,INM,INY,ILD,ILM,ILY
      CALL INVDAT(IND,INM,INY,NDAY,ILD,ILM,ILY)
      READ(LEC,3) NSP,NLIT,NHOR
C........POSSIBLE FUNCTIONS FOR ONE ORGAN.
      NOSEED=1
      NOFRUT=2
      NOPHOT=3
      NOROOT=4
      NOSTEM=5
      READ(LEC,3)(NORG(I),I=1,NSP )
      DO 23 I=1,NSP
      IBID=NORG(I)
   23 READ(LEC,3)(IFUN(I,J),J=1,IBID)
C........POSSIBLE LIFE FORMS.
      IANUAL=1
      ISHRB=2
      IMPER=3
      READ(LEC,3) (LIF(I),I=1,NSP)
C........READ THE ALPHABETICAL NAMES.
      READ(LEC,5)(NAMSP(I),I=1,NSP)
      DO 25 I=1,NSP
      IBID=NORG(I)
   25 READ(LEC,5)(NAMORG(I,J),J=1,IBID)
      READ(LEC,5)(NAMLIT(I),I=1,NLIT)
C.........READ INITIAL DATA FOR DRY MATTER IN THE SPECIES.
      DO 26 I=1,NSP
      IBID=NORG(I)
   26 READ(LEC,4)(DMSP(I,J),J=1,IBID)
C.........READ INITIAL DATA FOR DRY MATTER IN THE DEAD MATERIAL.
      READ(LEC,4)( CLIT(I),I=1,NLIT)
C........READ IN PARAMETERS FOR EACH SUBROUTINE.
      CALL INDMRP
      CALL INDMEX
      CALL INDMPN
      CALL INDMFO
      CALL INDMTR
      CALL INDMDT
      CALL INDMOM
      CALL INDMDL
      CALL INDMED
      CALL INDMEV
      CALL INDMOG
      CALL INDMWT
      CALL INFILL
      IDAY=0
      IREP=1
C.........BEGIN THE LOOP FOR EACH DAY.
 1001 IDAY=IDAY+1
      CALL DATE
      CALL JULES
      CALL NJMOIS(ICM,ICY,JOURS,THIS )
      CALL SEASON
      CALL DMEXO
      CALL DLIGHT
      CALL EOAPH
      IF(IDAY.EQ.1) GOTO 1100
      LOOP=0
C........BEGINNING OF THE LOOP IN ONE DAY.
 1002 LOOP=LOOP+1
      IF (LOOP.LE.10) GO TO 1003
      WRITE(IMP,1004)      ICD,ICM,ICY
      GO TO1102
 1003 CONTINUE
      DO 1005 ISP=1,NSP
      CALL DMPHEN
      CALLDMPHOT
      CALLDMTR
      CALLDMDT
 1005 CONTINUE
      CALL DMOM
      IF(LOOP.EQ.1) COEF=1.
      FGOOD=1.
C........TEST FOR THE DRY MATTER
```

```
      DO 1010  I=1,NSP
      IBID=NORG(I)
      DO 1009 J=1,IBID
      BGOOD=DDMSP(I,J)*COEF
      AGOOD=DMSP(I,J)+BGOOD
      IF(AGOOD.GE.0.) GO TO 1009
      FT=-DMSP(I,J)/BGOOD
      IF(FT.LT.FGOOD) FGOOD=FT
 1009 CONTINUE
 1010 CONTINUE
C........TEST FOR THE DEAD MATERIAL.
      DO 1011 I=1,NLIT
      BGOOD=DCLIT(I)*COEF
      AGOOD=CLIT(I)+BGOOD
      IF(AGOOD.GE.0.) GO TO 1011
      FT=-CLIT(I)/BGOOD
      IF(FT.LT.FGOOD) FGOOD=FT
 1011 CONTINUE
C........ADJUST THE STATE VARIABLES
      DO 1021 I=1,NSP
      IBID=NORG(I)
      DO 1020 J=4
      DO 1020 J=1,IBID
      DMSP(I,J)=DMSP(I,J)+DDMSP(I,J)*FGOOD
 1020 CONTINUE
 1021 CONTINUE
      DO 1022 I=1,NLIT
      CLIT(I)=CLIT(I)+DCLIT(I)*FGOOD
 1022 CONTINUE
      IF(FGOOD.EQ.1.) GO TO 1100
      COEF=COEF*(1.-FGOOD)
      GO TO 1002
 1100 CONTINUE
      DO 1101 I=1,NSP
      DMT(I   )=0.
      IBID=NORG(I)
      DO 1101 J=1,IBID
 1101 DMT(I)= DMT(I)+DMSP(I,J)
      CALL REPORT
      CALL FILLIX
      IF(IDAY.GE.NDAY) GO TO 1102
      IPDAY=IDAY
      GO TO 1001
 1102 CALL PREPAR
      STOP
    1 FORMAT(20A4)
    2 FORMAT(1X,20A4)
    3 FORMAT(12I5)
    4 FORMAT(6F10.0)
    5 FORMAT(10A8)
 1034 FORMAT(' TROP DE BOUCLES LE '3I5)
      END
```

## *Subroutine* DATE

```
C***********************************************************************
      SUBROUTINE DATE
C-----------------------------------------------------------------------
C   COMPUTE THE DATE(ICD,ICM ,ICY) WITH THE CURRENT DAY(IDAY)          I
C-----------------------------------------------------------------------
C........IBIS=DUMMY VARIABLE
C........IND =INITIAL DAY     (INPUT)
C........INM =    *    MONTH  (INPUT)
C........INY =    *    YEAR   (INPUT)
C........IDAY=CURRENT DAY, COUNTING FROM THE INITIAL DAY(INCLUDED)
C               (INPUT)
C........ICD=THE DATE WITHIN THE CURRENT DAY       (OUTPUT)
C........ICM = THE MONTH WITHIN THE CURRENT YEAR (OUTPUT)
C........ICY=THE CURRENT YEAR                     (OUTPUT)
      COMMON /DATUM/ IND,INM,INY,IDAY,JULDAY,ICD,ICM,ICY,IS,IBIS,JOURS ,
     1                    NDAY,IPDAY
      ICD=IND
      ICM=INM
      ICY=INY
      IF(IDAY.LE.1) RETURN
      DO 10 K=2,IDAY
      ICD=ICD+1
      CALL NJMOIS(ICM ,ICY,NJ,IBIS)
      IF(ICD.LE.NJ) GO TO 10
      ICM=ICM+1
      ICD=1
      IF(ICM .LE.12) GO TO 10
      ICY=ICY+1
      ICM=1
      ICD=1
   10 CONTINUE
      RETURN
      END
```

## *Subroutine* DEGREE

```
C***********************************************************************
      SUBROUTINE DEGREE
C             ...............................................
C             .          COMPUTE SOIL TEMPERATURES          .
C             ...............................................
      COMMON /EDAFUN/  DD(11),DTIME
      COMMON /EXO/ DARAIN,TDAY,DAPHOT,DAYRAD,DALITE,TRAIN
      COMMON /GRADE/ STEMP(11),CV(11),CONDUC(11),BEGTEM(11)
      COMMON /INOU/ LEC,IMP,IPU
      COMMON /RCHECK/ CHECK(20)
      COMMON /SOIL/  WATER(10),SOILTE(10),       NHOR
      DIMENSION F(11),E(11)
      K=NHOR-1
      KK=K+1
      STEMP(1)=TDAY
      STEMP(KK)=BEGTEM(KK)
C-*********************************************************************
C-         SOLUTION TO TRI-DIAGONAL MATRIX
C-*********************************************************************
      DO 46 I=2,K
      POT=(DD(I+1)-DD(I-1))/(2.*DTIME)
      DLXA=(DD(I)-DD(I-1))
      DLXB=(DD(I+1)-DD(I))
      BB=CV(I)*POT+CONDUC(I)/DLXB+CONDUC(I-1)/DLXA
      DA=CV(I)*POT*BEGTEM(I)
      IF (I .GT. 2) GO TO 44
      DA=DA+CONDUC(I-1)*STEMP(I-1)/DLXA
      F(I)=DA/BB
      E(I)=(CONDUC(I)/DLXB)/BB
      GO TO 46
   44 IF (I .GE. K) GO TO 47
   45 E(I)=(CONDUC(I)/DLXB)/(BB-(CONDUC(I-1)/DLXA)*E(I-1))
      F(I)=(DA+(CONDUC(I-1)/DLXA)*F(I-1))/(BB-(CONDUC(I-1)/DLXA)*E(I-1))
   46 CONTINUE
   47 BB=BB-CONDUC(I)/DLXB
      STEMP(I)=(DA+(CONDUC(I-1)/DLXA)*F(I-1))/(BB-(CONDUC(I-1)/DLXA)*
     1E(I-1))
   48 I=I-1
      STEMP(I)=E(I)*STEMP(I+1)+F(I)
      IF (I .GT. 2) GO TO 48
      STEMP(KK)=(BEGTEM(KK)+STEMP(K))*0.5
      DO 50 I=1,KK
      BEGTEM(I)=STEMP(I)
   50 CONTINUE
      DO 60 I=1,KK
   60 SOILTE(I)= STEMP(I)
      RETURN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      ENTRY INOMDG
      READ(LEC,2222) (CHECK(I),I=1,20)
      WRITE(IMP,2223) (CHECK(I),I=1,20)
 2222 FORMAT(20A4)
 2223 FORMAT(1X,20A4)
      KK=NHOR
C........READ,(NHOR  )*SOIL TEMPERATURES (DEGREE C.)
      READ(LEC,1)(BEGTEM(I),I=1,KK)
C........READ,(NHOR  )*SOIL HEAT CAPACITY(CAL/G)
      READ(LEC,1)(CV(I),I=1,KK)
C........READ,(NHOR+1)*SOIL THERMAL CONDUCTIVITY(CAL/CM-HR-DEG)
      READ(LEC,1)(CONDUC(I),I=1,KK)
      READ(LEC,1) DTIME
    1 FORMAT(6F10.0)
      RETURN
      END
```

## *Subroutine* DLIGHT

```
C***********************************************************************
      SUBROUTINE DLIGHT
C***********************************************************************
COMPUTE DAYLIGHT HOURS                                                 *
C***********************************************************************
      COMMON /CLIGHT/ DAYMIN(366),TOTMIN
      COMMON /DATUM/ IND,INM,INY,IDAY,JULDAY,ICD,ICM,ICY,IS,IBIS,JOURS,
     1                    NDAY,IPDAY
      COMMON /EXO/ DARAIN,TDAY,DAPHOT,DAYRAD,DALITE,TRAIN
        COMMON /INOU/ LEC,IMP,IPU
      COMMON /RCHECK/ CHECK(20)
      DALITE=DAYMIN(JULDAY)/TOTMIN
      DAPHOT=DAYMIN(JULDAY)/60.
      RETURN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      ENTRY INOMDL
      READ(LEC,2222) (CHECK(I),I=1,20)
      WRITE(IMP,2223) (CHECK(I),I=1,20)
 2222 FORMAT(20A4)
 2223 FORMAT(1X,20A4)
      READ(LEC,1) RLAT
      TOTMIN=0.
      DO 10 I=1,365
      C=I
      A=730.-0.274*RLAT+0.00793*(RLAT**2)
      B=34.2-0.78*RLAT+0.1*(RLAT**2)
      Z=2.0*3.1416*((C+285.0)/365.)
      DAYMIN(I)=A+B*SIN(Z)
   10 TOTMIN=TOTMIN+DAYMIN(I)
      DAYMIN(366)=DAYMIN(365)
      RETURN
    1 FORMAT(6F10.0)
      END
```

## *Subroutine* DMOM

```
C***********************************************************************
      SUBROUTINE DMOM
      COMMON /RCHECK/ CHECK(20)
      COMMON /DATUM/ IND,INM,INY,IDAY,JULDAY,ICD,ICM,ICY,IS,IBIS,JOURS ,
     1                    NDAY,IPDAY
      COMMON /INOU/ LEC,IMP,IPU
      COMMON /LITTER/ CLIT(10),DCLIT(10),NLIT
      COMMON /LITPAR/ RTLI(5,10,10)
C........PROVISIONAL VERSION TO COMPUTE THE VARIATIONS IN DEAD MATERIAL.
      DO 20 LD=1,NLIT
      DO 10 LR=1,NLIT
      IF(LD.EQ.LR) GO TO 10
      DELTA=CLIT(LD)*RTLI(IS,LD,LR)
      DCLIT(LD)=DCLIT(LD)-DELTA
      DCLIT(LR)=DCLIT(LR)+DELTA
   10 CONTINUE
   20 CONTINUE
      RETURN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      ENTRY INOMDM
      READ(LEC,2222) (CHECK(I),I=1,20)
      WRITE(IMP,2223) (CHECK(I),I=1,20)
 2222 FORMAT(20A4)
 2223 FORMAT(1X,20A4)
C........READ IN PARAMETERS FOR EACH SEASON.
      DO 30 K=1,4
      DO 30 LD=1,NLIT
   30 READ(LEC,1)(RTLI(K,LD,LR),LR=1,NLIT)
    1 FORMAT(6F10.0)
      RETURN
      END
```

## *Subroutine* DMDT

```
C***********************************************************************
      SUBROUTINE DMDT
      COMMON /DATUM/ IND,INM,INY,IDAY,JULDAY,ICD,ICM,ICY,IS,IBIS,JOURS,
     1                    NDAY,IPDAY
      COMMON /DEATH/WTIME(20),LREP(20,10),PODT1(20,10),PODT2(20,10),
     1                    PODT3(20,10),PDT(4,20,10)
      COMMON /INOU/ LEC,IMP,IPU
      COMMON /LITTER/ CLIT(10),DCLIT(10),NLIT
      COMMON /RCHECK/ CHECK(20)
      COMMON /VEG/ ISP,NSP,IANUAL,ISHRB,NOSEED,NOPHOT,
     1              NORG(20),LIF(20),IPHENO(20),IPHENN(20),IFUN(20,10),
     2              DMSP(20,10),DDMSP(20,10),DMT(20),DMNEW(20),PHSATE,
     3               NOGER,NOLO,NOVEG,NOFR,NODOR,TCOVER
      FUNEX(AE,BE,CE,XE)=AE+BE*EXP(CE*XE)
      IBID=NORG(ISP)
      IF(IPHENO(ISP).NE.NODOR) GO TO 100
C........THIS SECTION DEALS WITH THE DEATH OCCURING DURING THE
C            DORMANCY.
      IF(IPHENO(ISP).NE.IPHENN(ISP)) GO TO 10
      IF(IDAY.EQ.IPDAY) GO TO 11
      WTIME(ISP)= WTIME(ISP)+1.
      GO TO 11
   10 WTIME(ISP)=0.
   11 DO 15 J=1,IBID
      DRATE=FUNEX(PODT1(ISP,J),PODT2(ISP,J),PODT3(ISP,J),WTIME(ISP))
      D=DRATE*DMSP(ISP,J)
      DDMSP(ISP,J)=DDMSP(ISP,J)-D
```

```
      N=LREP(ISP,J)
      DCLIT(N)=DCLIT(N)+D
   15 CONTINUE
      RETURN
  100 CONTINUE
C........THIS SECTION DEALS WITH THE DEATH DURING ALL PHENOLOGICAL
C          STAGES,EXCEPT THE DORMANCY.
      K=IPHENO(ISP)
      DO 115 J=1,IBID
      D= POT(K,ISP,J)*DMSP(ISP,J)
      DDMSP(ISP,J)=DDMSP(ISP,J)-D
      N=LREP(ISP,J)
      DCLIT(N)=DCLIT(N)+D
  115 CONTINUE
      RETURN
C**********************************************************************
      ENTRY INDMOT
      READ(LEC,2222) (CHECK(I),I=1,20)
      WRITE(IMP,2223) (CHECK(I),I=1,20)
 2222 FORMAT(20A4)
 2223 FORMAT(1X,20A4)
      READ(LEC,1)(WTIME(I),I=1,NSP)
      DO 500 I=1,NSP
      IBID=NORG(I)
  500 READ(LEC,2)(LREP(I,J),J=1,IBID)
      DO 501 I=1,NSP
      IBID=NORG(I)
      DO 501 J=1,IBID
  501 READ(LEC,1) (PODT1(I,J),PODT2(I,J),PODT3(I,J)
      DO 503 K=1,4
      DO 502 I=1,NSP
      IBID=NORG(I)
  502 READ(LEC,1)(POT(K,I,J),J=1,IBID)
  503 CONTINUE
    1 FORMAT(6F10.0)
    2 FORMAT(12I5)
      RETURN
      END
```

## *Subroutine* DMEXO

```
C**********************************************************************
      SUBROUTINE DMEXO
C**********************************************************************
COMPUTE THE RAINFALL (DARAIN) & TEMPERATURE (TDAY) OF THE DAY 'IDAY'   *
C**********************************************************************
      COMMON /DATUM/ IND,INM,INY,IDAY,JULDAY,ICD,ICM,ICY,IS,IBIS,JOURS ,
     1                   NDAY,IPDAY
      COMMON /EXO/ DARAIN,TDAY,DAPHOT,DAYRAD ,DALITE,TRAIN
      COMMON /INOU/ LEC,IMP,IPU
      COMMON /RCHECK/ CHECK(20)
      COMMON /RT/ NDR,JDR(100),ARAIN(100),NDTC,JDTC(100),ARTE(100)
C........RAINFALL
      DARAIN=0.
      DO 30 I=1,NDR
      IF(IDAY.NE.JDR(I)) GO TO 30
      DARAIN=ARAIN(I)
      GO TO 31
   30 CONTINUE
C........TEMPERATURE
   31 DO 32 I=1,NDTC
      TDAY=ARTE(I)
      IF(I.EQ.NDTC) GO TO 33
      I1=I+1
      IF(IDAY.LT.JDTC(I1)) GO TO 33
   32 CONTINUE
   33 RETURN
C**********************************************************************
      ENTRY INDMEX
      READ(LEC,2222) (CHECK(I),I=1,20)
      WRITE(IMP,2223) (CHECK(I),I=1,20)
 2222 FORMAT(20A4)
 2223 FORMAT(1X,20A4)
C.....................................................................
C NDR            NUMBER OF DAYS WITH RAINFALL                          .
C NDTC           NUMBER OF DAYS WHOSE THE TEMPERATURF CHANGES.(INCLUDED .
C                THE INITIAL DAY)                                      .
C.....................................................................
      READ(LEC,1)NDR,NDTC
      DO 20 I=1,NDR
      READ(LEC,1)ID,IM,IY,P
      CALL INVDAT(IND,INM,INY,IDAT,ID,IM,IY)
      JDR(I)=IDAT
      ARAIN(I)=P
   20 CONTINUE
      DO 21 I=1,NDTC
      READ(LEC,1)ID,IM,IY,T
      CALL INVDAT(IND,INM,INY,IDAT,ID,IM,IY)
      JDTC(I)=IDAT
      ARTE(I)=T
   21 CONTINUE
      RETURN
    1 FORMAT( 3I5,F10.0)
      END
```

## *Subroutine* DMPHEN

```
C**********************************************************************
      SUBROUTINE DMPHEN
C         ........................................
C         .  DETERMINE THE PHENOLOGICAL STAGE   .
C         ........................................
      COMMON /DATUM/ IND,INM,INY,IDAY,JULDAY,ICD,ICM,ICY,IS,IBIS,JOURS,
     1                   NDAY,IPDAY
      COMMON /EXO/ DARAIN,TDAY,DAPHOT,DAYRAD,DALITE,TRAIN
      COMMON /INOU/ LEC,IMP,IPU
      COMMON /PHENO/ PARPH1(20),PARPH2(20),PARPH3(20),PARPH4(20),
     1               PARPH5(20),PARPH6(20),CRATLO(20),CRATFT(20),
     2               THTPVG(20),THWTVG(20),PHOVMN(20),PHOVMX(20),
     3               THRTVG(20),THTPVD(20),
     4               THWTVD(20),THRTVD(20),THTPLU(20),THWTLU(20),
     5               PHOTMN(20),PHOTMX(20),
     6               IPGERM(20),IPFRUT(20),NDGERM(20),NDFRUT(20),
     7               LCOUCH(10)
      COMMON /RCHECK/ CHECK(20)
      COMMON /SOIL/  WATER(10),SOILTE(10),      NHOR
      COMMON /VEG/ ISP,NSP,IANUAL,ISHRB,NOSEED,NOPHOT,
     1           NORG(20),LIF(20),IPHENO(20),IPHENN(20),IFUN(20,10),
     2           DMSP(20,10),DDMSP(20,10),DMT(20),DMNEW(20),PHSATE,
     3            NOGER,NOLO,NOVEG,NOFR,NODOR,TCOVER
       FUNX(AE,BE,CE,XE)=AE+BE*EXP(CE*XE)
      LSOIL=LCOUCH(ISP)
      IF(IDAY.EQ.IPDAY) GO TO 299
      IRAIN1=IRAIN2
      IRAIN2=IRAIN3
      IRAIN3=0
      IF(DARAIN.GT.0.0) IRAIN3=1
  299 ISTAGE=IPHENO(ISP)
      GO TO(300,300,500,700,900),ISTAGE
C.....................................................................
C........TEST FOR JUMP FROM GERMINATION (OR LEAFING-OUT) TO VEGETATIVE .
C          STAGE.                                                      .
C.....................................................................
  300 IF(IPHENO(ISP).NE.IPHENN(ISP)) GO TO 310
      IF(IDAY.LE.2) GO TO 310
      IF(IDAY.EQ.IPDAY) GO TO 315
      IPGERM(ISP)=IPGERM(ISP)+1
      IF(IRAIN1.EQ.1.OR.IRAIN2.EQ.1) GO TO 310
      GO TO 315
  310 CRATLO(ISP)=FUNX(PARPH1(ISP),PARPH2(ISP),PARPH3(ISP),WATER(LSOIL))
  315 IBID=NORG(ISP)
      DO 350 JORG=1,IBID
      IF(IFUN(ISP,JORG).EQ.NOSEED) GO TO 316
  350 CONTINUE
C........IF COMPARTMENT OF SEEDS NOT GIVEN  GO TO VEGETATIVE STAGE
      GO TO 330
C........IF  COMPARTMENT WITH SEEDS EMPTY, JUMP TO VEGETATIVE STAGE.
  316 IF(DMSP(ISP,JORG).EQ.0.0) GO TO 330
      IF(LIF(ISP).NE. IANUAL) GO TO 320
      X=DMT(ISP)/DMSP(ISP,JORG)
      GO TO 325
  320 X=DMNEW(ISP)/DMT(ISP)
  325 IF(X.GE.CRATLO(ISP)) GO TO 330
C........TEST FOR LIMITING  THE PERIODE OF GERMINATION.
      IF(IPGERM(ISP).LT.NDGERM(ISP)) GO TO 999
  330  IPHENO(ISP)=NOVEG
      DMNEW(ISP)=0.
      IPGERM(ISP)=0
      GO TO 999
C.....................................................................
C........TEST FOR JUMP FROM VEGETATIVE TO FRUITING STAGE.              .
C.....................................................................
  500 IF(SOILTE(LSOIL).LT.THTPVG(ISP)) GO TO 559
      IF(WATER(LSOIL).LT.THWTVG(ISP)) GO TO 559
      IF(DAPHOT.LT.PHOVMN(ISP).OR.DAPHOT.GT.PHOVMX(ISP)) GO TO 559
      IPHENO(ISP)=NOFR
      GO TO 700
C.....................................................................
C........TEST FOR JUMP FROM VEGETATIVE TO DORMANT STAGE.               .
C.....................................................................
  559 IF(WATER(LSOIL).GT.THWTVD(ISP)) GO TO 999
      IF(SOILTE(LSOIL).GT.THTPVD(ISP)) GO TO 999
      IPHENO(ISP)= NODOR
      DMNEW(ISP)=0.
      GO TO 999
C.....................................................................
C........TEST FOR RETURN FROM FRUITING TO VEGETATIVE  STAGE.           .
C.....................................................................
  700 IF(IPHENO(ISP).NE.IPHENN(ISP)) GO TO 710
      IPFRUT(ISP)=IPFRUT(ISP)+1
      IF(IRAIN1.EQ.1.OR.IRAIN2.EQ.1) GOTO 710
      GO TO 715
  710 CRATFT(ISP)=FUNX(PARPH4(ISP),PARPH5(ISP),PARPH6(ISP),WATER(LSOIL))
  715 X=DMNEW(ISP)/DMT(ISP)
      IF(X.GE.CRATFT(ISP)) GO TO 798
      IF(IPFRUT(ISP).LT.NDFRUT(ISP)) GO TO 999
C........TEST FOR LIMITING THE FRUITING STAGE.
  798 IPHENO(ISP)=NOVEG
      DMNEW(ISP)=0.0
      IPFRUT(ISP)=0
      GO TO 999
C.....................................................................
C........TEST FOR JUMP FROM DORMANT TO GERMINATION(  OR  LEAFING-OUT).  .
C.....................................................................
  900 IF(SOILTE(LSOIL).LT.THTPLO(ISP)) GO TO 999
      IF (WATER(LSOIL).LT.THWTLO(ISP)) GO TO 999
      IF(DAPHOT.LT.PHOTMN(ISP).OR.DAPHOT.GT.PHOTMX(ISP)) GO TO 999
      IF(LIF(ISP).EQ.IANUAL) GO TO 920
      IPHENO(ISP)=NOLO
      GO TO 950
  920 IPHENO(ISP)=NOGER
  950 DMNEW(ISP)=0.0
      GO TO 300
  999 IPHENN(ISP)=ISTAGE
      RETURN
C**********************************************************************
      ENTRY INDMPN
      READ(LEC,2222) (CHECK(I),I=1,20)
      WRITE(IMP,2223) (CHECK(I),I=1,20)
 2222 FORMAT(20A4)
 2223 FORMAT(1X,20A4)
      NOGER=1
      NOLO=2
      NOVEG=3
      NOFR=4
      NODOR=5
      IRAIN1=0
      IRAIN2=0
      IRAIN3=0
      READ(LEC,1) (IPHENO(I),I=1,NSP)
      DO 1002 I=1,NSP
 1002 IPHENN(I)=IPHENO(I)
      DO 1000 I=1,NSP
 1000 READ(LEC,1) NDGERM(I),NDFRUT(I),IPGERM(I),IPFRUT(I)
      READ(LEC,1)(LCOUCH(I),I=1,NSP)
      DO 1001 I=1,NSP
 1001 READ(LEC,2)    PARPH1(I),PARPH2(I),PARPH3(I),PARPH4(I),PARPH5(I),
     1               PARPH6(I),
     2    THTPVG(I),THWTVG(I),PHOVMN(I),PHOVMX(I),THRTVG(I),THTPVD(I),
     3    THWTVD(I),THRTVD(I),THTPLO(I),THWTLO(I),PHOTMN(I),PHOTMX(I)
      RETURN
    1 FORMAT(12I5)
    2 FORMAT(6F10.0)
      END
```

## *Subroutine* DMPHOT

```
C**********************************************************************
      SUBROUTINE DMPHOT
C             ........................................
C             .  COMPUTE A TOTAL DAYLY INCREMENT  .
C             ........................................
      COMMON /EXO/ DARAIN,TDAY,DAPHOT,DAYRAD,DALITE,TRAIN
      COMMON /INOU/ LEC,IMP,IPU
      COMMON /PHOTO/ KMLITE(20),CCPS(20),RRPS(20),TEMPOT(20),TEMPOM(20),
     1                 DUMMAX(20),WMIN(20),WMAX(20),LAYCH(20)
      COMMON /PROVIS/ PRLITE(20), PRTEMP(20),PRMOIS(20),PRFACT(20),
     1                 PRSATE(20)
      COMMON /RCHECK/ CHECK(20)
      COMMON /VEG/ ISP,NSP,IANUAL,ISHRB,NOSEED,NOPHOT,
     1              NORG(20),LIF(20),IPHENO(20),IPHENN(20),IFUN(20,10),
     2              DMSP(20,10),DDMSP(20,10),DMT(20),DMNEW(20),PHSATE,
     3               NOGER,NOLO,NOVEG,NOFR,NODOR,TCOVER
      COMMON /SOIL/  WATER(10),SOILTE(10),      NHOR
      REAL KMLITE,LIGHTF
C1 FUNSIG        SIGMOID ARITHMETIC STATEMENT FUNCTION.
      FUNSIG(ASY,CC,RR,VAL)=ASY/(1.+ASY*CC*EXP(-RR*VAL))
C1 FUNLIN        LINEAR  ARITHMETIC STATEMENT FUNCTION.
```

```
      FUNLIN(BIGMAG,SMAMAG,VALUE)=(BIGMAG-VALUE)/(BIGMAG-SMAMAG)
C1 TLEAF            TEMPERATURE OF THE LEAVES.
      TLEAF=TDAY
C.......................................................................
C........EFFECT OF SUNLIGHT.                                            .
C.......................................................................
      LIGHTF=DAYRAD/(KMLITE(ISP)+DAYRAD)
C.......................................................................
C........EFFECT OF TEMPERATURE.                                         .
C.......................................................................
      IF(TLEAF.GT.TEMPUM(ISP)) GO TO 30
      TEMPF=FUNSIG(1.0,CCPS(ISP),RRPS(ISP),TLEAF)
      GO TO 50
   30 TEMPF=FUNLIN(TEMPUT(ISP),TEMPUM(ISP),TLEAF)
   50 CONTINUE
C.......................................................................
C........EFFECT OF SOIL MOISTURE                                        .
C.......................................................................
      K=LAYCH(ISP)
      WHID= WATER(K)
      IF(WHID    .GT.WMAX(K)) GO TO 90
      IF(WHID    .LT.WMIN(K)) GO TO 91
      PHSF=(WHID     -WMIN(K))/(WMAX(K)-WMIN(K))
      GO TO 92
   90 PHSF=1.
      GO TO 92
   91 PHSF=0.
   92 CONTINUE
C........CALCULATE NET RATE.
      PSRATE=DUMMAX(ISP)*LIGHTF*TEMPF*PHSF
      PHSATE=0.
      IBID=NORG(ISP)
      DO 101 JORG=1,IBID
      IF(IFUN(ISP,JORG).NE.NOPHOT) GO TO 101
      PHSATE=PHSATE+   DMSP(ISP,JORG)*PSRATE
  101 CONTINUE
      PRLITE(ISP)=LIGHTF
      PRTEMP(ISP)=TEMPF
      PRMOIS(ISP)=PHSF
      PRFACT(ISP)= PSRATE
      IF(IPHENO(ISP).NE.NODOR) GO TO 998
      PHSATE(ISP)=0.0
      PHSATE=0.
      GO TO 999
  998 PRSATE(ISP)=PHSATE
  999 RETURN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      ENTRY INUMED
      READ(LEC,2222) (CHECK(I),I=1,20)
      WRITE(IMP,2223) (CHECK(I),I=1,20)
 2222 FORMAT(20A4)
 2223 FORMAT(1X,20A4)
      DO 1000 I=1,NSP
 1000 READ(LEC,1)KMLITE(I),CCPS(I),RRPS(I),TEMPUT(I),TEMPUM(I),DUMMAX(I)
     1              ,WMIN(I),WMAX(I)
      READ(LEC,2)(LAYCH(I),I=1,NSP)
    1 FORMAT(6F10.0)
    2 FORMAT(12I5)
      RETURN
      END
```

## *Subroutine* DMTR

```
C***********************************************************************
      SUBROUTINE DMTR
C         .....................................
C         .  TRANSLOCATION BETWEEN ORGANS     .
C         .....................................
      COMMON /INOU/ LEC,IMP,IPU
      COMMON /RCHECK/ CHECK(20)
      COMMON /TRANS/ RTPH(20,10),RTGR(20,10,10),RTLD(20,10,10),
     1               RTVG(20,10,10),RTFR(20,10,10),TRMAT(10,10)
      COMMON /VEG/ ISP,NSP,IANUAL,ISHRB,NOSEED,NOPHOT,
     1            NORG(20),LIF(20),IPHENO(20),IPHENN(20),IFUN(20,10),
     2            DMSP(20,10),DDMSP(20,10),DMT(20),DMNEW(20),PHSATE,
     3             NOGER,NOLO,NOVEG,NOFR,NODOR,ICOVER
      IBID=NORG(ISP)
      DO 100 J=1,IBID
  100 DDMSP(ISP,J)=0.
C.......................................................................
C........ALLOCATES THE DAILY INCREMENT OF DRY MATTER, IF GREATER THAN   .
C         0.0,  TO PHOTOSYNTHETICS ORGANS.                              .
C.......................................................................
      IF (PHSATE.EQ.0.0) GO TO 120
      IF(IPHENO(ISP).EQ.NOGER) GO TO 60
      IF(IPHENO(ISP).EQ.NOLO) GO TO 60
      GO TO 61
   60 IF(IPHENO(ISP).NE.IPHENN(ISP)) DMNEW(ISP) =0.
      DMNEW(ISP)=DMNEW(ISP)+PHSATE
   61 DO 110 JORG=1,IBID
      IF(IFUN(ISP,JORG).NE.NOPHOT) GO TO 110
      DDMSP(ISP,JORG)=PHSATE*   RTPH(ISP,JORG)
  110 CONTINUE
  120 ISTAGE=IPHENO(ISP)
      GO TO(10,20,30,40,1000),ISTAGE
C.......................................................................
C........THE TRANSLOCATION IS ASSUMED TO BE PROPORTIONAL TO THE AMOUNT  .
C         OF MATERIAL PRESENT IN THE DONOR COMPARTMENT AT THE BEGINNING .
C         OF THE DAY (OR  TIME-LOOP).                                   .
C.......................................................................
C........GERMINATION
   10 DO 11 JR=1,IBID
      DO 11 JD=1,IBID
   11 TRMAT(JD,JR)=RTGR(ISP,JD,JR)
      GO TO 50
C........LEAFING-OUT
   20 DO 21 JR=1,IBID
      DO 21 JD=1,IBID
   21 TRMAT(JD,JR)=RTLD(ISP,JD,JR)
      GO TO 50
C........VEGETATIVE STAGE
   30 DO 31 JR=1,IBID
      DO 31 JD=1,IBID
   31 TRMAT(JD,JR)=RTVG(ISP,JD,JR)
      GO TO 50
C........FRUITING STAGE
   40 DO 41 JR=1,IBID
      DO 41 JD=1,IBID
   41 TRMAT(JD,JR)=RTFR(ISP,JD,JR)
      GO TO 50
C.......................................................................
C........CALCULE THE AMOUNT OF TRANSFERRED MATTER BETWEEN THE DONOR     .
C         COMPARTMENT (JDORG) AND THE RECEPTOR COMPARTMENT (JRORG).     .
C.......................................................................
   50 DO 52 JRORG=1,IBID
      DO 51 JDORG=1,IBID
      IF(JRORG.EQ.JDORG) GO TO 51
      TRLC=DMSP(ISP,JDORG)*TRMAT(JDORG,JRORG)
      DDMSP(ISP,JDORG)=DDMSP(ISP,JDORG)-TRLC
      DDMSP(ISP,JRORG)=DDMSP(ISP,JRORG)+TRLC
      IF(IPHENO(ISP).NE.NOFR) GO TO 51
      IF(IPHENO(ISP).NE.IPHENN(ISP)) DMNEW(ISP)=0.
      DMNEW(ISP)= DMNEW(ISP)+TRLC
   51 CONTINUE
   52 CONTINUE
 1000 RETURN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      ENTRY INDMTR
      READ(LEC,2222) (CHECK(I),I=1,20)
      WRITE(IMP,2223) (CHECK(I),I=1,20)
 2222 FORMAT(20A4)
 2223 FORMAT(1X,20A4)
      DO 1003 I=1,NSP
      IBID=NORG(I)
      READ(LEC,9) (RTPH(I,J    ),J =1,IBID)
 1003 CONTINUE
      DO 1010 K=1,4
      DO 1009 I=1,NSP
      IBID=NORG(I)
      DO 1008 JD=1,IBID
      GO TO (1,2,3,4),K
    1 READ(LEC,9) (RTGR(I,JD,JR),JR=1,IBID)
      GO TO 1008
    2 READ(LEC,9) (RTLD(I,JD,JR),JR=1,IBID)
      GO TO 1008
    3 READ(LEC,9) (RTVG(I,JD,JR),JR=1,IBID)
      GO TO 1008
    4 READ(LEC,9) (RTFR(I,JD,JR),JR=1,IBID)
 1008 CONTINUE
 1009 CONTINUE
 1010 CONTINUE
      RETURN
    9 FORMAT(6F10.0)
      END
```

## *Subroutine* EDAPH

```
C***********************************************************************
      SUBROUTINE EDAPH
C       ..........................................................
C       .  THIS SUBROUTINE DEALS  WITH THE SOIL PROCESSES  .
C       ..........................................................
      COMMON /CLIGHT/ DAYMIN(366),TOTMIN
      COMMON /DATUM/ IND,INM,INY,IDAY,JULDAY,ICD,ICM,ICY,IS,IBIS,JOURS,
     1               NDAY,IPDAY
      COMMON /EDAFUN/  DD(11),DTIME
      COMMON /ERAIN/ IERAIN,FORCE
      COMMON /EVTP/ ET,EVAP,FACTOR(4),FARTOF(4),NT
      COMMON /EXO/ DARAIN,IDAY,DAPHOT,DAYRAD,DALITE,TRAIN
      COMMON /GRADE/ STEMP(11),CV(11),CONDUC(11),REGTEM(11)
      COMMON /INOU/ LEC,IMP,IPU
      COMMON /RCHECK/ CHECK(20)
      COMMON /SOIL/  WATER(10),SOILTE(10),      NHOR
      COMMON /VEG/ FANTOM(732),TCOVER
      COMMON /WAT/ WATABS(10),RUNOF,    SALNTY(10),EOR,ETIME,ETOUT,
     1            HROUT
      COMMON /TORO/ ALAMBA,CB    ,COND  ,CONT  ,DETT  ,DELW  ,
     1              DELX  ,DIFA  ,DIFB  ,DIFD  ,
     2              HDRY  ,HWET  ,HLOW  ,HMI   ,RRES  ,SOCON ,
     3              SOURCE,TAA   ,TIME  ,TT,ND ,WFOD  ,LL,MM ,DELT  ,NB,
     4              TM    ,TDB   ,PIT   ,SMAX  ,CWFLX ,N,K,KK,KCK   ,
     5              D(60),P(60),T(60),
     6              C(11),G(11),H(11),ROF(11),SD(11),SE(11),SS(11),
     7          W(11),WATH(11),WATL(11),Y(11),A(11),B(11),E(11),F(11),
     8              IWRITE
      LOGICAL IWRITE
      DIMENSION DEPTH(10)
C........COMPUTE THE NUMBER OF HOURS 'TRAIN' WITH RAIN FOR THE CURRENT
C           DAY.
      TRAIN=DARAIN/FORCE
      IF(TRAIN.GT.24.) TRAIN=24.
      RUNOF=0.
      CALL DEGREE
      IERAIN=0
      CALL EVAPO
      EOR=EVAP
      HRAIN=TRAIN
      REPET=0.
      IF(TRAIN.LE.0.0) GO TO 60
   20 IF (HRAIN.LE.0.0) GO TO 50
      ETIME=AMIN1(1.,HRAIN)
      REPET=REPET+ETIME
      HRAIN=AMAX1(0.,HRAIN-1.)
      CALL SOWAT
      ETOUT=0.
      GO TO 20
   50 ETIME=24.-REPET
      IF(ETIME.LE.0.0) GO TO 62
      CALL EVAPO
      EOR=EVAP
      GO TO 61
   60 ETIME=24.
   61 CALL SOWAT
   62 CONTINUE
 1000 CONTINUE
      RETURN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      ENTRY INUMED
      READ(LEC,2222) (CHECK(I),I=1,20)
      WRITE(IMP,2223) (CHECK(I),I=1,20)
 2222 FORMAT(20A4)
 2223 FORMAT(1X,20A4)
C1 FORCE            RAINFALL INTENSITY (MM/HOUR).
      READ(LEC,1) FORCE
C........READ THE DEPTH OF THE BOTTOM OF EACH HORIZON.
      READ(LEC,1)(DEPTH(I),I=1,NHOR)
C........THE FIRST HORIZON (VERY SMALL) IS A THEORETICAL  LAYER FOR
C          THE INTERFACE SOIL-ATMOSPHERE. THE 'DEPTH' OF THE BOTTOM OF
C          EACH HORIZON IS CONVERTED IN DEPTH, DD(I),COMPATIBLE WITH THE
C          'SOWAT' SUBROUTINE WHICH ASSUMES THAT THE BOTTOM OF AN HORIZON
C          I IS HALF-WAY  BETWEEN DD(I) AND DD(I+1). (IF   IT IS NECESSARY
C          ADD AN EXTRA HORIZON BELOW THE TRUE HORIZONS TO FIT WITH SOWAT.
      NHOR1 =NHOR-1
      DD(1)=0.
      DO 500 I=2,NHOR1
  500 DD(I)=(DEPTH(I-1)-DD(I-1))*2.+DD(I-1)
      DD(NHOR)=DEPTH(NHOR)
      RETURN
    1 FORMAT(6F10.0)
      END
```

## *Subroutine* EVAPO

```
C***********************************************************************
      SUBROUTINE EVAPO
      COMMON /ERAIN/ IERAIN,FORCE
      COMMON /EVTP/ ET,EVAP,FACTOR(4),FARTOF(4),NT
      COMMON /EXO/ DARAIN,IDAY,DAPHOT,DAYRAD,DALITE,TRAIN
      COMMON /INOU/ LEC,IMP,IPU
      COMMON /RCHECK/ CHECK(20)
      COMMON /VEG/ ISP,NSP,IANUAL,ISHRB,NOSEED,NOPHOT,
     1            NORG(20),LIF(20),IPHENO(20),IPHENN(20),IFUN(20,10),
     2            DMSP(20,10),DDMSP(20,10),DMT(20),DMNEW(20),PHSATE,
     3             NOGER,NOLO,NOVEG,NOFR,NODOR,ICOVER
C........DARAIC=RAIN IN CM
      DARAIC=DARAIN/10.
```

```
      IF(DARAIC.LE.0.0) GO TO 21
C.........TEST IF THE RAIN IS FINISHED FOR THE CURRENT DAY.
      IF(IERAIN.EQ.1) GO TO 21
      GO TO 20
   21 IERAIN=0
      DO 10 I=1,NT
      J=I
      IF(TDAY.LT.TARTUF(I)) GO TO 15
   10 CONTINUE
   15 TEMP=(1.8*TDAY)+32.
      ET=-(DALITE*TEMP*FACTOR(J))*2.54/24.
      EVAP= ET*(1.-TCOVER)
      RETURN
C.........IF RAIN OCCURS
   20 ET=0.
C.........'EVAP' FOR 1 HOUR= INTENSITY OF THE RAIN.(CM)
      EVAP=DARAIC/TRAIN
      IERAIN=1
      RETURN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      ENTRY INOMEV
      READ(LEC,2222) (CHECK(I),I=1,20)
      WRITE(IMP,2223) (CHECK(I),I=1,20)
 2222 FORMAT(20A4)
 2223 FORMAT(1X,20A4)
C1 TARTUF(I)      IN DEGREE C.-(NT-1) THRESHOLDS USED TO CALCULATE EVAP
C2 TARTUF         AND ET.
      READ(LEC,1) NT
      NT1=NT-1
      READ(LEC,2)(TARTUF(I),I=1,NT1)
      TARTUF(NT)=TARTUF(NT1)
      READ(LEC,2)(FACTOR(I),I=1,NT)
      RETURN
    1 FORMAT(12I5)
    2 FORMAT(8F10.0)
      END
```

## *Subroutine* FILLTX

```
C*********************************************************************
      SUBROUTINE FILLTX
C.....................................................................
C        THIS SUBROUTINE DEALS WITH THE STORAGE OF THE STATE VARIABLES.
C.....................................................................
      COMMON /DATUM/ IND,INM,INY,IDAY,JULDAY,ICD,ICM,ICY,IS,IBIS,JOURS,
     1               NDAY,IPDAY
      COMMON /EXO/ DARAIN,TDAY,DAPHOT,DAYRAD,DALITE,TRAIN
      COMMON /FILL/ TX(50,100)
      COMMON /INOU/ LEC,IMP,IPU
      COMMON /KAS/ K1,K2,K3,K4,K5,K6,K7,K8,K9,K10,K11,K12,K13,K14,K15
      COMMON /LITTER/ CLIT(10),DCLIT(10),NLIT
      COMMON /RCHECK/ CHECK(20)
      COMMON /SOIL/  WATER(10),SOILTE(10),      NHOR
      COMMON /VEG/ ISP,NSP,IANUAL,ISHRB,NOSEED,NOPHOT,
     1            NORG(20),LIF(20),IPHENO(20),IPHENN(20),IFUN(20,10),
     2            DMSP(20,10),DDMSP(20,10),DMT(20),DMNEW(20),PHSATE,
     3             NOGER,NOLO,NOVEG,NOFR,NODOR,TCOVER
      COMMON /WAT/ WATABS(10),RUNOF,    SALNTY(10),COR,ETIME,ETOUT,
     1             HROUT
C.........TEST IF THE FIRST DAY
      IF (IDAY.EQ.1) GO TO 20
      IF(NDAY.LE.100) GO TO 22
      FIDAY=IDAY
      FNDAY=NDAY
      FIABS=FIDAY/(FNDAY/100.)
      IABS=FIABS
      IF(IABS.GT.100) IABS=100
      GO TO 19
   22 IABS=IDAY
   19 IF(IABS.LT.2) RETURN
      GO TO 21
   20 IABS=1
   21 K=0
C.........DRY MATTER FOR EACH SPECIES
      DO 23 I=1,NSP
      K=K+1
   23 TX(K,IABS)=DMT(I)
      K1=K
C.........DRY MATTER  FOR EACH ORGAN OF EACH SPECIES
      DO 26 I=1,NSP
      IBID=NORG(I)
      DO 26 J=1,IBID
      K=K+1
   26 TX(K,IABS)=DMSP(I,J)
      K2=K
C.........DEAD MATERIAL
      DO 24 I=1,NLIT
      K=K+1
   24 TX(K,IABS)=CLIT(I)
      K3=K
C.........WATER
      DO 25 I=1,NHOR
      K=K+1
   25 TX(K,IABS)=WATER(I)
      K4=K
C.........SOIL TEMPERATURE
      DO 27 I=1,NHOR
      K=K+1
   27 TX(K,IABS)=SOILTE(I)
      K5=K
C.........RAIN
      K=K+1
      TX(K,IABS)=DARAIN
      K6=K
C.........TEMPERATURE(AIR)
      K=K+1
      TX(K,IABS)=     TDAY
      K7=K
C.........PHENOLOGY
      DO 28 I=1,NSP
      K=K+1
   28 TX(K,IABS)=IPHENO(I)
      K8=K
C.........WATABS
      DO 29 I=1,NHOR
      K=K+1
   29 TX(K,IABS)=WATABS(I)
      RETURN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      ENTRY INFILL
      READ(LEC,2222) (CHECK(I),I=1,20)
      WRITE(IMP,2223) (CHECK(I),I=1,20)
 2222 FORMAT(20A4)
 2223 FORMAT(1X,20A4)
C.........TO CLEAR THE STORAGE ARRAY.
      DO 100 I=1,50
      DO 100 J=1,100
  100 TX(I,J)=0.
      RETURN
      END
```

## *Subroutine* INVDAT

```
C*********************************************************************
      SUBROUTINE INVDAT (IND,INM ,INY,IDAY,ICD,ICM,ICY)
C---------------------------------------------------------------------
C   COMPUTE THE CURRENT DAY(IDAY) WITH THE DATE(ICD,ICM,ICY)          I
C---------------------------------------------------------------------
C.........IBIS=DUMMY VARIABLE
C.........IND =INITIAL DAY     (INPUT)
C.........INM =   *    MONTH  (INPUT)
C.........INY =   *    YEAR   (INPUT)
C.........IDAY=CURRENT DAY, COUNTING FROM THE INITIAL DAY(INCLUDED)OUTPUT
C.........ICD=THE DATE  WITHIN THE CURRENT MONTH(INPUT)
C..........ICM=THE MONTH WITHIN THE CURRENT YEAR(INPUT)
C.........ICY= THE      CURRENT YEAR(INPUT)
      IF(INY.LT.1900) INY=INY+1900
      ID=IND
      IM=INM
      IY=INY
      IDAY=1
   11 IF(ID.NE.ICD) GO TO 10
      IF(IM.NE.ICM) GO TO 10
      IF(IY.NE.ICY) GO TO 10
      RETURN
   10 IDAY=IDAY+1
      ID=ID+1
      CALL NJMOIS(IM,IY,NJ,IBIS)
      IF(ID.LE.NJ) GO TO 11
      IM=IM+1
      ID=1
      IF(IM.LE.12) GO TO 11
      IY=IY+1
      IM=1
      ID=1
      GO TO 11
      END
```

## *Subroutine* JULES

```
C*********************************************************************
      SUBROUTINE JULES
C*********************************************************************
COMPUTE THE 'JULIAN DAY'  FOR THE CURRENT DAY 'IDAY'.                *
C*********************************************************************
      COMMON /DATUM/ IND,INM,INY,IDAY,JULDAY,ICD,ICM,ICY,IS,IBIS,JOURS ,
     1               NDAY
      JULDAT=0
      M=ICM-1
      DO 10  I=1,M
      CALL NJMOIS(I,ICY,JOURS,IBIS)
   10 JULDAT=JULDAT+JOURS
      JULDAT=JULDAT+ICD
      RETURN
      END
```

## *Subroutine* NJMOIS

```
C*********************************************************************
      SUBROUTINE NJMOIS(MOIS,IAN,JOURS,IBIS)
C......... CALCULE LE NOMBRE DE JOURS DU MOIS=IEME MOIS DE L' ANNEE IAN.
      DIMENSION NJOUR(12)
      DATA NJOUR/31,0,31,30,31,30,31,31,30,31,30,31/
      IBIS=0
      JOURS=NJOUR(MOIS)
      IF(JOURS)101,101,102
  101 AN=IAN
      X=AMOD(AN,4.)
      IF(X)104,104,103
  104 JOURS=29
      IBIS=1
      GO TO 102
  103 JOURS=28
  102 RETURN
C.........IBIS=1,FEBRUARY IS 29 DAYS.   IBIS=0 IN OTHER CASE.
      END
```

## *Subroutine* PLOT

```
C*********************************************************************
      SUBROUTINE  PLOT(XMAX,XMIN,NV,IND,XPAS,KOPT,KCHOIM,KSUP)
C XXXXXX WARNING... IN 'PLOT', 'IND' IS NOT THE DAY OF THE INITIAL DATE.
      COMMON /INOU/ LEC,IMP,IPU
      COMMON /DIAGR/ TVEC(10,100),LEG(10,11)
      COMMON /HEAD/ TITRE(20)
      DIMENSION     GRAPH(53,103),Y(30),SYMBOL(30),XVAL(6)
      DIMENSION TABEL(4,10)
C......... KOPT= 1,PAS DE GRAPHIQUE,
C.........    * = 2, UN GRAPHIQUE GENERAL,DANS CE CAS KCHOIM=2.
C.........    * = 3, UN GRAPHIQUE PAR VARIABLE,
C.........    * = 4, UN GRAPHIQUE PAR VARIABLE $ UN GENERAL.
C......... KCHOIM= 1, MAX. ET MIN. POUR CHAQUE GRAPHIQUE.
C.........  *     = 2, MEME MAX. ET MIN. POUR TOUS LES GRAPHIQUES.
C1 KSUP            WRITE THE SUPERPOSED SYMBOLS IN DIAGRAMS(=0 NOT)
      DATA YAXIS/'I'/
      DATA SYMBOL/'A','B','C','D','E','F','G','H','I','J','K','L','M',
     1'N','O','P','Q','R','S','T','U','V','W','X','Y','Z','+','-','*',
     2'.'/
      YMAX=TVEC(1,1)
      YMIN=TVEC(1,1)
      DO 120 K=1,IND
      DO 120 I=1,NV
      YMAX=AMAX1(TVEC(I,K),YMAX)
  120 YMIN=AMIN1(TVEC(I,K),YMIN)
      IV=0
C     BLANK THE GRAPH
  209 BLANC=' '
      DO 30 I=1,53
      DO 30 J=1,103
   30 GRAPH(I,J)=' '
C     SET UP Y-AXIS
      DO 50 I=2,52
      IF (MOD(I-2,5) .EQ. 0) GO TO 40
      GRAPH(I,1)=YAXIS
      GRAPH(I,103)=YAXIS
      GO TO 50
   40 GRAPH(I,1)='+'
      GRAPH(I,103)='+'
   50 CONTINUE
C     SET UP X-AXIS
```

```
      DO 70 J=2,102
      IF (MOD(J-2,10) .EQ. 0) GO TO 60
      GRAPH(1,J)='-'
      GRAPH(53,J)='-'
      GO TO 70
   60 GRAPH(1,J)='+'
      GRAPH(53,J)='+'
   70 CONTINUE
      XDIV=(XMAX-XMIN)/100.0
      YDIV=(YMAX-YMIN)/50.0
      GO TO (208,221,220,220),KOPT
  220 IV=IV+1
      GO TO(41,42),KCHOIM
   41 YMINS=TVEC(IV,1)
      YMAXS=TVEC(IV,1)
      DO 43 KYM=1,IND
      YMAXS=AMAX1(TVEC(IV,KYM),YMAXS)
   43 YMINS=AMIN1(TVEC(IV,KYM),YMINS)
      YDIVS=(YMAXS-YMINS)/50.
      YMIP=YMINS
      YDIVP=YDIVS
      GO TO 47
   42 YDIVP=YDIV
      YMIP=YMIN
   47 DO 205 K=1,IND
      Y(1)=TVEC(IV,K)
      X=K
      X=X*XPAS
      J=2.5+(X-XMIN)/XDIV
      I=52-(Y(1)-YMIP)/YDIVP
      IF(GRAPH(I,J)-BLANC)210,211,210
  210 WRITE(IMP,2)K2    ,X,GRAPH(I,J),SYMBOL(IV)
    2 FORMAT(1X,I4,F8.0,10X,A1,'=',A1)
  211 CONTINUE
  205 GRAPH(I,J)=SYMBOL(IV)
      GO TO 207
  221 IF(KSUP.EQ.0) GO TO 225
      WRITE(IMP,3)
    3 FORMAT('1','SYMBOLES SUPERPOSES DANS LE GRAPHIQUE SUIVANT(A=ANCIEN
     1,N=NOUVEAU)'/1X,10('PAS JOUR A=N*'))
      ICOUNT=0
      DO 236 KLM=1,10
      DO 236 MLK=1,4
  236 TABEL(MLK,KLM) =' '
  225 DO 202 K=1,IND
      X=K
      X=X*XPAS
      DO 203 I=1,NV
  203 Y(I)=TVEC(I,K)
      J=2.5+(X-XMIN)/XDIV
      DO 204 L=1,NV
      I=52-(Y(L)-YMIN)/YDIV
      IF(KSUP.EQ.0) GO TO 213
      IF(GRAPH(I,J)-BLANC)212,213,212
  212 ICOUNT=ICOUNT+1
      TABEL(1,ICOUNT)=K
      TABEL(2,ICOUNT)=X
      TABEL(3,ICOUNT)=GRAPH(I,J)
      TABEL(4,ICOUNT)=SYMBOL(L)
      IF(ICOUNT-10) 213,231,231
  231 WRITE(IMP,233)((TABEL(1,KLM),TABEL(2,KLM),TABEL(3,KLM),TABEL(4,KLM
     1)),KLM=1,ICOUNT)
  233 FORMAT(1X,10(I3,F5.0,1X,A1,'='A1'*'))
      ICOUNT=0
      DO 235 KLM=1,10
      DO 235 MLK=1,4
  235 TABEL(MLK,KLM) =' '
  213 CONTINUE
  204 GRAPH(I,J)=SYMBOL(L)
  202 CONTINUE
      IF(ICOUNT)237,238,237
  237 WRITE(IMP,233)((TABEL(1,KLM),TABEL(2,KLM),TABEL(3,KLM),TABEL(4,KLM
     1)),KLM=1,ICOUNT)
  238 CONTINUE
C     PRINT THE GRAPH
  207 WRITE(IMP,90) (TITRE(ITI),ITI=1,20)
   90 FORMAT('1',20A4)
      GO TO(44,45),KCHOIM
   44 YMIM=YMINS
      YDIM=YDIVS
      GO TO 46
   45 YMIM=YMIN
      YDIM=YDIV
   46 CONTINUE
  140 DO 150 K=1,6
  150 XVAL(K) = XMIN+(K-1)*20.0*XDIV
      WRITE(6,160)XVAL
  160 FORMAT(7X,6(E10.3,10X))
      DO 190 I=1,53
      WRITE(6,170)(GRAPH(I,J),J=1,103)
  170 FORMAT(12X,103A1)
      IF (MOD(I-2,10) .NE. 0) GO TO 190
      H=YMIM+YDIM*(52-I)
      WRITE(6,180)H,H
  180 FORMAT('+',1X,E9.3,104X,E10.3)
  190 CONTINUE
      WRITE(6,160)XVAL
      DO 175 IRS=1,NV
  175 WRITE(IMP,176) SYMBOL(IRS),(LEG(IRS,ITS),ITS=1,11)
  176 FORMAT(1X,A1,2X,11A4)
      WRITE(IMP,177) XDIV,YDIM
  177 FORMAT(' 1 COLONNE EN ABSCISSE='E10.3,'  1 LIGNE EN ORD.=' E10.3)
      GO TO(208,208,222,222),KOPT
  222 IF(IV-NV)209,219,208
  219 IV=IV+1
      GO TO(208,208,208,221),KOPT
  208 RETURN
      END
```

## *Subroutine* PREPAR

```
C***********************************************************************
      SUBROUTINE PREPAR
C.......................................................................
C          PREPARE THE DATA FOR PLOT                                   .
C.......................................................................
C........MAXIMUM...30 VARIABLES FOR 1 DIAGRAMM.                        .
C........IGEN=0, TO INDICATE THE END OF THE LIST OF THE VARIABLES FOR  .
C                 THE CURRENT DIAGRAM. (=1 EMPTY CARD AFTER THE GROUP  .
C                OF VARIABLES FOR 1 DIAGRAMM. )                        .
C........IGEN=1, THE STATE VARIABLE REQUIRED IS THE TOTAL DRY MATTER   .
C                 FOR THE SPECIES 'IND1'.                              .
C........IGEN=2, THE STATE VARIABLE REQUIRED IS THE DRY MATTER FOR THE .
C                 SPECIES 'IND1' AND THE ORGAN 'IND2'.                 .
C........IGEN=3, THE STATE VARIABLE REQUIRED IS THE DRY MATTER FOR THE .
C                 'IND1' CATEGORY OF DEAD MATERIAL.                    .
C........IGEN=4, THE       VARIABLE REQUIRED IS THE WATER IN HORIZON   .
C                 'IND1'.                                              .
C........IGEN=5, THE       VARIABLE REQUIRED IS THE SOIL TEMPERATURE IN.
C                HORIZON 'IND1'.                                       .
C........IGEN=6, THE       VARIABLE REQUIRED IS THE RAIN FOR THE DAY.  .
C........IGEN=7, THE       VARIABLE REQUIRED IS THE DAILY TEMPERATURE. .
C........IGEN=8, THE       VARIABLE REQUIRED IS THE PHENOLOGICAL STAGE .
C                OF THE SPECIES 'IND1'.                                .
C........IGEN=9, THE       VARIABLE REQUIRED IS THE AMOUNT(MM) OF      .
C                 TOTAL WATER IN THE HORIZON 'IND1'.                   .
C........IGEN GREATER THAN 99, NO OTHER DIAGRAM REQUIRED.              .
C........LEG(NV,I) NAME OF THE VARIABLES (COL. 16 TO 59).              .
C.......................................................................
      COMMON /DATUM/ IND,INM,INY,IDAY,JULDAY,ICD,ICM,ICY,IS,IBIS,JOURS,
     1               NDAY,IPDAY
      COMMON /DIAGR/ TV(10,100),LEG(10,11)
      COMMON /FILL/ TX(50,100)
      COMMON /INOU/ LEC,IMP,IPU
      COMMON /KAS/ K1,K2,K3,K4,K5,K6,K7,K8,K9,K10,K11,K12,K13,K14,K15
      COMMON /LITTER/ CLIT(10),DCLIT(10),NLIT
      COMMON /RCHECK/ CHECK(20)
      COMMON /SOIL/  WATER(10),SOILTE(10),       NHOR
      COMMON /VEG/ ISP,NSP,IANUAL,ISHRB,NOSEED,NOPHOT,
     1             NORG(20),LIF(20),IPHENO(20),IPHENN(20),IFUN(20,10),
     2             DMSP(20,10),DDMSP(20,10),DMT(20),DMNEW(20),PHSATE,
     3              NOGER,NOLO,NOVEG,NOFR,NODOR,TCOVER
      READ(LEC,2222) (CHECK(I),I=1,20)
      WRITE(IMP,2223) (CHECK(I),I=1,20)
 2222 FORMAT(20A4)
 2223 FORMAT(1X,20A4)
      READ(LEC,1) KSUP
    9 NV=0
   10 NV=NV+1
      IF(NV.LE.30) GO TO 12
      NV=30
      READ(LEC,1) IGEN
      IF(IGEN.EQ.0) GO TO 500
      GO TO 10
   12 READ(LEC,1)IGEN,IND1,IND2,( LEG(NV,I),I=1,11)
      IF(IGEN.GT.99) GO TO 1000
      IF(IGEN.EQ.0) GO TO 500
      GO TO(21,22,23,24,25,26,27,28,29),IGEN
C........TOTAL DRY MATTER FOR EACH SPECIES
   21 KT=IND1
      GO TO 400
C........DRY MATTER FOR ORGANS
   22 KT=K1
      IF(IND1.LE.1)GO TO 102
      IND1=IND1-1
      DO 101 I=1,IND1
      IBID=NORG(I)
  101 KT=NORG(I)+KT
  102 KT=KT+IND2
      GO TO 400
C........DEAD MATERIAL
   23 KT=K2+IND1
      GO TO 400
C........WATER IN SOIL.
   24 KT=K3+IND1
      GO TO 400
C........SOIL TEMPERATURE.
   25 KT=K4+IND1
      GO TO 400
C........RAIN
   26 KT=K5+1
      GO TO 400
C........DAILY TEMPERATURE.
   27 KT=K6+1
      GO TO 400
C........PHENOLOGY.
   28 KT=K7+IND1
      GO TO 400
C........WATABS
   29 KT =K8+IND1
C........FILL THE ARRAY 'TV' WHICH IS CALLED BY 'PLOT', FOR EACH
C            DIAGRAMM.
  400 LATV=MIN0(100,NDAY)
      DO 401 K=1,LATV
  401 TV(NV,K)= TX(KT,K)
      GO TO 10
  500 NV=NV-1
      KOPT=2
      KCHOIM=2
      FNDAY=NDAY
      XPAS=1.
      IF(NDAY.GT.100) XPAS=FNDAY/100.
      XMIN=1.
      XMAX=NDAY
      CALL        PLOT(XMAX,XMIN,NV,LATV,XPAS,KOPT,KCHOIM,KSUP)
      GO TO 9
 1000 RETURN
    1 FORMAT(3I5,11A4)
      END
```

## *Subroutine* REPORT

```
C***********************************************************************
      SUBROUTINE REPORT
C                   ........................................
C                   .         WRITE REPORT IF NECESSARY      .
C                   ........................................
      COMMON /DATUM/ IND,INM,INY,IDAY,JULDAY,ICD,ICM,ICY,IS,IBIS,JOURS,
     1               NDAY,IPDAY
      COMMON /EDAFON/  DD(11),DTIME
      COMMON /EVTP/ ET,EVAP,FACTOR(4),FARTOF(4),NT
      COMMON /EXO/ DARAIN,TDAY,DAPHOT,DAYRAD,DALITE,TRAIN
      COMMON /HEAD/ STATE(20)
      COMMON /INOU/ LEC,IMP,IPU
      COMMON /LITTER/ CLIT(10),DCLIT(10),NLIT
      COMMON /NAME/ NAMSP(20),NAMORG(20,10),NAMLIT(10)
      COMMON /PROVIS/ PRLITE(20), PRTEMP(20),PRMOIS(20),PRFACT(20),
     1                 PRSATE(20)
      COMMON /RCHECK/ CHECK(20)
      COMMON /REP/ IDATR(20),NREP ,IREP
      COMMON /SOIL/  WATER(10),SOILTE(10),       NHOR
      COMMON /VEG/ ISP,NSP,IANUAL,ISHRB,NOSEED,NOPHOT,
     1             NORG(20),LIF(20),IPHENO(20),IPHENN(20),IFUN(20,10),
     2             DMSP(20,10),DDMSP(20,10),DMT(20),DMNEW(20),PHSATE,
     3              NOGER,NOLO,NOVEG,NOFR,NODOR,TCOVER
      COMMON /WAT/ WATABS(10),RUNOF,     SALNTY(10),EOR,ETIME,ETOUT,
     1              WROUT
      DOUBLE PRECISION NAMSP,NAMORG,NAMLIT
      IF(IREP.GT.NREP) RETURN
      IF (IDAY.NE.IDATR(IREP)) RETURN
      IREP=IREP+1
      WRITE(IMP,6) (STATE(I),I=1,20)
      IDAY1=IDAY-1
      WRITE(IMP,2) ICD,ICM,ICY,IDAY1
      WRITE(IMP,12)DARAIN,TDAY,DAPHOT,DAYRAD,DALITE,TRAIN
      WRITE(IMP,9)
      DO 20 I=1,NSP
      WRITE(IMP,3) NAMSP(I),DMT(I),IPHENO(I),PRLITE(I),PRTEMP(I),
     1              PRMOIS(I),PRFACT(I),PRSATE(I)
      IBID=NORG(I)
      DO 20 J=1,IBID
```

```
   20 WRITE(IMP,4) NAMORG(I,J),DMSP(I,J)
      WRITE(IMP,7)
      DO 21 I=1,NLIT
   21 WRITE(IMP,3) NAMLIT(I),CLIT(I)
C........SOILWATER POTENTIAL.
      WRITE(IMP,8)
      DO 22 I=1,NHOR
      PF=-WATER(I)*1000.
      IF(PF.GE.1.) GO TO 23
      PF=0.
      GO TO 22
   23 PF=ALOG10(PF)
   22 WRITE(IMP,10)I,WATER(I),WATABS(I),PF
      WRITE(IMP,11) ET,EVAP
      RETURN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      ENTRY INDMRP
      READ(LEC,2222) (CHECK(I),I=1,20)
      WRITE(IPP,2223) (CHECK(I),I=1,20)
 2222 FORMAT(20A4)
 2223 FORMAT(1X,20A4)
      READ(LEC,1)NREP
      DO 50 I=1,NREP
      READ(LEC,1)ID,IM,IY
      CALL INVDAT(IND,INM,INY,IDAT,ID,IM,IY)
   50 IDATR(I)=IDAT
      RETURN
    1 FORMAT(12I5)
    2 FORMAT(1X,'JOUR=',I3,' MOIS=',I3,' ANNEE',I5,' JOURS SIMULES=',
     1I5/ )
    3 FORMAT(  2X,A8,12X,F10.0,10X,I5,6X,5(E10.3))
    4 FORMAT(4X,A8,F10.0)
    6 FORMAT('0',20A4/  )
    7 FORMAT( //1X,' MATERIEL MORT' )
    8 FORMAT(//' ETAT HYDRIQUE DU SOL'/'  HORIZON  POTENTIEL(BARS)  EAU
     1TOTALE    PF')
    9 FORMAT(10X,'M.S./ORG.       M.S./SP.',10X,'PHENOLOGIE  LIGHTF
     1TEMPF     PHSF      PSRATE     PHSATE')
   10 FORMAT(1X,I5,5X,F10.2,2X,F10.2,2X,2F10.2)
   11 FORMAT           (' ET='E10.4,'  EVAP='E10.4,'CM/HEURE')
   12 FORMAT(1X,'PLUIE(MM) TEMP.(AIR)  DAPHOT   DAYRAD    DALITE    TRAI
     1N'/1X,6(E10.3)/)
      END
```

## *Subroutine* SEASON

```
C**********************************************************************
      SUBROUTINE SEASON
      COMMON /DATUM/ IND,INM,INY,IDAY,JULDAY,ICD,ICM,ICY,IS,IBIS,JOURS ,
     1                   NDAY,IPDAY
C........COMPUTE THE SEASON 'IS'.
C           IS=1=WINTER,IS=2=SPRING,IS=3=SUMMER,IS=4=FALL.
      A=80
      B=172
      C=264
      D=355
      IF(JULDAY.LT.A) GO TO 11
      IF(JULDAY.LT.B) GO TO 12
      IF(JULDAY.LT.C) GO TO 13
      IF(JULDAY.LT.D) GO TO 14
   11 IS=1
      RETURN
   12 IS=2
      RETURN
   13 IS=3
      RETURN
   14 IS=4
      RETURN
      END
```

## *Subroutine* SOWAT

```
C**********************************************************************
      SUBROUTINE SOWAT
      COMMON /DATUM/ IND,INM,INY,IDAY,JULDAY,ICD,ICM,ICY,IS,IBIS,JOURS,
     1                   NDAY,IPDAY
      COMMON /EDAFON/  DD(11),DTIME
      COMMON /EVTP/ ET,EVAP,FACTOR(4),IARTOF(4),NT
      COMMON /HEAD/ STATE(20)
      COMMON /INDU/ LEC,IMP,IPU
      COMMON /RCHECK/ CHECK(20)
      COMMON /REP/ IDATR(20),NREP ,IREP
      COMMON /SOIL/  WATER(10),SOILTE(10),        NHOR
      COMMON /WAT/ WATABS(10),RUNOF,     SALNTY(10),EOR,ETIME,ETOUT,
     1              HROOT
      COMMON /YORO/ ALAMBA,CB    ,CONQ  ,CONT  ,DETT  ,DELW  ,
     1                  DELX  ,DIFA  ,DIFB  ,DIFO  ,
     2                  HDRY  ,HWET  ,HLOW  ,HHI   ,RRES  ,SUCON ,
     3                  SOURCE,TAA   ,TIME  ,TT,NO ,WFOD  ,LL,MM ,DELT  ,NB,
     4                  TH    ,TBB   ,PIT   ,SMAX  ,CWFLX ,N,K,KK,KCK   ,
     5                  D(60),P(60),T(60),
     6                  C(11),G(11),H(11),ROF(11),SD(11),SE(11),SS(11),
     7              W(11),WATH(11),WATL(11),Y(11),A(11),B(11),E(11),F(11),
     8                  IWRITE
      LOGICAL IWRITE
      TIME=0.0
      RUNOF=0.0
      CUMS=0.0
      CUMM=0.0
      SUMA=0.0
C-*********************************************************************
C----COMPUTATION OF CONDUCTIVITY (H) AND WATER CAPACITY (C)
   16 Y(1)=(W(1)+Y(1))*.5
      J=(Y(1)-T(1))/DELW+1.0
      BB=(Y(1)-T(J))/DELW
      IF (EOR-0.0) 155,156,155
155   G(1)=(P(J+1)-P(J))*BB+P(J)
156   DO 161 I=2,KK
      J=(W(I)-T(1))/DELW+1.0
      BB=(W(I)-T(J))/DELW
      G(I)=(P(J+1)-P(J))*BB+P(J)
      TW=(W(I)-Y(I))+W(I)
      IF (TW-WATH(I)) 157,157,159
  157 IF (TW-WATL(I)) 158,160,160
  158 TW=WATL(I)
      GO TO 160
  159 TW=WATH(I)
160   Y(I)=W(I)
      W(I)=TW
      SS(I)=SE(I)
161   CONTINUE
      SS(1)=SE(1)
      TOP=WATH(1)
      BOT=WATL(1)
      HKP=H(1)
      WKP=W(1)
      IF (EOR-0.0) 17,19,18
   17 W(1)=WATL(1)
      H(1)=HDRY
      GO TO 19
   18 W(1)=WATH(1)
      H(1)=HWET
19    TWW=(W(1)+Y(1))*0.5
      J=(TWW-T(1))/DELW+1.0
      BB=(TWW-T(J))/DELW
      DIFFA=(D(J+1)-D(J))*BB+D(J)
      HI=(P(J+1)-P(J))*BB+P(J)
      DO 37 I=1,K
      TW=(W(I+1)+Y(I+1))*0.5
      J=(TW -T(1))/DELW+1.0
      BB=(TW-T(J))/DELW
      DIFFB=(D(J+1)-D(J))*BB+D(J)
      GI=(P(J+1)-P(J))*BB+P(J)
  219 IF(HI-GI)20,32,20
20    H(I)=(DIFFA-DIFFB)/(HI-GI)
      IF (I-1) 21,21,33
21    IF (EOR-0.0) 22,33,22
  22  ER=(B(1)*(H(1)*TT-H(2)*TT-G(2)*TW+G(1)*TW+DD(2)))/DD(2)
      IF (ABS(1.1*EOR-ER)-ABS(0.1*EOR)) 236,236,23
23    IF(KCK.EQ.1) GO TO 220
C-*********************************************************************
C----THE SURFACE PRESSURE HEAD
C-*********************************************************************
      IF (KCK-20)305,236,236
  236 H(1)=(1.1*EOR*DD(2)/H(1)+H(2)*TT-G(1)*TW+G(2)*TW-DD(2))/TT
      IF(H(1).LT.HDRY) H(1)=HDRY
      IF (H(1).GT.HWET) H(1)=HWET
      GO TO 33
220   H(1)=HKP
      W(1)=WKP
      KCK=KCK+1
      GO TO 19
305   KCK=KCK+1
      IF (ER-EOR) 24,33,26
   24 IF (W(1)-WATH(1)) 25,33,33
25    BOT=W(1)
      W(1)=(W(1)+TOP)*0.5
      GO TO 28
   26 IF (W(1)-WATL(1)) 33,33,27
27    TOP=W(1)
      W(1)=(W(1)+BOT)*0.5
   28 J=(W(1)-T(1))/DELW+1.0
      BB=(W(1)-T(J))/DELW
      IF(EOR-0.0)30,33,30
30    H(1)=(P(J+1)-P(J))*BB+P(J)
  218 TWW=(W(1)+Y(1))*0.5
      J=(TWW-T(1))/DELW+1.0
      BB=(TWW-T(J))/DELW
      DIFFA=(D(J+1)-D(J))*BB+D(J)
      HI=(P(J+1)-P(J))*BB+P(J)
      GO TO 219
32    H(I)=(D(J+1)-D(J))/(P(J+1)-P(J))
      IF (I-1) 33,21,33
33    TWW=TW
      HI=GI
      DIFFA=DIFFB
      TW=(W(I+1)+Y(I+1))*0.5
      J=(TW -T(1))/DELW+1.0
35    C(I+1)=DELW/(P(J+1)-P(J))
37    CONTINUE
      KCK=1
      IF(EOR.GT.0.0.AND.ET.GE.0.0) GO TO 6666
      IF(EOR.GT.0.0.AND.ET.LT.0.0) GO TO 5555
 6666 ETPL=ET-EOR
      IF(ET.GE.0.0) GO TO 39
      IF(ETPL-0.0) 365,39,39
 5555 ETPL=ET
C-*********************************************************************
C-     SEARCHING FOR THE PROPER HROOT VALUE
C-*********************************************************************
365   HHOLD=HROOT
      HROOT=HLOW
      SINK=0.0
      DO 250 I=2,K
  250 E(I)=G(I)-36.00 *SE(I)-DD(I)*RRES
      DO 420 I=2,K
      IF((HROOT-E(I)).GT.0.0) GO TO 420
      SINK=B(I)*ROF(I)*(HROOT-E(I))+SINK
 420  CONTINUE
      IF ((SINK-ETPL).GT.0.0) GO TO 402
      HROOT=HHOLD
410   HROOT=1.2*HROOT
      SINK=0.0
      DO 421 I=2,K
      IF((HROOT-E(I)).GT.0.0) GO TO 421
      SINK=B(I)*ROF(I)*(HROOT-E(I))+SINK
 421  CONTINUE
      IF(SINK-ETPL)411,402,410
 411  HRLO=HROOT
      HROOT=HHOLD
      LCOUNT=0
412   HROOT=0.8*HROOT
      LCOUNT=LCOUNT+1
      IF(LCOUNT.EQ.5) GO TO 490
      SINK=0.0
      DO 422 I=2,K
      IF((HROOT-E(I)).GT.0.0) GO TO 422
      SINK=B(I)*ROF(I)*(HROOT-E(I))+SINK
 422  CONTINUE
      IF(SINK-ETPL)412,402,413
 413  HRHI=HROOT
      GO TO 491
  490 HRHI=HHI
491   LCOUNT=0
      HROOT=HHOLD
405   SINK=0.0
      DO 400 I=2,K
      IF((HROOT-E(I)).GT.0.0) GO TO 400
      SINK=B(I)*ROF(I)*(HROOT-E(I))+SINK
400   CONTINUE
      LCOUNT=LCOUNT+1
      IF(LCOUNT.EQ.20) GO TO 402
      IF(ABS(SINK-ETPL)-0.002)402,402,401
401   IF(SINK-ETPL)403,402,404
403   HRLO=HROOT
      HROOT=0.5*(HROOT+HRHI)
      GO TO 405
 404  HRHI=HROOT
      HROOT=0.5*(HROOT+HRLO)
      GO TO 405
   39 DO 251 I=2,K
      SINK=0.0
  251 A(I)=0.0
      GO TO 38
C-*********************************************************************
C-     A IS THE DEL WATER/DELT CAUSED BY PLANT EXTRACTION
C-*********************************************************************
  402 DO 406 I=2,K
      IF((HROOT-E(I)).GT.0.0) GO TO 407
      A(I)=B(I)*(HROOT-E(I))*2.0*ROF(I)/(DD(I+1)-DD(I-1))
      GO TO 406
```

```fortran
  407 A(I)=0.0
  406 CONTINUE
C-*******************************************************************
C-----COMPUTATION OF TRIDIAGONAL MATRIX MAIN BODY
C-*******************************************************************
38    DO 42 I=2,K
      POT=(DD(I+1)-DD(I-1))/(2.0*DELT)
      DLXA=(DD(I)-DD(I-1))
      DLXB=(DD(I+1)-DD(I))
      BB=C(I)*POT/TT+B(I)/DLXB+B(I-1)/DLXA
      DA=(C(I)*POT*G(I)+(B(I)/DLXB)*(TM*(G(I+1)-G(I))-DLXB)+(B(I-1)/DLXA
     1)*(TM*(G(I-1)-G(I))+DLXA)+A(I)*(DD(I+1)-DD(I-1))*0.5)/TT
      IF(I-2)390,390,40
  390 IF(H(1).GE.HWET.OR.H(1).LE.HDRY) GO TO 394
      DA=DA-((B(I-1)/DLXA)*(TM*(G(I-1)-G(I))+DLXA))/TT+EOR/TT
      BB=BB-B(I-1)/DLXA
      GO TO 393
  394 DA=DA+H(I-1)*B(I-1)/DLXA
  393 F(I)=DA/BB
      E(I)=(B(I)/DLXB)/BB
      GO TO 42
40    IF (I-K) 41,43,43
41    E(I)=(B(I)/DLXB)/(BB-(B(I-1)/DLXA)*F(I-1))
      F(I)=(DA+(B(I-1)/DLXA)*F(I-1))/(BB-(B(I-1)/DLXA)*E(I-1))
   42 CONTINUE
43    BB=BB-TAA*B(I)/DLXB
      DA=DA+TAA*(B(I)/DLXB)*((G(I)-G(I+1))*TM+DLXB)/TT+TBB*B(I)/DLXB*H(
     1KK)
      H(I)=(DA+(B(I-1)/DLXA)*F(I-1))/(BB-(B(I-1)/DLXA)*E(I-1))
44    I=I-1
      H(I)=E(I)*H(I+1)+F(I)
      IF (I-2) 45,45,44
45    IF(TAA-1.0)47,46,46
46    H(KK)=H(K)+DD(KK)-DD(K)
47    DO 60 I=2,KK
300   IF (H(I)-HWET-DD(I)) 60,60,55
55    H(I)=HWET+DD(I)
60    CONTINUE
C-*******************************************************************
C-----COMPUTATION OF WATER CONTENTS AS A FUNCTION OF PRESSURES JUST COMP
C-*******************************************************************
      IF(H(1).GE.HWET.OR.H(1).LE.HDRY) GO TO 1005
      WFDD=EOR
      H(1)=(EOR*DD(2)/B(1)+H(2)*TT-G(1)*TM+G(2)*TM-DD(2))/TT
      IF(H(1).LT.HDRY) H(1)=HDRY
      IF (H(1).GT.HWET) H(1)=HWET
      GO TO 134
 1005 WFDD=B(1)*((H(1)-H(2))*TT+(G(1)-G(2))*TM+DD(2))/DD(2)
 134  I=1
 62   IF (H(I)-G(I)) 65,116,65
   65 NHI=ND
      NLO=1
      J=25
66    IF (H(I)-P(J)) 67,72,68
67    NHI=J
      GO TO 69
68    NLO=J
69    JT=J
      J=(NHI-NLO)/2+NLO
      IF (J-JT) 66,70,66
70    IF (H(I)-P(J)) 71,72,72
71    J=J-1
   72 CONTINUE
      WAT=(H(I)-P(J))*DELW/(P(J+1)-P(J))+T(J)
      W(I)=WAT
      GO TO 117
116   W(I)=Y(I)
  117 DO 268 I=2,KK
      W(I)=C(I)*(H(I)-G(I))+Y(I)
      IF (W(I).GT.WATH(I)) W(I)=WATH(I)
  268 IF (W(I).LT.WATL(I)) W(I)=WATL(I)
269   SUM3=0.0
      SUM2=0.0
      SUM1=0.0
      DO 131 I=2,K
      SUM1=W(I)+SUM1
      SUM2=Y(I)+SUM2
      IF (ABS(SUM1-SUM2)-ABS(SUM3)) 131,131,130
130   SUM3=SUM1-SUM2
131   CONTINUE
      IF(ABS(SUM3)-ABS(CONQ))63,63,132
 132  IF(DELT-DETT*0.1)63,63,133
  133 DELT=0.5*DELT
      GO TO 38
   63 SUM1=0.0
      SUM2=0.0
      DO 800 I=2,K
      SUM1=W(I)*(DD(I+1)-DD(I-1))/2.+SUM1
  800 SUM2=Y(I)*(DD(I+1)-DD(I-1))/2.+SUM2
      CWF=SUM1-PIT
      CUMS=WFDD*DELT+CUMS
      SUMA=SUMA+SINK*DELT
      CWFLX=(SUM1-SUM2)
C-*******************************************************************
C-----SALT LOOP
C-*******************************************************************
      KB=K-1
      WFRU=B(1)*((H(1)-H(2))*TT+(G(1)-G(2))*TM+DD(2))/DD(2)
      DO 214 I=2,K
      DLXA=(DD(I)-DD(I-1))
      DLXB=(DD(I+1)-DD(I))
      DLXC=(DD(I+1)-DD(I-1))*0.5
      WFRD=B(I)*((H(I)-H(I+1))*TT+(G(I)-G(I+1))*TM+DLXB)/DLXB
  176 WATD=(Y(I)*TM+W(I)*TT+Y(I+1)*TM+W(I+1)*TT)/2.0
      DISD=DLXC*0.5*WFRD-(W(I)-Y(I))*(WFRD+WFRU)*WFRD*DELT/(8.0*WATD*
     1(W(I)+Y(I)))
      BETA=DIFU*DIFA*EXP(DIFB*WATD)+ALAMBA*ABS(WFRD/WATD)-DISD
      IF (I .GT. 2) GO TO 680
      ALFA=0.0
      IF (WFRU .GT. 0.0) GO TO 182
      WFRU=0.0
      GO TO 182
  680 WATU =(Y(I)*TM+W(I)*TT+Y(I-1)*TM+W(I-1)*TT)/2.0
      DISU=DLXC*0.5*WFRU-(W(I)-Y(I))*(WFRD+WFRU)*WFRU*DELT/(8.0*WATU*
     1(W(I)+Y(I)))
      ALFA=DIFU*DIFA*EXP(DIFB*WATU)+ALAMBA*ABS(WFRU/WATU)-DISU
      IF (WFRU .GE. 0.0) GO TO 182
      UP=0.0
      GO TO 183
  182 UP=1.0
  183 DN=1.0-UP
      IF (WFRD .GE. 0.0) GO TO 185
      UPP=0.0
      GO TO 186
  185 UPP=1.0
  186 DNN=1.0-UPP
      SE(I)=(DLXC*Y(I)*SS(I)/DELT+ALFA*(SS(I-1)-SS(I))/DLXA-BETA*(SS(I)-
     1SS(I+1))/DLXB-WFRD*(SS(I)*UPP+SS(I+1)*DNN)+WFRU*(SS(I-1)*UP+SS(I)
     2*DN)+SOURCE*DLXC)*DELT/(W(I)*DLXC)
      SE(I)=SS(I)+(SE(I)-SS(I))*SOCON
  214 WFRU=WFRD
      SE(KK)=SS(KK)
      SD(1)=SE(1)*W(1)
      DO 217 I=2,KK
  217 SD(I)=SE(I)*W(I)
706   IF(EOR-0.0)136,136,135
  135 RUNOF=RUNOF+(EOR-WFDD)*DELT*10.
136   TIME=TIME+DELT
      IF (SUM3-0.0) 139,301,139
  301 DELT=2.0*DELT
      GO TO 145
139   TW=ABS(CONQ*DELT/SUM3)
140   IF (TW-0.1*DETT) 141,142,142
  141 TW=0.1*DETT
      GO TO 144
  142 IF(TW-1000.0*DETT)144,144,143
 143  TW=1000.0*DETT
  144 IF(TW.GT.2.0*DELT) GO TO 301
      DELT=TW
C-*******************************************************************
C-----TEST TO SEE IF EVAP OR RAIN INTENSITY (EOR) HAS CHANGED
C-*******************************************************************
  145 IF (TIME-ETIME)148,147,148
  147 IF (IREP.GT.NREP) GO TO 1480
      IF(IDAY.NE.IDAIR(IREP))GO TO 1480
      WRITE(IMP,508) (STATE(I),I=1,20)
  508 FORMAT('1'20A4)
      WRITE(IMP,666)
      WRITE(IMP,168)(DD(I),W(I),H(I),A(I),SE(I),SD(I),SOILTE(I),I=1,K)
      WRITE(IMP,168)(DD(KK),W(KK),H(KK),A(KK),SE(KK),SD(KK))
      WRITE(IMP,184)
      WRITE(IMP,167)IDAY,TIME,ET,EOR,SUMA,RUNOF,HROOT,CWF,CUMS
 1480 DELT=DETT
      GO TO 162
  148 IF (TIME+DELT-ETIME) 16,16,149
  149 DELT=ETIME-TIME
      GO TO 16
  162 CONTINUE
      WATER(1)=H(1)/1017.
      WATABS( 1)=W(1)*(DD(2)/2.)*10.
      SALNTY(1)=SD(1)
      DO 1000 I=2,K
      WATER(I)=H(I)/1017.
      WATABS(I)=W(I)*((DD(I+1)-DD(I-1))/2.)*10.
      SALNTY(I   )=SD(I)
 1000 CONTINUE
      WATER(KK)=H(KK)/1017.
      WATABS(KK)=W(KK)*((DD(KK)-DD(K))/2.)*10.
      SALNTY(KK)=SD(KK)
      ETOUT=SUMA*10.
C-*******************************************************************
166   FORMAT (11E11.4)
  167 FORMAT (4X,I3,8(E12.4),//)
  666 FORMAT(1X,'PROFONDEUR EAU(FRACT.) POTENTIEL  EXT. RAC.  CONC. SEL
     1 QUANT. SEL TEMP. MIL. HOR.')
  168 FORMAT(1X,7E11.4)
170   FORMAT (119H   WATER    POTENTIAL   CONDUCTIVITY DIFFUSIVITY
     1C(I)     DEPTH       W-DEPTH      H-DEPTH      ROF-DEPTH   SE-DEPTH)
  172 FORMAT (53H   HDRY         HWET        CB           SYSTD         )
180   FORMAT (66H  DELX         DETT        GRAVY         CONQ          DELW
     1        TIME)
181   FORMAT (66H   TT          CUMT        TAA           HLOW          HHI
     1        RRES)
  184 FORMAT (4X,'DAY',3X,'CUM. HOURS',2X,'ET       ',4X,'EOR       ',
     *'CUM.TRANS.   RUNOFF      HROOT        CWF          CUMS')
  274 FORMAT (11E12.4)
  284 FORMAT(66H    ALAMBA     SOURCE      DIFU          DIFA          DIFB
     1        SOCON)
      RETURN
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
      ENTRY INDHWT
      READ(LEC,2222) (CHECK(I),I=1,20)
      WRITE(IMP,2223) (CHECK(I),I=1,20)
 2222 FORMAT(20A4)
 2223 FORMAT(1X,20A4)
C........ 1 BAR=0.987 ATMOSPHERE= 1017 CM OF WATER.
C........ PF= LOG(BASE 10) OF(- WATER POTENTIAL IN MILLIBARS)
      READ(LEC,502) MM,NB,ND
      READ(LEC,501) ALAMBA,CB,CONQ,CUMT,DETT,DELW,
     1            DELX,DIFA,DIFB,DIFU,SYSTD
      READ(LEC,501) HDRY,HWET,HLOW,HHI,RRES,SOCON,
     1            SOURCE,TAA,TIME,TT
C........D(I) IS THE WATER CONDUCTIVITY.
      READ(LEC,503) (D(I),I=1,ND)
C........P(I) IS READ IN IN BARS.
      READ(LEC,503) (P(I),I=1,ND)
      K=NHOR -1
      KK=NHOR
      READ(LEC,501)(W     (I),I=1,KK)
      READ(LEC,501)(WATL  (I),I=1,KK)
      READ(LEC,501)(WATH  (I),I=1,KK)
      READ(LEC,501)(ROF   (I),I=1,KK)
      READ(LEC,501)(SE    (I),I=1,KK)
      READ(LEC,504) IWRITE
  501 FORMAT(6F10.0)
  502 FORMAT(12I5)
  503 FORMAT(6E10.0)
  504 FORMAT( L5)
C-------------------------------------------------------------------
      DO 510 I=1,ND
  510 D(I)=D(I)*SYSTD
      GRAVY=DELX
      WFDD=-.009
      LL=MM
      DO 4 I=1,KK
    4 SE(I)=(SE(I)*10.)/(W(I)/WATH(I))
      P(1)=P(1)*1.0E+03
      T(1)=0.0
      DO 900 I=2,ND
      T(I)=DELW+T(I-1)
 900  P(I)=P(I)*1017.
      SMAX=350.
      CWFLX=0.0
      DELT=DETT
      TM=1.0-TT
      TBB=1.0-TAA
      DO 14 I=1,KK
      SS(I)=SE(I)
      SD(I)=SE(I)*W(I)
14    Y(I)=W(I)
      PIT=0.0
      DO 15 I=2,K
   15 PIT=W(I)*(DD(I+1)-DD(I-1))/2.+PIT
      IF (IWRITE) WRITE(IMP,170)
      TW=D(1)
C........BEYOND THIS POINT D(I) IS THE DIFFUSIVITY
      D(1)=(D(1)*(P(2)-P(1)))*CB
      J=(W(1)-T(1))/DELW+1.0
      H(1)=(P(J+1)-P(J))*(W(1)-T(J))/DELW+P(J)
      G(1)=H(1)
      C(1)=DELW/(P(J+1)-P(J))
      IF (IWRITE) WRITE(IMP,274)T(1),P(1),TW,D(1),C(1),DD(1),W(1),H(1),
     *  ROF(1),SE(1)
      DO 3 I=2,KK
      TW=D(I)
      D(I)=D(I)*(P(I)-P(I-1))*CB+D(I-1)
      J=(W(I)-T(I))/DELW+1.0
      H(I)=(P(J+1)-P(J))*(W(I)-T(J))/DELW+P(J)
      C(I)=DELW/(P(J+1)-P(J))
```

```
          G(I)=H(I)
          IF (IWRITE) WRITE(IMP,274)T(I),P(I),TW,D(I),C(I),DD(I),W(I),H(I),
     *    RUF(I),SE(I)
    3     CONTINUE
          N=KK+1
          DO 2 I=N,ND
          TW=D(I)
          D(I)=D(I)*(P(I)-P(I-1))*CB+D(I-1)
        2 IF (IWRITE)WRITE(IMP,274)T(I),P(I),TW,D(I)
C-*******************************************************************
          IF (.NOT.IWRITE) GO TO 11
          WRITE(IMP,180)
          WRITE(IMP,166)DELX,DETT,GRAVY,COWQ,DELW,TINF
          WRITE(IMP,181)
          WRITE(IMP,166)TT,CUMI,TAA,HLOW,HHI,RRES
          WRITE(IMP,172)
          WRITE(IMP,166)HDRY,HWET,CB,SYSTD
          WRITE(IMP,505)(I,I=1,KK)
  505        FORMAT(1X,11(' WATL(',I2')  '))
          WRITE(IMP,506) (WATL(I),I=1,KK)
  506 FORMAT(1X,11E11.3)
          WRITE(IMP,507)(I,I=1,KK)
  507        FORMAT(1X,11(' WATH(',I2')  '))
          WRITE(IMP,506) (WATH(I),I=1,KK)
          WRITE(IMP,284)
          WRITE(IMP,274)ALAMBA,SOURCE,DIFO,DIFA,DIFB,SUCON
   11 KCK=1
          HROOT=G(2)
          RETURN
          END
```

## APPENDIX 2

### INPUT/OUTPUT EXAMPLE

An example of each form of output is given: (1) parameters for the soil; (2) report for the initial day (November 11, 1971 -- day 1); (3) report for a day with rain (November 18, 1971 -- day 9); (4) report for a day without rain (December 1, 1971 -- day 22); (5) two examples of diagrams.

*Input Example*

```
                                  ......................
                                  .   G  A  B  E  S    .
                                  .   *************    .
                                  .       KM=52        .
                                  ......................
           (FRANCOIS ROMANE  - LOGAN, AVRIL 1974)
  CECI EST UN  ESSAI ,POUR AJUSTER LES PARAMETRES.

  GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS
    10   11 1971   15   12 1971                               DATES DEP./ARR.     MN
     4    4    4                                              NB/SP,LIT,HOR.      MN
     3    2    3    2                                         NB. ORG. /SP.       MN
     3    5    4                                              RANTH./FONCT. ORG.MN
     3    4                                                   PLANT./FONCT. ORG.MN
     3    5    4                                              LIGNE./FONCT. ORG.MN
     3    4                                                   ANNUE./FONCT. ORG.MN
     2    2    2    1                                         LIF(I)              MN
 RANTH.S.PLANT.A.A. LIGNEANNUELLE                             NAMSP(I)            MN
 POUSSES TIGES   RACINES                                      NAMORG(1,*)         MN
 POUSSES RACINES                                              NAMORG(2,*)         MN
 POUSSES TIGES   RACINES                                      NAMORG(3,*)         MN
 FEUILLESRACINES                                              NAMORG(4,*)         MN
 P.A.S.  LITIERE RAC.MORTPUITS                                NAMLIT(I)           MN
      31000.  1173000.   904337.                              RANTH.     MS=G/HA MN
      23000.   122262.                                        PLANT.     MS=G/HA MN
      39000.    88000.    83681.                              LIG. DIV.  MS=G/HA MN
      17000.    13940.                                        ANNUELLES  MS=G/HA MN
      27080.    84000.   112422.          0.                  CLIT (I)   MS=G/HA MN
     ENTREE INDMRP
      4                                                       SORTIES RESUL.INDMRP
     10   11 1971                                             DATE          INDMRP
     18   11 1971                                             DATE          INDMRP
      1   12 1971                                             DATE          INDMRP
     15   12 1971                                             DATE          INDMRP
     ENTREE INDMEX
     33   21                                                  NDR,NDTC      INDMEX
     18   11 1971         30.0                                PLUIE         INDMEX
     29   11 1971          9.0                                PLUIE         INDMEX
     13   12 1971          8.0                                PLUIE         INDMEX
     24    1 1972          7.0                                PLUIE         INDMEX
      2    2 1972          2.0                                PLUIE         INDMEX
     29    2 1972          4.0                                PLUIE         INDMEX
      2    3 1972          2.0                                PLUIE         INDMEX
     16    3 1972          9.0                                PLUIE         INDMEX
     21    3 1972          9.0                                PLUIE         INDMEX
     29    3 1972          2.0                                PLUIE         INDMEX
      4    4 1972          5.0                                PLUIE         INDMEX
     11    4 1972         40.0                                PLUIE         INDMEX
     19    4 1972         19.0                                PLUIE         INDMEX
     21    4 1972          5.0                                PLUIE         INDMEX
      8    5 1972         16.0                                PLUIE         INDMEX
      8    7 1972          7.0                                PLUIE         INDMEX
      5    9 1972          7.0                                PLUIE         INDMEX
      5   10 1972         65.1                                PLUIE/DATE AP.INDMEX
     15   10 1972          4.5                                PLUIE/DATE AP.INDMEX
     25   10 1972          1.1                                PLUIE/DATE AP.INDMEX
     25   11 1972          4.6                                PLUIE/DATE AP.INDMEX
      5   12 1972         23.4                                PLUIE/DATE AP.INDMEX
     25   12 1972         15.8                                PLUIE/DATE AP.INDMEX
     15    1 1973          5.1                                PLUIE/DATE AP.INDMEX
     25    1 1973          7.6                                PLUIE/DATE AP.INDMEX
      5    2 1973          3.7                                PLUIE/DATE AP.INDMEX
     15    2 1973          7.6                                PLUIE/DATE AP.INDMEX
     25    2 1973          1.3                                PLUIE/DATE AP.INDMEX
      5    3 1973          3.7                                PLUIE/DATE AP.INDMEX
     15    3 1973          6.4                                PLUIE/DATE AP.INDMEX
     25    3 1973         31.5                                PLUIE/DATE AP.INDMEX
     15    4 1973          2.5                                PLUIE/DATE AP.INDMEX
     25    4 1973          2.5                                PLUIE/DATE AP.INDMEX
     10   11 1971         11.1                                TEMPERATURE   INDMEX
     15   12 1971         10.2                                TEMPERATURE   INDMEX
     15    1 1972          8.1                                TEMPERATURE   INDMEX
     15    2 1972         11.9                                TEMPERATURE   INDMEX
     15    3 1972         14.4                                TEMPERATURE   INDMEX
     15    4 1972         15.6                                TEMPERATURE   INDMEX
     15    5 1972         18.8                                TEMPERATURE   INDMEX
     15    6 1972         24.6                                TEMPERATURE   INDMEX
     15    7 1972         26.3                                TEMPERATURE   INDMEX
     15    8 1972         26.1                                TEMPERATURE   INDMEX
     15    9 1972         24.6                                TEMPERATURE   INDMEX
     15   10 1972         20.1                                TEMPERATURE   INDMEX
     15   11 1972         13.1                                TEMPERATURE   INDMEX
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 83   15   12 1972        10.0                                              TEMPERATURE    INDMEX
 84   15    1 1973         8.7                                              TEMPERATURE    INDMEX
 85   15    2 1973         9.1                                              TEMPERATURE    INDMEX
 86   15    3 1973        10.5                                              TEMPERATURE    INDMEX
 87   15    4 1973        14.0                                              TEMPERATURE    INDMEX
 88   15    5 1973        20.7                                              TEMPERATURE    INDMEX
 89   15    6 1973        24.6                                              TEMPERATURE    INDMEX
 90   15    7 1973        28.8                                              TEMPERATURE    INDMEX
 91   ENTREE INDMPN
 92    3    3     3    5                                                    PHENOL./SP.    INDMPN
 93   15   15     0    0                                                    NDGERM,...SP1  INDMPN
 94   15   15     0    0                                                    NDGERM,...SP2  INDMPN
 95   15   15     0    0                                                    NDGERM,...SP3  INDMPN
 96   10   10     0    0                                                    NDGERM,...SP4  INDMPN
 97    3    3     3    2                                                    LCOUCH(*)      INDMPN
 98         0.0        1.0       0.1       0.0       0.15      0.08                    SP1 INDMPN
 99         7.0      -11.0      13.2      18.0       0.17       5.0                    SP1 INDMPN
100       -11.0       0.05       4.0     -12.0      11.0       13.0                    SP1 INDMPN
101         0.0        1.0       0.1       0.0       0.15      0.08                    SP2 INDMPN
102         7.0      -11.0      13.2      18.0       0.17       5.0                    SP2 INDMPN
103       -11.0       0.05       4.0     -12.0      11.0       13.0                    SP2 INDMPN
104         0.0        1.0       0.1       0.0       0.15      0.08                    SP3 INDMPN
105         7.0      -11.0      13.2      18.0       0.17       5.0                    SP3 INDMPN
106       -11.0       0.05       4.0     -12.0      11.0       13.0                    SP3 INDMPN
107         0.0        1.0       0.1       0.0       0.15      0.08                    SP4 INDMPN
108         7.0      -11.0      13.2      18.0       0.17       5.0                    SP4 INDMPN
109       -11.0       0.05       4.0     -12.0      11.0       13.0                    SP4 INDMPN
110   ENTREE INDMFO
111         75.        125.      0.65       35.       10.      0.05 SP1              INDMFO
112        -30.         -5.                                          SP1              INDMFO
113         75.        125.      0.65       35.       10.      0.05 SP2              INDMFO
114        -30.         -5.                                          SP2              INDMFO
115         75.        125.      0.65       35.       10.      0.05 SP3              INDMFO
116        -30.         -5.                                          SP3              INDMFO
117         75.        125.      0.65       35.       10.      0.05 SP4              INDMFO
118        -30.         -5.                                          SP4              INDMFO
119    3    3     3    2                                            LAYCH (*)        INDMFO
120   ENTREE INDMTR
121         1.0        0.0       0.0                                 RTPH/SP 1        INDMTR
122         1.0        0.0                                           RTPH/SP 2        INDMTR
123         1.0        0.0       0.0                                 RTPH/SP 3        INDMTR
124         1.0        0.0                                           RTPH/SP 4        INDMTR
125         1.00       0.00      0.00                                RTGR-SP1/POU.    INDMTR
126         0.02       0.94      0.02                                RTGR-SP1/TIGE    INDMTR
127         0.01       0.01      0.98                                RTGR-SP1/RAC.    INDMTR
128         0.95       0.05                                          RTGR-SP2/POU.    INDMTR
129         0.01       0.99                                          RTGR-SP2/RAC.    INDMTR
130         1.00       0.00      0.00                                RTGR-SP3/POU.    INDMTR
131         0.02       0.94      0.02                                RTGR-SP3/TIGE    INDMTR
132         0.01       0.01      0.98                                RTGR-SP3/RAC.    INDMTR
133         1.00       0.00                                          RTGR-SP4/FEUI    INDMTR
134         0.00       1.00                                          RTGR-SP4/RAC.    INDMTR
135         1.00       0.00      0.00                                RTLO-SP1/POU.    INDMTR
136         0.02       0.94      0.02                                RTLO-SP1/TIGE    INDMTR
137         0.01       0.01      0.98                                RTLO-SP1/RAC.    INDMTR
138         1.00       0.00                                          RTLO-SP2/POU.    INDMTR
139         0.01       0.99                                          RTLO-SP2/RAC.    INDMTR
140         1.00       0.00      0.00                                RTLO-SP3/POU.    INDMTR
141         0.02       0.94      0.02                                RTLO-SP3/TIGE    INDMTR
142         0.01       0.01      0.98                                RTLO-SP3/RAC.    INDMTR
143         1.00       0.00                                          RTLO-SP4/FEUI    INDMTR
144         0.00       1.00                                          RTLO-SP4/RAC.    INDMTR
145         0.98       0.01      0.01                                RTVG-SP1/POU.    INDMTR
146         0.00       1.00      0.00                                RTVG-SP1/TIGE    INDMTR
147         0.00       0.00      1.00                                RTVG-SP1/RAC.    INDMTR
148         0.99       0.01                                          RTVG-SP2/POU.    INDMTR
149         0.00       1.00                                          RTVG-SP2/RAC.    INDMTR
150         0.98       0.01      0.01                                RTVG-SP3/POU.    INDMTR
151         0.00       1.00      0.00                                RTVG-SP3/TIGE    INDMTR
152         0.00       0.00      1.00                                RTVG-SP3/RAC.    INDMTR
153         0.99       0.01                                          RTVG-SP4/FEU.    INDMTR
154         0.00       1.00                                          RTVG-SP4/TIGE    INDMTR
155         0.90       0.05      0.05                                RTFR-SP1/POU.    INDMTR
156         0.00       1.00      0.00                                RTFR-SP1/TIGE    INDMTR
157         0.00       0.00      1.00                                RTFR-SP1/RAC.    INDMTR
158         0.95       0.05                                          RTFR-SP2/POU.    INDMTR
159         0.00       1.00                                          RTFR-SP2/RAC.    INDMTR
160         0.90       0.05      0.05                                RTFR-SP3/POU.    INDMTR
161         0.00       1.00      0.00                                RTFR-SP3/TIGE    INDMTR
162         0.00       0.00      1.00                                RTFR-SP3/RAC.    INDMTR
163         0.99       0.01                                          RTFR-SP4/FEU.    INDMTR
164         0.00       1.00                                          RTFR-SP4/RAC.    INDMTR
165   ENTREE INDMOT
166         0.0        0.0       0.0      15.0                       WTIME(I)         INDMOT
167     2    1     3                                                 LREP/SP1         INDMOT
168     2    3                                                       LREP/SP2         INDMOT
169     2    1     3                                                 LREP/SP3         INDMOT
170     2    3                                                       LREP/SP4         INDMOT
171         0.0      0.0111     0.001                                PDDT1-3/(1,1)    INDMOT
172         0.0      0.0111     0.001                                PDDT1-3/(1,2)    INDMOT
173         0.0      0.0111     0.001                                PDDT1-3/(1,3)    INDMOT
174         0.0      0.0111     0.001                                PDDT1-3/(2,1)    INDMOT
175         0.0      0.0111     0.001                                PDDT1-3 (2,2)    INDMOT
176         0.0      0.0111     0.001                                PDDT1-3 (3,1)    INDMOT
177         0.0      0.0111     0.001                                PDDT1-3 (3,2)    INDMOT
178         0.0      0.0111     0.001                                PDDT1-3 (3,3)    INDMOT
179         0.0      0.0111      0.01                                PDDT1-3 (4,1)    INDMOT
180         0.0      0.0111      0.01                                PDDT1-3 (4,2)    INDMOT
181       0.000      0.000     0.000                                 PDT(1,1,*) GR    INDMOT
182       0.000      0.000                                           PDT(1,2,*) GR    INDMOT
183       0.000      0.000     0.000                                 PDT(1,3,*) GR    INDMOT
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       0.000      0.000                                                PDT(1,4,*) GR INDMDT
       0.000      0.000      0.000                                     PDT(2,1,*) LN INDMDT
       0.000      0.000                                                PDT(2,2,*) LN INDMDT
       0.000      0.000      0.000                                     PDT(2,3,*) LN INDMDT
       0.000      0.000                                                PDT(2,4,*) LN INDMDT
      0.0001     0.0001     0.0001                                     PDT(3,1,*) VG INDMDT
      0.0001     0.0001                                                PDT(3,2,*) VG INDMDT
      0.0001     0.0001     0.0001                                     PDT(3,3,*) VG INDMDT
      0.0001     0.0001                                                PDT(3,4,*) VG INDMDT
       0.001      0.002      0.001                                     PDT(4,1,*) FR INDMDT
       0.001      0.001                                                PDT(4,2,*) FR INDMDT
       0.001      0.002      0.001                                     PDT(4,3,*) FR INDMDT
       0.002      0.002                                                PDT(4,4,*) FR INDMDT
    FNTREE INDMOM
       0.999      0.001      0.000      0.000                          RTLI(1,1,*)PASINDMOM
      0.000       0.995     0.000       0.005                          RTLI(1,2,*)LITINDMOM
      0.0000     0.0000      0.999      0.001                          RTLI(1,3,*)RM INDMOM
         0.0        0.0        0.0        1.0                          RTLI(1,4,*)PUIINDMOM
       0.999      0.001      0.000      0.000                          RTLI(2,1,*)PASINDMOM
      0.0000     0.9999     0.0000     0.0001                          RTLI(2,2,*)LITINDMOM
      0.0000     0.0000     0.9999     0.0001                          RTLI(2,3,*)RM INDMOM
         0.0        0.0        0.0        1.0                          RTLI(2,4,*)PUIINDMOM
       0.999      0.001      0.000      0.000                          RTLI(3,1,*)PASINDMOM
      0.0000     0.9999     0.0000     0.0001                          RTLI(3,2,*)LITINDMOM
      0.0000     0.0000     0.9999     0.0001                          RTLI(3,3,*)RM INDMOM
         0.0        0.0        0.0        1.0                          RTLI(3,4,*)PUIINDMOM
       0.999      0.001      0.000      0.000                          RTLI(4,1,*)PASINDMOM
      0.000       0.995     0.000       0.005                          RTLI(4,2,*)LITINDMOM
      0.0000     0.0000      0.999      0.001                          RTLI(4,3,*)RM INDMOM
         0.0        0.0        0.0        1.0                          RTLI(4,4,*)PUIINDMOM
    FNTREE INDMOL
      42.000                                                           RLAT (DEGRE)  INDMOL
    ENTREE INDMED
          5.                                                           FORCE         INDMED
        0.05       40.0      100.0      120.0                          DEPTH(*)      INDMED
    ENTREE INDMEV
      4                                                                NT            INDMEV
         0.0        4.5       10.0                                     TARTUF(I)     INDMEV
         0.0       0.05        0.1        0.5                          FACTOR(I)     INDMEV
    ENTREE INDMOG
         12.        10.         9.         8.                          BEGTEM(*)     INDMOG
       . 0.3        0.3        0.3        0.3                          CV    (*)     INDMOG
         3.6        3.6        3.6        3.6                          CONDUC(*)     INDMOG
         24.                                                           DTIME         INDMOG
    ENTREE INDMWT
    99    2   54                                                       MM,NB,ND      INDMWT
         1.0        1.0       0.05       24.0     0.0024     0.01ALAMBA....  INDMWT
         7.6      0.001        1.0       0.01        0.1         DELX....    INDMWT
     -30000.        0.0    -16000.        0.0       1.05      0.1HDRY....    INDMWT
         0.0        1.0        0.0        1.0                    SOURCE....  INDMWT
   .800E-08   .100E-07   .150E-07   .200E-07   .280E-07   .380E-07D( 1) A D( 6) INDMWT
   .520E-07   .700E-07   .960E-07   .130E-06   .170E-06   .230E-06D( 7) A D(12) INDMWT
   .320E-06   .440E-06   .600E-06   .810E-06   .110E-05   .150E-05D(13) A D(18) INDMWT
   .210E-05   .290E-05   .380E-05   .540E-05   .720E-05   .990E-05D(19) A D(24) INDMWT
   .140E-04   .190E-04   .250E-04   .350E-04   .480E-04   .650E-04D(25) A D(30) INDMWT
   .900E-04   .120E-03   .170E-03   .230E-03   .320E-03   .440E-03D(31) A D(36) INDMWT
   .580E-03   .700E-03   .860E-03   .100E-02   .120E-02   .150E-02D(37) A D(42) INDMWT
   .180E-02   .220E-02   .260E-02   .320E-02   .380E-02   .460E-02D(43) A D(48) INDMWT
   .560E-02   .660E-02   .800E-02   .980E-02   .120E-01   .120E-01D(49) A D(54) INDMWT
  -.820E+03  -.500E+03  -.200E+03  -.100E+03  -.800E+02  -.400E+02P( 1) A P( 6) INDMWT
  -.250E+02  -.160E+02  -.100E+02  -.900E+01  -.750E+01  -.650E+01P( 7) A P(12) INDMWT
  -.550E+01  -.450E+01  -.350E+01  -.280E+01  -.220E+01  -.180E+01P(13) A P(18) INDMWT
  -.140E+01  -.100E+01  -.800E+00  -.775E+00  -.750E+00  -.725E+00P(19) A P(24) INDMWT
  -.700E+00  -.675E+00  -.650E+00  -.625E+00  -.600E+00  -.575E+00P(25) A P(30) INDMWT
  -.550E+00  -.525E+00  -.500E+00  -.475E+00  -.450E+00  -.425E+00P(31) A P(36) INDMWT
  -.400E+00  -.375E+00  -.350E+00  -.325E+00  -.300E+00  -.275E+00P(37) A P(42) INDMWT
  -.250E+00  -.225E+00  -.200E+00  -.175E+00  -.150E+00  -.125E+00P(43) A P(48) INDMWT
  -.100E+00  -.750E-01  -.500E-01  -.250E-01  -.000E+00  +.100E+07P(49) A P(54) INDMWT
       0.065      0.065      0.063      0.063                    W              INDMWT
       0.030      0.030      0.050      0.050                    WATL(ESTIME)   INDMWT
       0.520      0.520      0.520      0.520                    WATH(ESTIME)   INDMWT
         0.0        0.5        0.5        0.0                    RDF (ESTIME)   INDMWT
        0.00       0.65       0.50       0.50                    SE(M=MMHO/CM)  INDMWT
  TRUF                                                           IWRITE         INDMWT
     ENTREE INFILL
     ENTREE PREPAR
      1                                                          KSUP            PREPAR
      2    1    2 M.S. TIGES    (G/HA)     RANTHERIUM                            PREPAR
      2    1    3 M.S. RACINES (G/HA)      RANTHERIUM                            PREPAR
      1    1      M.S. TOTALE   (G/HA)     RANTHERIUM                            PREPAR
                                                                                 PREPAR
      2    2    3 M.S. RACINES (G/HA)      PLANTAGO                              PREPAR
      1    2      M.S. TOTALE   (G/HA)     PLANTAGO                              PREPAR
      2    3    2 M.S. TIGES    (G/HA)     AUTRES LIGNEUX                        PREPAR
      2    3    3 M.S. RACINES (G/HA)      AUTRES LIGNEUX                        PREPAR
      1    3      M.S. TOTALE   (G/HA)     AUTRES LIGNEUX                        PREPAR
                                                                                 PREPAR
      2    1    1 M.S. POUSSES (G/HA)      RANTHERIUM                            PREPAR
      2    2    1 M.S. POUSSES (G/HA)      PLANTAGO                              PREPAR
      2    3    1 M.S. POUSSES (G/HA)      AUTRES LIGNEUX                        PREPAR
      2    4    1 M.S. FEUILLES(G/HA)      ANNUELLES                             PREPAR
      2    4    2 M.S. RACINES (G/HA)      ANNUELLES                             PREPAR
      1    4      M.S. TOTALE   (G/HA)     ANNUELLES                             PREPAR
                                                                                 PREPAR
      3    1      M.S.  (G/HA) PARTIE AERIENNE SECHE                             PREPAR
      3    2      M.S.  (G/HA) LITIFRE                                           PREPAR
      3    3      M.S.  (G/HA) RACINES MORTES                                    PREPAR
                                                                                 PREPAR
      5    2     TEMPERATURE DE L'HORIZON 2 DU SOL/.05-40. CM                    PREPAR
      5    3     TEMPERATURE DE L'HORIZON 3 DU SOL/40-100 CM                     PREPAR
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284        7           TEMPERATURE (AIR)                                                   PREPAR
285        6          PLUIE (MM)                                                           PREPAR
286                                                                                        PREPAR
287          4    2     POTENTIEL EAU(BAR)-HOR.2(0.05 A 40.0 CM)                           PREPAR
288          4    3     POTENTIEL EAU(BAR)-HOR.3(40. A 100. CM)                            PREPAR
289                                                                                        PREPAR
290          9    2   EAU TOTALE (MM) DANS L'HORIZON 2/.05-40. CM                          PREPAR
291          9    3   EAU TOTALE (MM) DANS L'HORIZON 3/40-100 CM                           PREPAR
292                                                                                        PREPAR
293          8    1   PHENOLOGIE DE L'ESPECE 1(RANTHERIUM SUAV.)                           PREPAR
294          8    2   PHENOLOGIE DE L'ESPECE 2(PLANTAGO ALB.)                              PREPAR
295          8    3   PHENOLOGIE DE L'ESPECE 3(AUTRES LIGNEUX)                             PREPAR
296          8    4   PHENOLOGIE DE L'ESPECE 4 (ANNUELLES)                                 PREPAR
297                                                                                        PREPAR
298       100                                                                  FIN         PREPAR
299     LAST CARD
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*Output Example*

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                                   ........................
                                   .    G  A  B  E  S     .
                                   .    *************     .
                                   .         KM-52        .
                                   ........................
          (FRANCOIS ROMANE  - LOGAN, AVRIL 1974)
CECI EST UN  ESSAI ,POUR AJUSTER LES PARAMETRES.

  ENTREE INDMRP
  ENTREE INDMEX
  ENTREE INDMPN
  ENTREE INDMFO
  ENTREE INDMTR
  ENTREE INDMDT
  ENTREE INDMDM
  ENTREE INDMDL
  ENTREE INDMED
  ENTREE INDMEV
  ENTREE INDMDG
  ENTREE INDMWT
 WATER      POTENTIAL    CONDUCTIVITY DIFFUSIVITY        C(I)       DEPTH          W-DEPTH      H-DEPTH      RDF-DEPTH     SE-DEPTH
0.           -.8200E+06   .8000E-09    .2492E-03    .1093E-05  0.              .6500E-01   -.2085E+05   0.            0.
 .1000E-01   -.5085E+06   .1000E-08    .5607E-03    .1093E-05   .1000E+00      .6500E-01   -.2085E+05    .5000E+00    .5200E+02
 .2000E-01   -.2034E+06   .1500E-08    .1018E-02    .1093E-05   .7990E+02      .6300E-01   -.2268E+05    .5000E+00    .4127E+02
 .3000E-01   -.1017E+06   .2000E-08    .1222E-02    .1093E-05   .1200E+03      .6300E-01   -.2268E+05   0.            .4127E+02
 .4000E-01   -.8136E+05   .2800E-08    .1279E-02
 .5000E-01   -.4068E+05   .3800E-08    .1433E-02
 .6000E-01   -.2543E+05   .5200E-08    .1513E-02
 .7000E-01   -.1627E+05   .7000E-08    .1577E-02
 .8000E-01   -.1017E+05   .9600E-08    .1635E-02
 .9000E-01   -.9153E+04   .1300E-07    .1648E-02
 .1000E+00   -.7628E+04   .1700E-07    .1674E-02
 .1100E+00   -.6611E+04   .2300E-07    .1698E-02
 .1200E+00   -.5594E+04   .3200E-07    .1730E-02
 .1300E+00   -.4577E+04   .4400E-07    .1775E-02
 .1400E+00   -.3560E+04   .6000E-07    .1836E-02
 .1500E+00   -.2848E+04   .8100E-07    .1894E-02
 .1600E+00   -.2237E+04   .1100E-06    .1961E-02
 .1700E+00   -.1831E+04   .1500E-06    .2022E-02
 .1800E+00   -.1424E+04   .2100E-06    .2107E-02
 .1900E+00   -.1017E+04   .2900E-06    .2225E-02
 .2000E+00   -.8136E+03   .3800E-06    .2303E-02
 .2100E+00   -.7882E+03   .5400E-06    .2316E-02
 .2200E+00   -.7628E+03   .7200E-06    .2335E-02
 .2300E+00   -.7373E+03   .9900E-06    .2360E-02
 .2400E+00   -.7119E+03   .1400E-05    .2395E-02
 .2500E+00   -.6865E+03   .1900E-05    .2444E-02
 .2600E+00   -.6611E+03   .2500E-05    .2507E-02
 .2700E+00   -.6356E+03   .3500E-05    .2596E-02
 .2800E+00   -.6102E+03   .4800E-05    .2718E-02
 .2900E+00   -.5848E+03   .6500E-05    .2884E-02
 .3000E+00   -.5594E+03   .9000E-05    .3112E-02
 .3100E+00   -.5339E+03   .1200E-04    .3418E-02
 .3200E+00   -.5085E+03   .1700E-04    .3850E-02
 .3300E+00   -.4831E+03   .2300E-04    .4435E-02
 .3400E+00   -.4577E+03   .3200E-04    .5248E-02
 .3500E+00   -.4322E+03   .4400E-04    .6367E-02
 .3600E+00   -.4068E+03   .5800E-04    .7841E-02
 .3700E+00   -.3814E+03   .7000E-04    .9621E-02
 .3800E+00   -.3560E+03   .8600E-04    .1181E-01
 .3900E+00   -.3305E+03   .1000E-03    .1435E-01
 .4000E+00   -.3051E+03   .1200E-03    .1740E-01
 .4100E+00   -.2797E+03   .1500E-03    .2122E-01
 .4200E+00   -.2543E+03   .1800E-03    .2579E-01
 .4300E+00   -.2288E+03   .2200E-03    .3139E-01
 .4400E+00   -.2034E+03   .2600E-03    .3800E-01
 .4500E+00   -.1780E+03   .3200E-03    .4613E-01
 .4600E+00   -.1526E+03   .3800E-03    .5579E-01
 .4700E+00   -.1271E+03   .4600E-03    .6749E-01
 .4800E+00   -.1017E+03   .5600E-03    .8173E-01
 .4900E+00   -.7628E+02   .6600E-03    .9851E-01
 .5000E+00   -.5085E+02   .8000E-03    .1188E+00
 .5100E+00   -.2543E+02   .9800E-03    .1438E+00
 .5200E+00   0.           .1200E-02    .1743E+00
 .5300E+00    .1017E+10   .1200E-02    .1220E+07
DELX         DETT        GRAVY        CONQ         DELW         TIME
.7600E+01    .2400E-02   .7600E+01    .5000E-01    .1000E-01 0.
 TT           CUMT        TAA          HLOW         HHI          HRES
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```
 .1000E+01  .2400E+02  .1000E+01 -.1600E+05 0.           .1050E+01
  HDRY        HWET        CB          SYSTD
 -.3000E+05 0.          .1000E+01  .1000E+00
  WATL( 1)   WATL( 2)   WATL( 3)   WATL( 4)   WATL(
   .300E-01   .300E-01   .500E-01   .500E-01
  WATH( 1)   WATH( 2)   WATH( 3)   WATH( 4)   WATH(
   .520E+00   .520E+00   .520E+00   .520E+00
   ALAMBA      SOURCE       DIFO        DIFA        DIFB        SUCUN
  .1000E+01  0.          .1000E-01   .1000E-02   .1000E+01   .1000E+00
   ENTREE INFTLL


  GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS
 PROFONDEUR EAU(FRACT.) POTENTIEL  EXT. RAC.  CONC. SEL  QUANT. SEL TEMP. MIL. HOR.
  0.         .5700E-01 -.3000E+05 0.          0.         0.         .1110E+02
  .1000E+00  .6475E-01 -.2108E+05 0.          .5202E+02  .3368E+01  .1108E+02
  .7990E+02  .6300E-01 -.2268E+05 0.          .4127E+02  .2600E+01  .9118E+01
  .1200E+03  .6304E-01 -.2264E+05 0.          .4127E+02  .2602E+01
   DAY   CUM. HOURS  ET           EOR        CUM.TRANS.  RUNOFF      HROOT      CWF        CUMS
    1   .2400E+02  -.6118E-02  -.4894E-02  0.          0.          -.1600E+05 -.9906E-02 -.9906E-02


  GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS

 JOUR= 10 MOIS= 11 ANNEE 1971 JOURS SIMULES=    0

 PLUIE(MM) TEMP.(AIR)  DAPHOT   DAYRAD    DALITE    TRAIN
  0.         .111E+02  .991E+01  .275E+03  .222E-02 0.

          M.S./ORG.       M.S./SP.           PHENOLOGIE  LIGHTF      TEMPF      PHSF       PSRATE     PHSATE
  RANTH.S.               2108337.               3        0.          0.         0.         0.         0.
    POUSSES     31000.
    TIGES     1173000.
    RACINES    904337.
  PLANT.A.                145262.               3        0.          0.         0.         0.         0.
    POUSSES     23000.
    RACINES    122262.
  A. LIGNE                210681.               3        0.          0.         0.         0.         0.
    POUSSES     39000.
    TIGES       88000.
    RACINES     83681.
  ANNUELLE                 30940.               5        0.          0.         0.         0.         0.
    FEUILLES    17000.
    RACINES     13940.


  MATERIEL MORT
  P.A.S.                   27080.
  LITIERE                  84000.
  RAC.MORT                112422.
  PUITS                        0.


 ETAT HYDRIQUE DU SOL
  HORIZON  POTENTIEL(BARS)  EAU TOTALE    PF
     1          -29.50         0.03      4.47
     2          -20.72        25.87      4.32
     3          -22.30        37.77      4.35
     4          -22.26        12.64      4.35
 ET=-.6118E-02  EVAP=-.4894E-02CM/HEURE


  GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS
 PROFONDEUR EAU(FRACT.) POTENTIEL  EXT. RAC.  CONC. SEL  QUANT. SEL TEMP. MIL. HOR.
  0.         .5200E+00 0.         0.          0.         0.         .1110E+02
   .1000E+00  .7506E-01 -.1319E+05 0.          .5128E+02  .3849E+01  .1110E+02
   .7990E+02  .6300E-01 -.2268E+05 0.          .4127E+02  .2600E+01  .9858E+01
   .1200E+03  .6304E-01 -.2264E+05 0.          .4127E+02  .2602E+01
    DAY   CUM. HOURS  ET           EOR        CUM.TRANS.  RUNOFF      HROOT      CWF        CUMS
     9   .1000E+01  0.           .5000E+00  0.          .2606E+00  -.1600E+05  .4018E+00  .4739E+00


  GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS
 PROFONDEUR EAU(FRACT.) POTENTIEL  EXT. RAC.  CONC. SEL  QUANT. SEL TEMP. MIL. HOR.
  0.         .1798E+00 -.1432E+04 0.          0.         0.         .1110E+02
   .1000E+00  .8596E-01 -.9564E+04 0.          .5060E+02  .4349E+01  .1110E+02
   .7990E+02  .6300E-01 -.2268E+05 0.          .4127E+02  .2600E+01  .9858E+01
   .1200E+03  .6304E-01 -.2264E+05 0.          .4127E+02  .2602E+01
    DAY   CUM. HOURS  ET           EOR        CUM.TRANS.  RUNOFF      HROOT      CWF        CUMS
     9   .1000E+01  0.           .5000E+00  0.          .6433E+00  -.1600E+05  .8375E+00  .4357E+00


  GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS
 PROFONDEUR EAU(FRACT.) POTENTIEL  EXT. RAC.  CONC. SEL  QUANT. SEL TEMP. MIL. HOR.
  0.         .5200E+00 0.         0.          0.         0.         .1110E+02
   .1000E+00  .9730E-01 -.8040E+04 0.          .4998E+02  .4863E+01  .1110E+02
   .7990E+02  .6300E-01 -.2268E+05 0.          .4127E+02  .2600E+01  .9858E+01
   .1200E+03  .6304E-01 -.2264E+05 0.          .4127E+02  .2602E+01
    DAY   CUM. HOURS  ET           EOR        CUM.TRANS.  RUNOFF      HROOT      CWF        CUMS
     9   .1000E+01  0.           .5000E+00  0.          .4728E+00  -.1600E+05  .1290E+01  .4527E+00
```

```
 GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS
PROFONDEUR EAU(FRACT.) POTENTIEL  EXT. RAC.   CONC. SEL   QUANT. SEL TEMP. MIL. HOR.
 0.          .4155E+00 -.2656E+03 0.          0.          0.          .1110E+02
  .1000E+00  .1087E+00 -.6744E+04 0.           .4944E+02  .5374E+01  .1110E+02
  .7990E+02  .6300E-01 -.2268E+05 0.           .4127E+02  .2600E+01  .9858E+01
  .1200E+03  .6304E-01 -.2264E+05 0.           .4127E+02  .2602E+01
   DAY   CUM. HOURS  ET            EUR        CUM.TRANS.   RUNOFF      HROOT       CWF         CUMS
     9   .1000E+01  0.             .5000E+00  0.           .4499E+00  -.1600E+05   .1745E+01   .4550E+00
```

```
 GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS
PROFONDEUR EAU(FRACT.) POTENTIEL  EXT. RAC.   CONC. SEL   QUANT. SEL TEMP. MIL. HOR.
 0.          .4852E+00 -.8840E+02 0.          0.          0.          .1110E+02
  .1000E+00  .1211E+00 -.5484E+04 0.           .4892E+02  .5923E+01  .1110E+02
  .7990E+02  .6300E-01 -.2268E+05 0.           .4127E+02  .2600E+01  .9858E+01
  .1200E+03  .6304E-01 -.2264E+05 0.           .4127E+02  .2602E+01
   DAY   CUM. HOURS  ET            EUR        CUM.TRANS.   RUNOFF      HROOT       CWF         CUMS
     9   .1000E+01  0.             .5000E+00  0.           .4925E-01  -.1600E+05   .2240E+01   .4951E+00
```

```
 GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS
PROFONDEUR EAU(FRACT.) POTENTIEL  EXT. RAC.   CONC. SEL   QUANT. SEL TEMP. MIL. HOR.
 0.          .5200E+00 0.         0.          0.          0.          .1110E+02
  .1000E+00  .1323E+00 -.4345E+04 0.           .4849E+02  .6414E+01  .1110E+02
  .7990E+02  .6300E-01 -.2268E+05 0.           .4127E+02  .2600E+01  .9858E+01
  .1200E+03  .6304E-01 -.2264E+05 0.           .4127E+02  .2602E+01
   DAY   CUM. HOURS  ET            EUR        CUM.TRANS.   RUNOFF      HROOT       CWF         CUMS
     9   .1000E+01  0.             .5000E+00  0.           .5260E+00  -.1600E+05   .2688E+01   .4474E+00
```

```
 GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS
PROFONDEUR EAU(FRACT.) POTENTIEL  EXT. RAC.   CONC. SEL   QUANT. SEL TEMP. MIL. HOR.
 0.          .5700E-01 -.3000E+05 0.          0.          0.          .1110E+02
  .1000E+00  .1311E+00 -.4469E+04 -.1681E-05  .4854E+02  .6361E+01  .1110E+02
  .7990E+02  .6300E-01 -.2268E+05 0.           .4127E+02  .2600E+01  .9858E+01
  .1200E+03  .6305E-01 -.2264E+05 0.           .4127E+02  .2602E+01
   DAY   CUM. HOURS  ET            EUR        CUM.TRANS.   RUNOFF      HROOT       CWF         CUMS
     9   .1800E+02  -.5973E-02  -.4778E-02  -.1230E-02  0.          -.1600E+05   .2639E+01  -.4723E-01
```

```
 GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS

JOUR= 18 MOIS= 11 ANNEE 1971 JOURS SIMULES=    8

PLUIE(MM) TEMP.(AIR)  DAPHOT   DAYRAD    DALITE    TRAIN
  .300E+02  .111E+02  .968E+01  .275E+03  .217E-02  .600E+01

          M.S./ORG.        M.S./SP.            PHENOLOGIE  LIGHTF     TEMPF      PHSF      PSRATE     PHSATE
 RANTH.S.                 2109435.                3        .786E+00  .956E+00  .308E+00  .116E-01  .338E+03
   POUSSES      28946.
   TIGES      1174468.
   RACINES     906020.
 PLANT.A.                  147285.                3        .786E+00  .956E+00  .308E+00  .116E-01  .269E+03
   POUSSES      23272.
   RACINES     124013.
 A. LIGNE                  214015.                3        .786E+00  .956E+00  .308E+00  .116E-01  .425E+03
   POUSSES      36416.
   TIGES        90957.
   RACINES      86641.
 ANNUELLE                   27754.                5        .786E+00  .956E+00  .100E+01  .376E-01 0.
   FEUILLES     15249.
   RACINES      12504.


 MATERIEL MORT
 P.A.S.                     30629.
 LITIERE                    78286.
 RAC.MORT                  118828.
 PUITS                      19036.


ETAT HYDRIQUE DU SOL
 HORIZON  POTENTIEL(BARS)  EAU TOTALE     PF
    1            -29.50       0.03       4.47
    2             -4.39      52.36       3.64
    3            -22.30      37.77       4.35
    4            -22.26      12.64       4.35
ET=-.5973E-02  EVAP=-.4778E-02CM/HEURE
```

```
 GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS
PROFONDEUR EAU(FRACT.) POTENTIEL  EXT. RAC.   CONC. SEL   QUANT. SEL TEMP. MIL. HOR.
 0.          .5700E-01 -.3000E+05 0.          0.          0.          .1110E+02
  .1000E+00  .1333E+00 -.4246E+04 -.1794E-05  .4846E+02  .6458E+01  .1110E+02
  .7990E+02  .6302E-01 -.2266E+05 0.           .4127E+02  .2601E+01  .1052E+02
  .1200E+03  .6306E-01 -.2262E+05 0.           .4127E+02  .2602E+01
   DAY   CUM. HOURS  ET            EUR        CUM.TRANS.   RUNOFF      HROOT       CWF         CUMS
    22   .2400E+02  -.5801E-02  -.4641E-02  -.1757E-02  0.          -.1600E+05   .2728E+01  -.6491E-01
```

```
 GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS

JOUR=  1 MOIS= 12 ANNEE 1971 JOURS SIMULES=   21

PLUIE(MM) TEMP.(AIR)  DAPHOT    DAYRAD     DALITE     TRAIN
 0.         .111E+02  .940E+01  .275E+03  .211E-02 0.

         M.S./ORG.        M.S./SP.             PHENOLOGIF  LIGHTF      TEMPF      PMSF      PSRATE     PHSATE
 RANTH.S.                 2110833.                 3       .786E+00  .956E+00  .309E+00  .116E-01  .303E+03
   POUSSES        25899.
   TIGES        1176517.
   RACINES       908417.
 PLANT.A.                  150626.                 3       .786E+00  .956E+00  .309E+00  .116E-01  .275E+03
   POUSSES        23723.
   RACINES       126902.
 A. LIGNE                  218944.                 3       .786E+00  .956E+00  .309E+00  .116E-01  .381E+03
   POUSSES        32583.
   TIGES          95335.
   RACINES        91026.
 ANNUELLE                   22805.                 5       .786E+00  .956E+00  .100E+01  .376E-01 0.
   FEUILLES       12530.
   RACINES        10275.


 MATERIEL MORT
 P.A.S.                     49172.
 LITIERE                    52787.
 RAC.MORT                  151584.
 PUITS                     117818.


ETAT HYDRIQUE DU SOL
 HORIZON  POTENTIEL(BARS)  EAU TOTALE    PF
    1          -29.50        0.03      4.47
    2           -4.17       53.24      3.62
    3          -22.29       37.78      4.35
    4          -22.25       12.64      4.35
ET=-.5801E-02  EVAP=-.4641E-02CM/HEURE
```

```
  GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS
 PROFONDEUR EAU(FRACT.) POTENTIEL  EXT. RAC.  CONC. SEL  QUANT. SEL TEMP. MIL. HOR.
  0.         .5700E-01 -.3000E+05 0.         0.         0.         .1020E+02
   .1000E+00  .1319E+00 -.4388E+04 -.1725E-05  .4852E+02  .6398E+01  .1021E+02
   .7990E+02  .6303E-01 -.2265E+05 0.          .4127E+02  .2601E+01  .1079E+02
   .1200E+03  .6308E-01 -.2261E+05 0.          .4127E+02  .2603E+01
   DAY    CUM. HOURS  ET          EOR         CUM.TRANS.   RUNOFF         HROUT         CWF           CUMS
    36   .2400E+02  -.5534E-02  -.4427E-02  -.1689E-02  0.             -.1600E+05   .2673E+01   -.6323E-01
```

```
 GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS

JOUR= 15 MOIS= 12 ANNEE 1971 JOURS SIMULES=   35

PLUIE(MM) TEMP.(AIR)  DAPHOT    DAYRAD     DALITE     TRAIN
 0.         .102E+02  .925E+01  .275E+03  .208E-02 0.

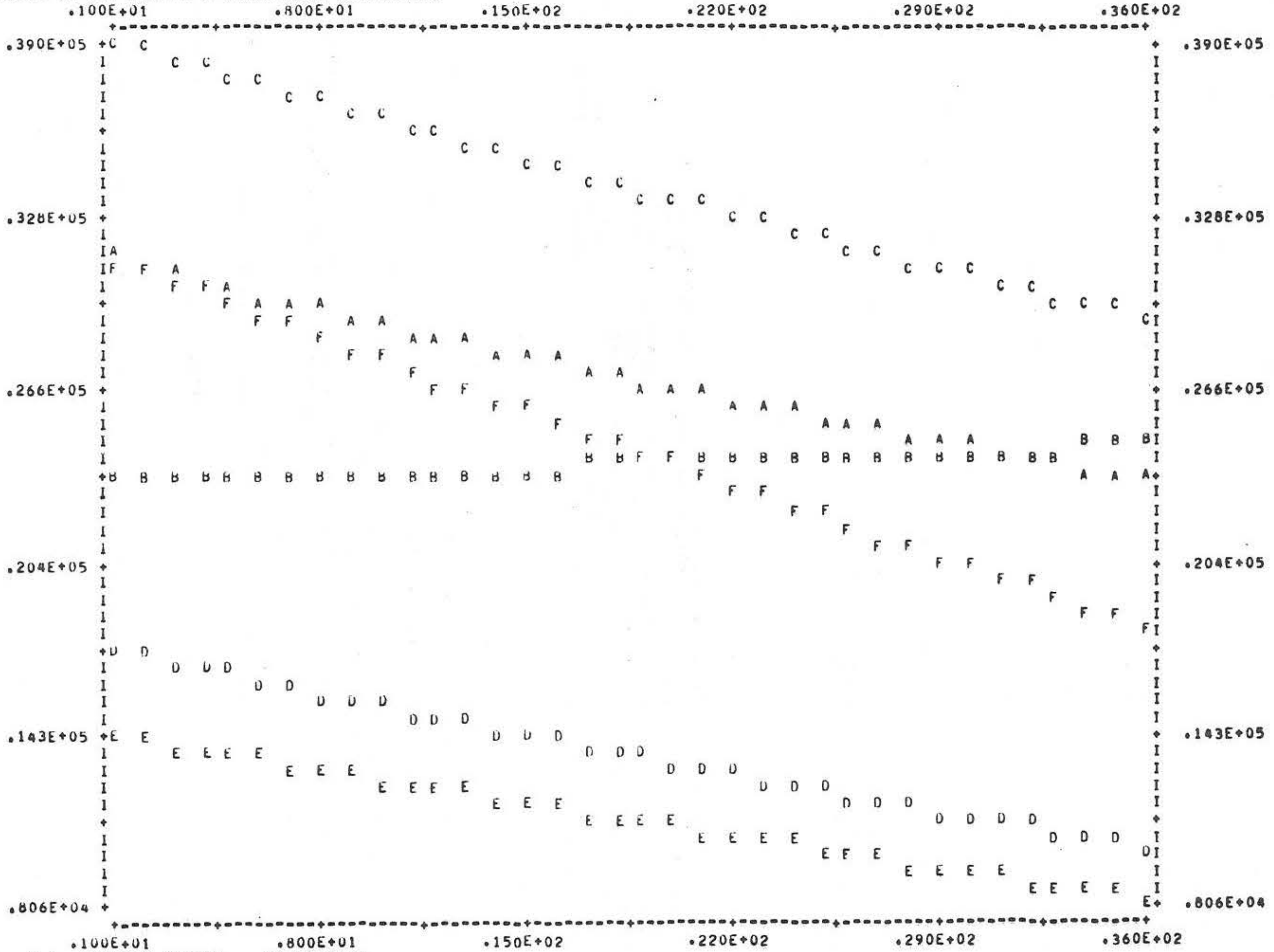
         M.S./ORG.        M.S./SP.             PHENOLOGIE  LIGHTF      TEMPF      PMSF      PSRATE     PHSATE
 RANTH.S.                 2111869.                 3       .786E+00  .992E+00  .309E+00  .120E-01  .279E+03
   POUSSES        22992.
   TIGES        1178300.
   RACINES       910576.
 PLANT.A.                  154314.                 3       .786E+00  .992E+00  .309E+00  .120E-01  .291E+03
   POUSSES        24238.
   RACINES       130076.
 A. LIGNE                  223656.                 3       .786E+00  .992E+00  .309E+00  .120E-01  .351E+03
   POUSSES        28926.
   TIGES          99517.
   RACINES        95213.
 ANNUELLE                   17896.                 5       .786E+00  .992E+00  .100E+01  .390E-01 0.
   FEUILLES        9833.
   RACINES         8063.


 MATERIEL MORT
 P.A.S.                     83543.
 LITIERE                    25270.
 RAC.MORT                  210013.
 PUITS                     302573.


ETAT HYDRIQUE DU SOL
 HORIZON  POTENTIEL(BARS)  EAU TOTALE    PF
    1          -29.50        0.03      4.47
    2           -4.31       52.68      3.63
    3          -22.27       37.79      4.35
    4          -22.23       12.65      4.35
ET=-.5534E-02  EVAP=-.4427E-02CM/HEURE
   ENTREE PREPAR
```

```
SYMBOLES SUPERPOSES DANS LE GRAPHIQUE SUIVANT(A=ANCIEN.N=NOUVEAU)
PAS JOUR A=N*PAS JOUR A=N*PAS JOUR A=N*PAS JOUR A=N*PAS JOUR A=N*PAS JOUR A=N*PAS JOUR A=N*PAS JOUR A=N*PAS JOUR A=N*PAS JOUR A=N*
  2    2. A=F*  4    4. A=F* 19  19. B=F* 20  20. B=F* 31  31. A=B* 32  32. A=B* 33  33. A=B*
```

GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS



```
A   M.S. POUSSES (G/HA)    RANTHERIUM
B   M.S. POUSSES (G/HA)    PLANTAGO
C   M.S. POUSSES (G/HA)    AUTRES LIGNEUX
D   M.S. FEUILLES(G/HA)    ANNUELLES
E   M.S. RACINES (G/HA)    ANNUELLES
F   M.S. TOTALE  (G/HA)    ANNUELLES
1 COLONNE EN ABSCISSE=  .350E+00  1 LIGNE EN ORD.=  .619E+03
```

```
SYMBOLES SUPERPOSES DANS LE GRAPHIQUE SUIVANT(A=ANCIEN,N=NOUVEAU)
PAS JOUR A=N*PAS JOUR A=N*PAS JOUR A=N*PAS JOUR A=N*PAS JOUR A=N*PAS JOUR A=N*PAS JOUR A=N*PAS JOUR A=N*PAS JOUR A=N*PAS JOUR A=N*


 GABES KM 52. STEPPE A RANTHERIUM SUAVEOLENS
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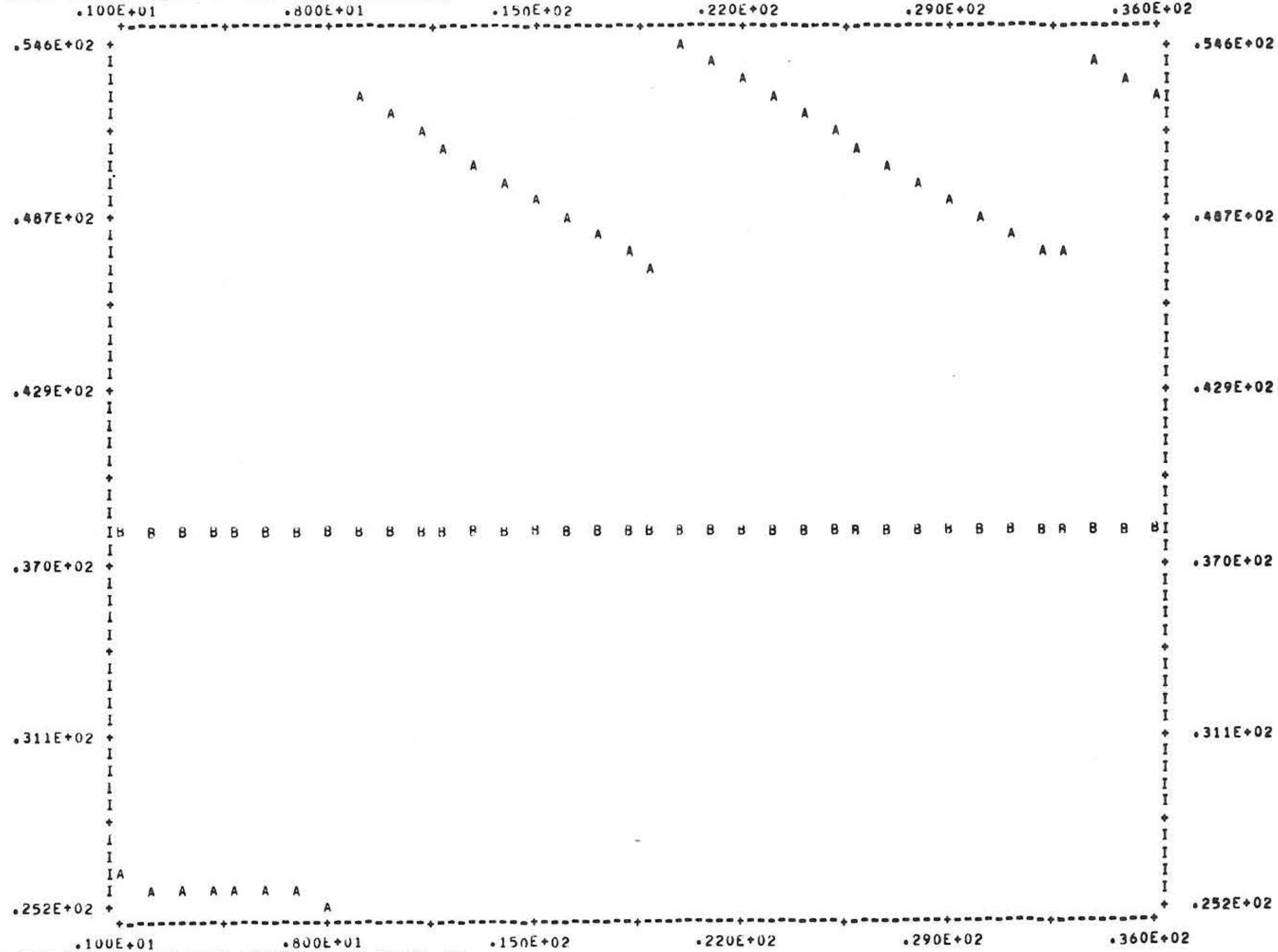

```
A  EAU TOTALE (MM) DANS L'HORIZON 2/.05-40. CM
B  EAU TOTALE (MM) DANS L'HORIZON 3/40-100 CM
1 COLONNE EN ABSCISSE=  .350E+00  1 LIGNE EN ORD.=  .587E+00
```

1972/73 PROGRESS REPORT

# A MODEL OF PHOTOSYNTHESIS FOR DESERT SPECIES

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Australian National University
Canberra

**US/IBP DESERT BIOME**
**RESEARCH MEMORANDUM 74-56**

**in**

**REPORTS OF 1973 PROGRESS**
**Volume 1: Central Office, Modelling**
Auxiliary Submodels Section, pp. 31-41

**MAY, 1974**

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Utah State Univ., Logan. 11 pp.

Ecology Center, Utah State University, Logan, Utah 84322

# GENERAL INTRODUCTION

Several models of photosynthesis of varying resolution levels and to differing degrees of completion have been prepared.

At a meeting of experimental workers and modellers held in Logan on October 5, 1972, it appeared that there was a general desire for two classes of models, one suitable for plants which possess crassulacean acid metabolism and one for other plants. Within these two divisions, two levels of complexity were also desirable. I decided upon three levels of complexity, resulting in a plan for a potential of six models.

Data for plants with non-crassulacean acid metabolism (*Artemisia tridentata*) came to hand immediately after the meeting and these were used to prepare models for this class of plant. The first and second level models have been completed, debugged and given limited exercise. Their outputs are presented later. The third level model is coded and hopefully may be debugged and running also.

Data for *Ambrosia dumosa* have since arrived but there will not be time to utilize them. At a suitable place in the model descriptions it will be indicated where and how they should be utilized.

Data for plants with crassulacean acid metabolism have been received but the models in this area have been taken only to a preliminary stage. At the lowest level of complexity, a model has been coded and recorded on Fastrand, but it lacks driving data and so cannot be debugged at present. The second and third levels of complexity have been taken only to the box and arrow diagram stage. The data would permit further development of these models, but time does not.

The data used in devloping these models were collected and provided by M. M. Caldwell and E. De Puit (*Artemisia tridenta*); S. Bamberg (*Ambrosia dumosa*); and I. Ting (crassulacean acid metabolism plants).

Symbology used for these models is as follows:

| Level | Non-CAM | Stage reached | CAM | Stage reached |
|---|---|---|---|---|
| First | PHOTO1 | running | PHOTO2 | coded |
| Second | PHOTO3 | running | PHOTO4 | planned |
| Third | PHOTO5 | running? | PHOTO6 | planned |

# SUBMODEL PHOTO1

First level of resolution, non-CAM plants.

## INTRODUCTION AND SIMPLIFYING ASSUMPTIONS

This model considers photosynthesis as the net flow of carbon from the atmospheric pool into the plant (see PHOTO1 diagram). Respiration, the reverse direction flow, is not considered explicitly. The only factors considered to influence the net flow of carbon are irradiance, temperature, plant water potential, and phenological stage. The temperature used is air temperature.

## VERBAL DESCRIPTION -- WORD MODEL

The driving variables consist of experimental data on the effects of irradiance, temperature and plant water potential at several phenological stages on the photosynthesis of *Artemisia tridentata* at Green Canyon (near Logan, Utah) in 1971. Radiation is supplied as daily totals of photosynthetically active radiation (global radiation, solar and scattered x 0.47) measured above the Natural Resources-Biology building at Utah State University in 1971.

There are two state variables, the atmospheric pool of $CO_2$ and the photosynthate. Since the first of these is

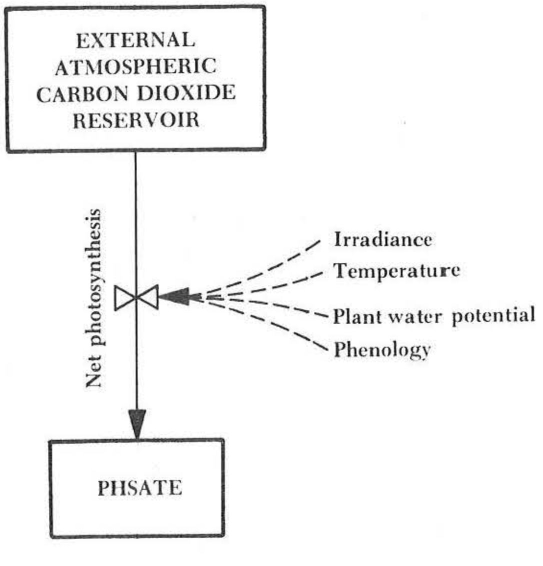


PHOTO1

effectively infinite in size and since variations in $CO_2$ concentration are not considered to influence the net flow, it is not explicitly modelled although it is conceptually necessary. The second state variable is contained within the calling routine VEGET where it is called PHSATE. Hence this subroutine effectively only calculates the rate of the net flow of carbon, PSRATE.

There is one process, net flow of carbon, and this is considered to be controlled by four information flows. These are irradiance, temperature, plant water potential, and phenological stage. The effect of each of these factors is scaled from 0 to 1.

The last of these, phenological stage, is provided for by supplying the driving data in sets, each set applying to one particular phenological stage. These stages are identified by the subscript (M) and the cycling through the values of (m), (8) is provided within VEGET. Thus no equation for the effect of phenology is provided.

The effect of irradiance is provided for by an equation which relates irradiance to rate of net photosynthesis, which is of the Michaelis-Menton form. The effect of temperature is obtained by interpolating linearly between data values, using the function subroutine AINT3. The effect of plant water potential is obtained in the same way. All three effects are expressed on the scale 0-1.

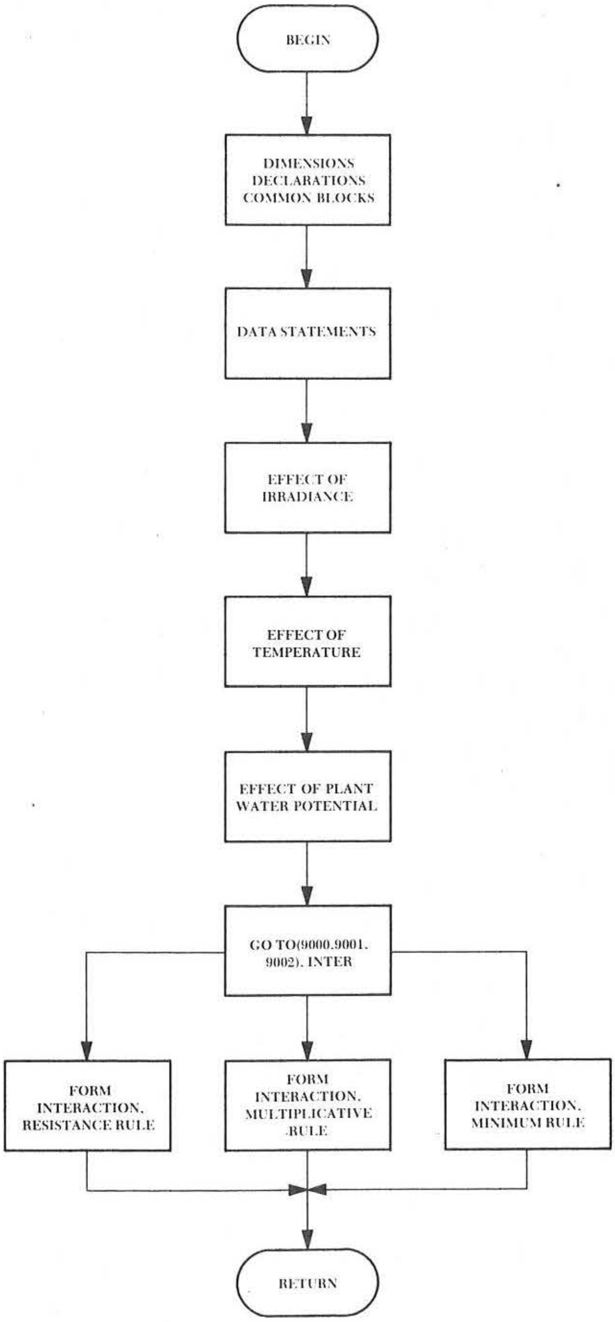
The interaction between these three controlling factors may be chosen from three possible alternatives. Which of these three alternatives is actually used depends on the value of INTER which is allotted in PHOTOSDATA.

When INTER = 1 the interaction is formed by regarding the three effects as conductances (in the electrical analogue sense). The overall conductance is given by taking the reciprocal of the sum of the reciprocal conductances, or the resistances. This overall conductance is then multiplied by the number of factors concerned (3) and by the maximum photosynthetic rate available in the data, expressed as g carbon/g protein carbon.

When INTER = 2 the interaction is formed by multiplying the three conductances together, i.e., the overall conductance is considered to be the product of the individual conductances. This product is then multiplied by the maximum photosynthetic rate as before.

When INTER = 3 the interaction is obtained by selecting the smallest of the three conductances and multiplying the maximum rate of photosynthesis available in the data by this. This applies the concept of limiting factors.

Since the available data are expressed in terms of rates per hour it was convenient to make all the calculations as rates per hour, multiplying the final rate by the photoperiod length in hours to obtain the daily rates. This has the advantage that it provides for the possibility of utilizing hourly values of irradiance, temperature and plant water potential if or when they should become available. This is done in other models of this series.



FLOW DIAGRAM

### ALPHABETICAL LIST OF VARIABLE NAMES -- A USER-DEFINED FUNCTION FOR INTERPOLATING VALUES FROM A TABLE SUPPLIED

CURV = The curvature parameter for the photosynthesis irradiation curve, calories/$cm^2$/hr.
DAPHOT = The photoperiod, hours.
IDAY = The current time interval.
I = The counter for cohorts.
IRADF = The effect of irradiation on photosynthesis, 0-1.
IRRAD = The actual radiation (400-700) for the day, cal/$cm^2$.
IRRADM = The average radiation per hour for the day, cal/$cm^2$.
M = The counter for the phenological stage.
MNPHOT = Net photosynthesis calculated by the minimum rule, g C/g protein C/hr.
MTPHOT = Net photosynthesis calculated by the multiplicative rule, g C/g protein C/hr.
NFACT = The number of factors affecting the process.
NTPHOT = Net photosynthesis calculated by the resistance formula, g C/g protein C/hr.
PMAXI = The maximum rate of photosynthesis on the scale 0-1.
PMAXL = The maximum rate of photosynthesis available in the data, mg $CO_2$/dm $leaf^2$ (2 sides)/hr.
PMAXN = The maximum photosynthetic rate g $CO_2$/g protein C/day.
PSRATE = The photosynthetic rate, g C/g protein C/day.
PWPOT = The average plant water potential for the month, bars.
PWPOTF = The effect of plant water potential on photosynthesis, 0-1.
PWPX = The set of X values for the PWP data, bars.
PWPY = The corresponding set of Y values, 0-1.
TDAY = The average daytime temperature, °C.
TEMPF = The effect of temperature on photosynthesis, 0-1.
TEMPX = The set of X values for the effect of temperature on photosynthesis (DATA), °C.
TEMPY = The corresponding set of Y values, 0-1.

## SUBMODEL PHOTO 2

First level of resolution, CAM plants.

### INTRODUCTION AND SIMPLIFYING ASSUMPTIONS

In this model, only the net flow of carbon from the atmosphere into the plant is considered, where it is regarded as being a part of the organic acid pool. Thus it concerns itself only with $CO_2$ fixation, which in CAM plants is a "dark" process, and decarboxylations and subsequent photosynthesis of released $CO_2$ are regarded as internal rearrangements within the internal pool of carbon compounds. If this results in loss of $CO_2$, this loss will be accounted for by the use of **net** uptake.

The net uptake of $CO_2$ is modelled as being influenced by irradiance (which in this case means its effect on stomatal aperture, not on photosynthesis), temperature, plant water potential, and the size of the organic acid pool.

### VERBAL DESCRIPTION -- WORD MODEL

The data from Dr. Ting arrived too late to be used. Hopefully it will be possible to replace that being used (which is not relevant, being carried over from PHOTO1) with Dr. Ting's data.

The program as it stands is to be regarded as a sketch or illustration of an idea, which may need to be changed to fit the data which are actually to be used. In it, the effect of irradiation (IRADF) is read from a table of supplied data by

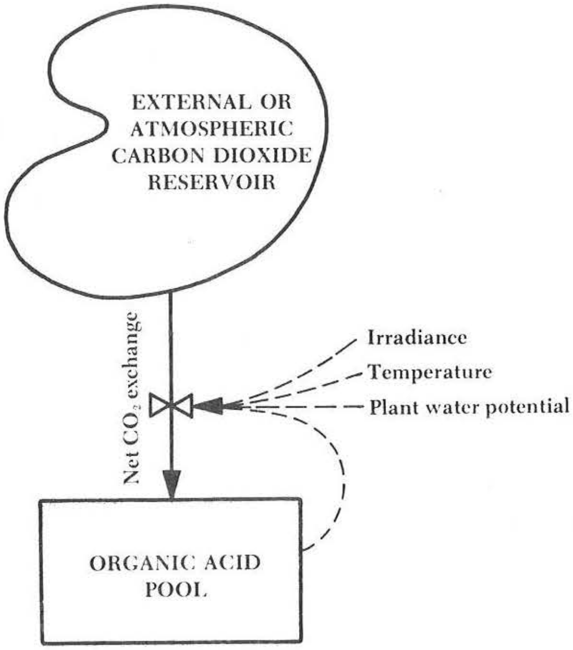


PHOTO2

the interpolation routine, AINT3. So are the effects of temperature (TEMPF) and of plant water potential (PWPOTF). The effect of the organic acid pool size (ORAGCF) is modelled as a descending curve from the maximum value (1) at zero pool size to minimum (0) at a pool size of 1.0 g C/g protein C(value of BBB). The curve is a generalized Poisson density function, the parameters of which may be varied to match the curve to data if it becomes available. However, such data may be hard to obtain and the curve may need to be shaped on theoretical grounds. The organic acid pool is accumulated and used as a parameter in the equation. The four factors are combined as in the other models of the series by means of a choice of three interaction mechanisms, the resistance formula, the multiplicative rule and the minimum rule.

## ALPHABETICAL LIST OF VARIABLE NAMES

AAA = The photosynthate level at which photosynthesis is maximal.
AINT3 = A user-defined function for interpolating values from a table supplied.
FXMAXL = The maximum rate of fixation available in data.
FXMAXN = The maximum rate of fixation g $CO_2$/g protein C/day.
DAPHOT = The photoperiod, hours.
I = The counter for cohorts.
IDAY = The current time interval.
INTER = The integer label used in VEGET to select the interaction which is to be used: 1 = resistance formula; 2 = multiplicative rule; 3 = minimum rule.
IRADF = The effect of irradiation on photosynthesis, 0-1, leaf.
IRRAD = The actual radiation (400-700) for the day, cal/$cm^2$.
IRRADM = The average radiation per hr for the day, cal/$cm^2$.
M = The counter for the phenological stage.
MNFIX = Net fixation calculated by the minimum rule, g C/g protein C/hr.
MTFIX = Net fixation calculated by the multiplicative rule, g C/g protein C/hr.
NFACTP = The number of factors influencing photosynthesis.
PWPOT = The average plant water potential for the month, bars.
PWPOTF = The effect of plant water potential on photosynthesis, 0-1.
PWPX = The set of X values for the PWP data, bars.
PWPY = The corresponding set of Y values, 0-1.
RSFIX = Net fixation calculated by the resistance formula, g C/g protein C/hr.
TDAY = The average daytime temperature, °C.
TEMPF = The effect of temperature on photosynthesis, 0-1, respiration.
TEMPX = The set of X values for the effect of temperature on photosynthesis (data) °C.
TEMPY = The corresponding set of Y values, 0-1.
ZZZ = An intermediate variable defined in the context of use.

# SUBMODEL PHOTO3

Second level of resolution, non-CAM plants.

## INTRODUCTION AND SIMPLIFYING ASSUMPTIONS

This model considers influx of carbon dioxide into the leaf as well as efflux from it, gross photosynthesis and dark respiration (see PHOTO3 diagram). Photorespiration is assumed to be present and net photosynthesis is obtained as the algebraic sum of gross photosynthesis and dark respiration. The temperature used is air temperature.

## VERBAL DESCRIPTION -- WORD MODEL

The driving variables consist of experimental data on the effects of irradiance, temperature and plant water potential at several phenological stages on the photosynthesis of *Artemisia tridentata* at Green Canyon in 1971. Radiation is supplied as daily totals of photosynthetically active radiation (global radiation, solar and scattered x 0.47) measured above the Natural Resources-Biology building at

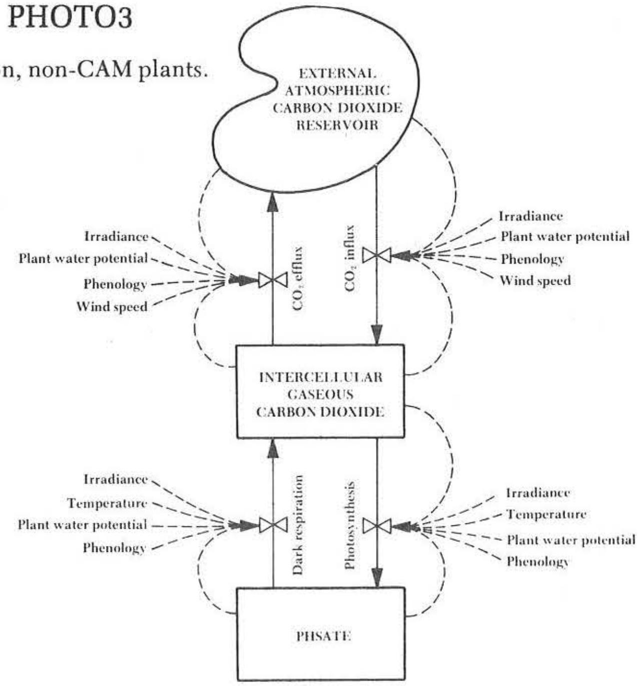


PHOTO3

USU in 1971. Wind speed used is that supplied by EXOGEN as DWINAV.

There are three state variables; the atmospheric pool of $CO_2$, intercellular gaseous $CO_2$ and the photosynthate. Since the first of these is effectively infinite in size, its magnitude is not monitored but is regarded as a constant. The third state variable is contained within the calling routine VEGET where it is called PHSATE. It is therefore not updated in this subroutine.

Carbon dioxide efflux and influx are both controlled by the same information flows, internal and external $CO_2$ concentrations, irradiance, plant water potential, wind speed, and phenological state. These controls are all assumed to act via the same mechanisms for efflux and influx, the only difference being the difference of direction of the flow. All controls are scaled from 0-1.

The effect of phenological stage is provided for by supplying the driving data in sets, each set applying to one particular phenological stage. These stages are identified by the subscript (M), and the cycling through the values of (M), (8) is provided within VEGET. Thus no equation for the effect of phenology is provided.

The effect of irradiance is provided as a linear increase of $CO_2$ flow as irradiance increases from 0 to 5 calories/cm$^2$/hr, the flow varying from 0 to 1 in this range. At levels of irradiance above this the rate of flow is set equal to 1. This amounts to assuming that stomatal resistance decreases linearly with irradiance from 0 to 5 calories/cm$^2$/hr at which level it is nonlimiting. This is, of course, a simplification of the probable state of affairs and is a point at which refinement might be introduced if the necessary data became available.

The effect of wind speed is handled as a linear increase of flow of carbon dioxide from 0.01 to 1 as the wind speed increases from 1 km/hr to 20 km/hr. Below 1 km/hr, wind speed is considered to be without effect but this does not prevent passage of $CO_2$ as would be implied by use of the factor 0. Instead, the factor 0.01 is employed as an estimate of the rate of passage of $CO_2$ to or from the bulk air by diffusion alone. Between wind speeds of 20 km/hr and 40 km/hr no change in rate of $CO_2$ passage occurs, but above this speed, a step function is employed to reduce passage of $CO_2$ drastically, simulating stomatal closure. The use of the factor 0.000001 simulates cuticular diffusion under these conditions.

Since no data are available for the effect of plant water potential on carbon dioxide efflux and influx, a simple linear relationship is assumed, with a negative slope from the value of 1 at 0 plant water potential to 0 at plant water potential of -30 bars.

The effects of external and internal concentrations of gaseous $CO_2$ are handled by calculating the differential and using the Ohm's law analogy, the resistance used being the reciprocal of the effect of irradiation, which is equivalent to stomatal aperture.

Dark respiration is regarded as being controlled by irradiance (photorespiration), temperature, plant water potential, photosynthate level, and phenological status. Phenological status is handled by the method already described.

Photorespiration has been assumed to be related to irradiance by a Michaelis-Menton curve, plateauing at 30 calories/cm$^2$/hr and reaching half the maximum rate at 6 calories/cm$^2$/hr.

The effects of temperature and of plant water potential are documented in the data provided by Caldwell and DePuit. Use is therefore made of the interpolation routine to read suitable values for these factors from the data.

The effect of photosynthate level on dark respiration has also been assumed to follow Michaelis-Menton kinetics with a maximum rate at 1.0 g C/g protein C and half the maximum rate at 0.02 g C/g protein C.

Photosynthesis is controlled in this model by irradiance, temperature, plant water potential, phenology, intercellular gaseous $CO_2$ concentration, and level of photosynthate.

The effect of irradiance is a hyperbolic curve with half the maximum rate being reached at 10.0 calories/cm$^2$ for phenological stages 1 and 3 to 8, 16.6 calories /cm$^2$ at phenological stage 2 (data of Caldwell and De Puit).

The effects of temperature and of plant water potential are read from data tables by means of the interpolation routine.

The effect of photosynthate level is modelled as a curve which falls from 1 at 0 photosynthate, to 0 at a photosynthate level of 1.0 g C/g protein carbon, following the curve of a generalized Poisson density function.

The effect of internal $CO_2$ concentration is handled as a hyperbolic function with half the maximum rate being reached at $6 \times 10^{-7}$ g C/g protein C.

In all cases, the interaction between the various controlling factors may be chosen (by means of the value allotted to INTER in PHOTOSDATA) from the resistance rule, the multiplicative rule or the minimum rule. Reference should be made to the documentation of PHOTO1 for details.

The relationship between net and gross photosynthesis has been handled in the following way. The data for photosynthesis are always for net photosynthesis. However, data for dark respiration are also available. Therefore, gross photosynthesis has been calculated as net photosynthesis plus dark respiration for the duration of the photoperiod. The net photosynthetic rate which is provided as final output is then calculated as the gross photosynthesis minus the dark respiration for the whole 24 hr.

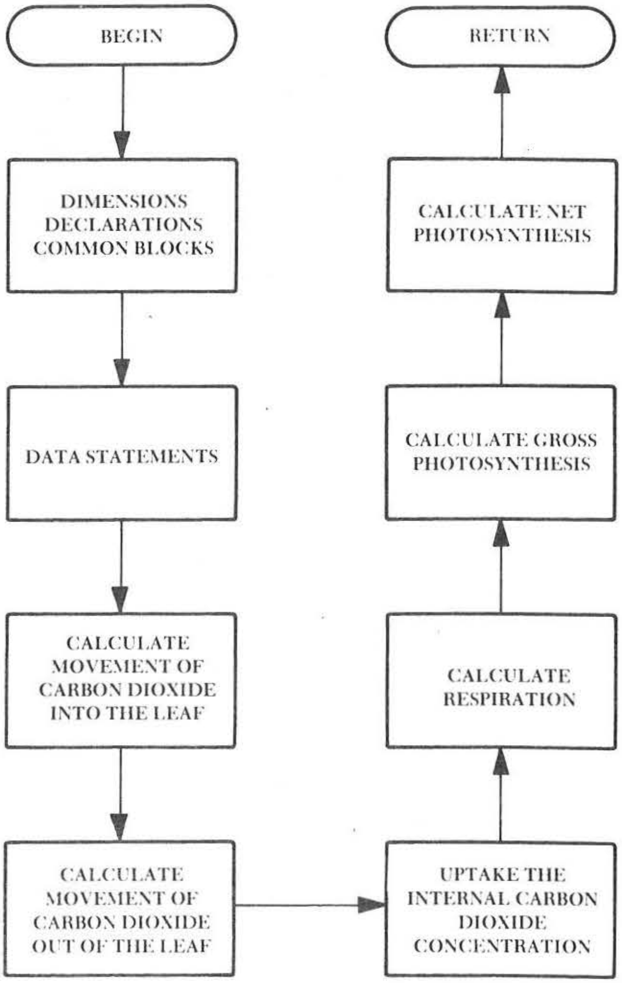
## ALPHABETICAL LIST OF VARIABLE NAMES

AAA = The photosynthate level at which photosynthesis is maximal.

AINT3 = A user-defined function for interpolating values from a table supplied.

BBB = The level of photosynthate in the leaves at which photosynthesis is reduced to zero.

CCC = See DDD



FLOW DIAGRAM

CO2IRT = Rate of movement of $CO_2$ into leaf, g C/g protein C/hr.

CO2ORT = Rate of movement of $CO_2$ out of the leaf, g C/g protein C/hr.

CURV = The curvature parameter for the photosynthesis/irradiation curve.

DAPHOT = The photoperiod, hours.

DCO2 = The differential $CO_2$ concentration inside/outside the leaf.

DCO2F = The effect of $CO_2$ differential on movement of $CO_2$ into or out of the leaf.

DDD = Shape parameters for the curve of photosynthesis/photosynthate.

I = The counter for cohorts.

ICO2PF = The effect of internal $CO_2$ concentration on photosynthesis, 0-1.

IDAY = The current time interval.

INCO2 = Amount of $CO_2$ inside the leaf air spaces, g C/g protein C.

INCO2C = Concentration of $CO_2$ in leaf intercellular spaces, g C/ml.

INTER = The integer label used in VEGET to select the interaction which is to be used: 1 = resistance formula; 2 = multiplicative rule; 3 = minimum rule.

IRADF = The effect of irradiation on photosynthesis, 0-1.

IRADIF = Effect of irradiation on rate of movement of $CO_2$ into the leaf.

IRADOF = The effect of irradiation on movement of $CO_2$ out of the leaf.

IRRAD = The actual radiation (400-700) for the day, $cal/cm^2$.

IRRADM = The average radiation per hour for the day, $cal/cm^2$.

M = The counter for the phenological stage.

MNCO2I = Rate of movement of $CO_2$ into leaf calculated using the minimum rule.

MNCO2O = Rate of movement of $CO_2$ out of leaf calculated using the minimum rule.

MNPHOT = Net photosynthesis calculated by the minimum rule, g C/g protein C/hr.

MTPHOT = Net photosynthesis calculated by the multiplicative rule, g C/g protein C/hr.

MNRESP = Respiration calculated by the minimum rule.

MTCO2I = Rate of movement of $CO_2$ into leaf calculated using the multiplicative rule.

MTCO2O = Rate of movement of $CO_2$ out of leaf calculated using the multiplicative rule.

MTRESP = Respiration calculated by the multiplicative rule.

NEWPHL = New photosynthate in the leaf, g C/g protein C.

NFACTI = The number of factors influencing movement of $CO_2$ into a leaf.

NFACTO = The number of factors affecting movement of $CO_2$ out of the leaf.

NFACTP = The number of factors influencing photosynthesis.
NFACTR = The number of factors influencing respiration.
OUTCO2 = The external air $CO_2$ concentration, g/mg.
PMAXI = The maximum rate of photosynthesis on the scale 0-1.
PMAXL = The maximum rate of photosynthesis available in the data, mg $CO_2/dm^2$ leaf (2 sides/hr.
PMAXN = The maximum photosynthetic rate g $CO_2$/g protein C/day.
PSATPF = The effect of concentration of photosynthate in the leaf on photosynthesis, 0-1.
PSAIRF = The effect of photosynthate level on respiration.
PSRATE = The photosynthetic rate, g C/g protein C/day.
PWPIF = Effect of plant water potential on rate of movement of $CO_2$ into the leaf.
PWPOT = The average plant water potential for the month, bars.
PWPOTF = The effect of plant water potential on photosynthesis, 0-1.
PWPRF = The effect of plant water potential on respiration.
PWPX = The set of X values for the PWP data, bars.
PWPY = The corresponding set of Y values, 0-1.
RMAXI = Maximum rate of respiration, 0-1.
RMAXL = Maximum rate of respiration in the data, mg $CO_2$/mg leaf/hr.
RMAXN = Maximum rate of respiration, g C/g protein C/day.
RSCO2I = Rate of movement of $CO_2$ into the leaf calculated by the resistance formula.
RESCO2O = Rate of movement of $CO_2$ out of the leaf calculated by the resistance formula.
RSPHOT = Net photosynthesis calculated by the resistance formula, g C/g protein C/hr.
RSRATE = Dark respiration rate, g C/g protein C/day.
RSRESP = Respiration calculated by the resistance formula.
TDAY = The average daytime temperature, °C.
TEMPF = The effect of temperature on photosynthesis, 0-1.
TEMPRF = The effect of temperature on respiration.
TEMPRX = The data table of X values.
TEMPRY = The data table of Y values for the effect of temperature on respiration.
TEMPX = The set of X values for the effect of temperature on photosynthesis (data), °C.
TEMPY = The corresponding set of Y values, 0-1.
WINDAV = The average wind velocity for the day, km/hr.
WINDIF = Effect of wind on rate of movement of $CO_2$ into the leaf.
WINDOF = The effect of wind on movement of $CO_2$ out of the leaf.
ZZZ = An intermediate variable defined in the context of use.

## SUBMODEL PHOTO5

Third level of resolution, non-CAM plants.

### INTRODUCTION AND SIMPLIFYING ASSUMPTIONS

This model is developed from PHOTO 3 and is similar to it in many respects. However, the temperature of the photosynthetic organs is here simulated and, by the means of an internal loop, the simulation is run on an hourly basis. A by-product of the simulation of photosynthetic organ temperature is the estimation of transpiration rate. This might be of use elsewhere in the model.

### VERBAL DESCRIPTION -- WORD MODEL

The driving variables consist of experimental data on the effects of irradiance, temperature and plant water potential at several phenological stages, on the photosynthesis of *Artemisia tridentata* at Green Canyon in 1971. Radiation is supplied as hourly totals of global radiation (solar and scattered) measured above the Natural Resources-Biology

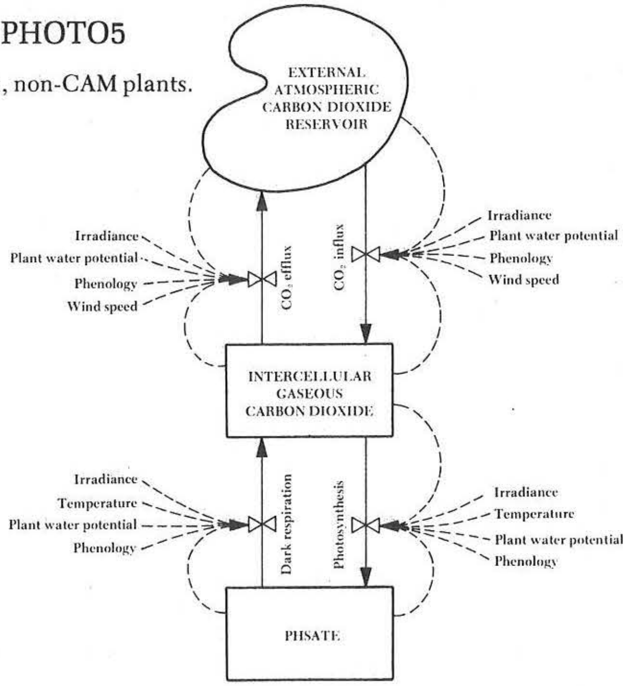
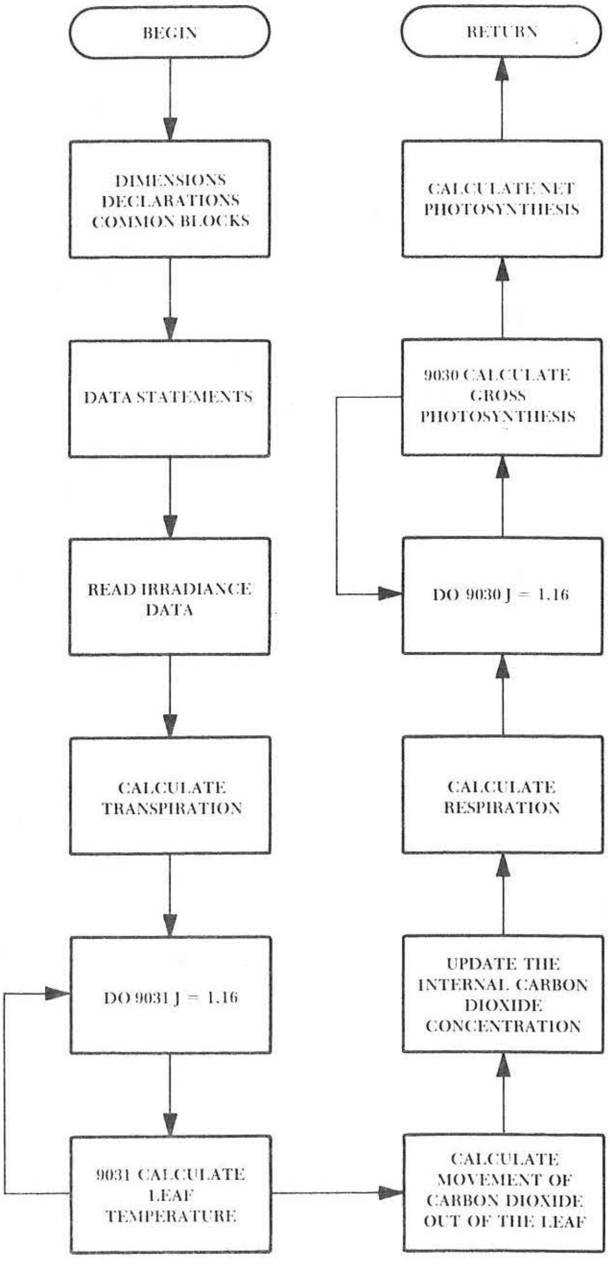


**PHOTO5**

building at USU in 1971. These data are stored in PHOTOSDATA and ready by this subroutine. Wind speed is that supplied by EXOGEN as DWINAV.

Data for emissivity of the leaf and of its surroundings, average leaf thickness and leaf area index are needed, as is the volumetric soil moisture. Since these are not immediately available, estimates of them have been made so that progress can be made, but attention should be given to these.



**FLOW DIAGRAM**

In order to calculate leaf or other photosynthetic organ temperatures it is necessary to know, among other things, the evaporative heat loss. This makes it necessary to first calculate transpiration. This is done here by means of Thornwaite's equation for evapotranspiration. Depending on the value of the evapotranspiration so calculated, a set of values for the parameters in an arctangent function are calculated and used to predict transpiration. The arctangent function itself is contained in the function subroutine ATANF.

The program then proceeds to the calculation of leaf temperature. The temperature of the photosynthetic organ TORG is initially set equal to air temperature. A loop is then entered in which first the initial heat content of the organ is calculated. Then the evaporative heat loss, the sensible heat loss, the long wave-length radiation from the leaf, and the radiation input are summed to obtain the heat gain of the organ. The heat content is obtained from the initial heat content plus the heat gain. Thence the temperature of the organ can be obtained from the heat content, the specific heat and the thickness of the organ. This loop is repeated for the 16 hr of the maximum photoperiod. The organ temperature so obtained is used elsewhere in the model in place of TDAY which is used in PHOTO1 and PHOTO3.

Although the effect of irradiance on photosynthesis is essentially the same in this model as in PHOTO3, in this case it is calculated from the hourly data for irradiation in another DO LOOP incremented for each of the 16 hr of the maximum photoperiod, which should improve the resolution of this section of the model significantly. Included in this DO LOOP is the calculation of new photosynthate, which is utilized as a modifying factor of the rate of photosynthesis. This should thus vary in its effect during the photoperiod in a realistic manner.

The remaining functions are identical with those used in PHOTO3, to which reference may be made.

## ALPHABETICAL LIST OF VARIABLE NAMES

AAA = The photosynthate level at which photosynthesis is maximal.
AINT3 = A user-defined function for interpolating values from a table supplied.
ALAI = The leaf area index for the area being considered.
BBB = The level of photosynthate in the leaves at which photosynthesis is reduced to zero.
BLRES = Boundary layer resistance, sec/cm.
CCC = See DDD
CO2IRI = Rate of movement of $CO_2$ into leaf, g C/g protein C/hr.
CO2ORT = Rate of movement of $CO_2$ out of the leaf, g C/g protein C/hr.

CURV = The curvature parameter for the photosynthesis/irradiation curve.
CCURV = The curvature parameter for the curve relating CO$_2$ concentration to photsynthetic rate, g C/g protein C.
DAPHOT = The photoperiod, hours.
DCO2 = The differential CO$_2$ concentration inside/outside the leaf.
DCO2F = The effect of CO$_2$ differential on movement of CO$_2$ into or out of the leaf.
DDD = Shape parameters for the curve of photosynthesis/photosynthate.
DPHS = Daily photosynthesis g C/g protein C/day.
DPL = Diffusion path length, mm.
EHL = Evaporative heat loss, calories.
EMISL = The emmissivity of the leaf (=1.0).
EMISW = Emissivity of the surroundings of the leaf -- assumed = 1.0.
EVAPT = Evapotranspiration, mm.
HCORG = The heat content of the photosynthetic organs, calories.
HCORGI = The initial heat content of the organ, calories.
HGORG = The heat gain of the photosynthetic organs, calories.
HPHS = Hourly photosynthesis g C/g protein C/hr.
I = The counter for cohorts.
ICO2PF = The effect of internal CO$_2$ concentration on photosynthesis, 0-1.
IDAY = The current time interval.
INCO2 = Amount of CO$_2$ inside the leaf air spaces, g C/g protein C.
INCO2C = Concentration of CO$_2$ in leaf intercellular spaces, g C/ml.
INTER = The integer label used in VEGET to select the interaction which is to be used: 1 = resistance formula; 2 = multiplicative rule; 3 = minimum rule.
IRADF = The effect of irradiation on photosynthesis, 0-1.
IRADIF = Effect of irradiation on rate of movement of CO$_2$ into the leaf.
IRADOF = The effect of irradiation on movement of CO$_2$ out of the leaf.
IRRAD = The actual radiation (400-700) for the day, cal/cm$^2$.
IRRADA = The irradiance absorbed by the photosynthetic organs.
IRRADI = The irradiance incident on photosynthetic organs, cal/cm$^2$.
IRRADM = The average radiation per hour for the day, cal/cm$^2$.
LWR = Long-wave radiation from the leaf, calories.
M = The counter for the phenological stage.
MNCO2I = Rate of movement of CO$_2$ into leaf calculated using the minimum rule.
MNCO2O = Rate of the movement of CO$_2$ out of leaf calculated using the minimum rule.
MNPHOT = Net photosynthesis calculated by the minimum rule, g C/g protein C/hr.
MTPHOT = Net photosynthesis calculated by the multiplicative rule, g C/g protein C/hr.
MNRESP = Respiration calculated by the minimum rule.
MTCO2I = Rate of movement of CO$_2$ into leaf calculated using the multiplicative rule.
MNCO2O = Rate of movement of CO$_2$ out of leaf calculated using the multiplicative rule.
MTRESP = Respiration calculated by the multiplicative rule.
NEWPHL = New photosynthate in the leaf, g C/g protein C.
NFACII = The number of factors influencing movement of CO$_2$ into a leaf.
NFACTO = The number of factors affecting movement of CO$_2$ out of a leaf.
NFACTP = The number of factors influencing photosynthesis.
NFACTR = The number of factors influencing respiration.
OTCN = The thickness of the photosynthetic organ, mm.
OUTCO2 = The external air CO$_2$ concentration, g/ml.

## SUBMODELS PHOTO4 AND PHOTO6

Levels 2 and 3, CAM plants.

At this stage there is no point in presenting more than the box and arrow diagram which was planned for use in these models. The general outline which is present in PHOTO3 and PHOTO5 will be applicable, and it is expected that it may be found advantageous, as in those models, to make a distinction between PHOTO4 which should run on a daily time step and PHOTO6 with an hourly time step. The variable names used in PHOTO2 will be found applicable, although no doubt others will also be needed.

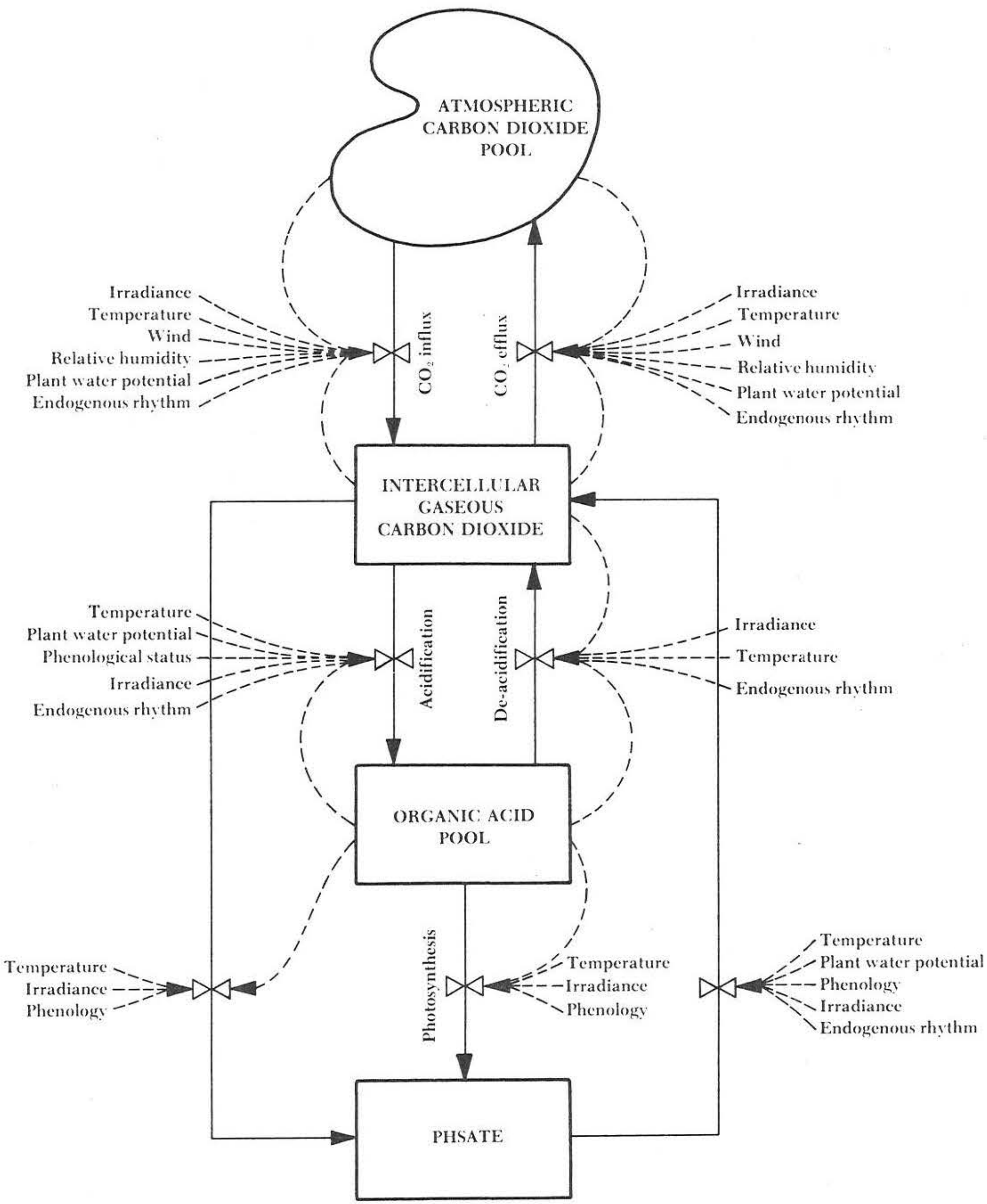
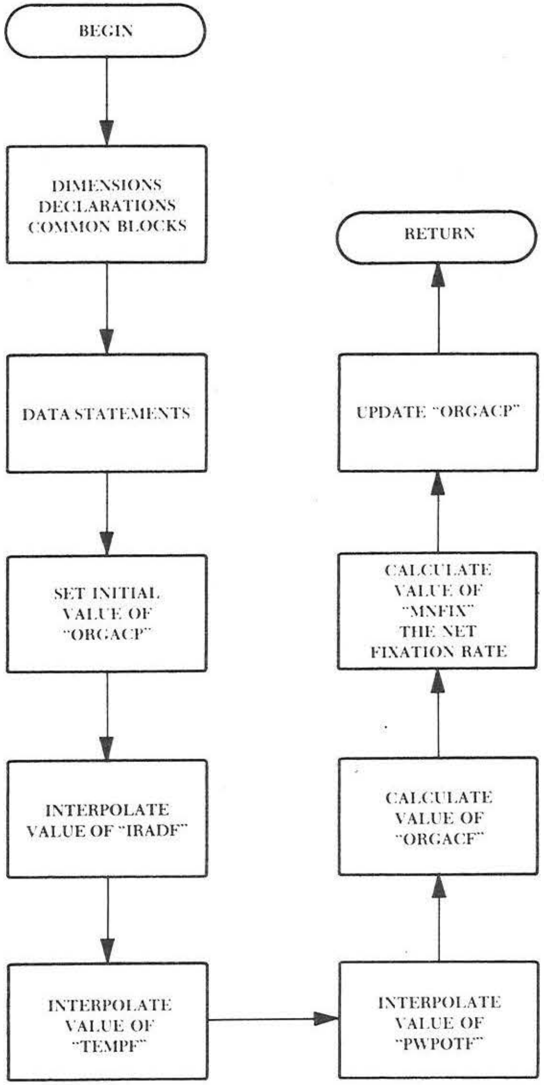


PHOTO4 AND PHOTO6



FLOW DIAGRAM

1973/74 PROGRESS REPORT

# AN APPROACH FOR A PHOTOSYNTHESIS MODEL OF DESERT PLANTS

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# INTRODUCTION

A number of approach efforts have been made to develop mathematical models to compute the net fixation of $CO_2$ by plants from meteorological parameters and to predict their productivity (e.g., DeWitt, 1965; Cunningham and Balding, 1972; Brittain, 1974; De Puit, 1973). One basic requirement for the realization of such models is a detailed knowledge of the functional relationships between the photosynthetic efficiency of a plant and the external conditions characteristic to its particular habitat. Special attention must be paid to the responses of the different morphological types, considering the variability of their physiological state and their capacity for regulative adaptations (Mooney and Shropshire, 1968; Bjorkman, 1968). With the more sophisticated models which have been proposed recently, large gaps in our knowledge about the influence of important internal and external factors on the $CO_2$ exchange of plants have become apparent (Lommen et al., 1971; Hall, 1971). Therefore, during our work on productivity of desert plants and the development of a model on net photosynthesis under desert conditions, we focused our interest on a functional analysis of the photosynthetic responses of the plants in their natural habitat.

The photosynthesis modeling committee of the Desert Biome recommended during its meeting (July 30, 1973), that emphasis should be given to an empirical model which is based on data which can be taken in the field and on data which are already present at this time. Consequently the following model follows the approach of Cunningham and Balding (1972) and Brittain (1974). The main stress was laid upon derivation of the input functions for the photosynthesis submodel from actual field data. Because of the short time period available for this work, *Hammada scoparia* was chosen as the test plant. We had access to a considerable amount of information on this species from previous work.* However, all programs were made so general that they can also be used for any other test plant.

# THE MODEL

The model should calculate rates of net photosynthesis (NP) taking the meteorological factors, light (L), temperature (TEMP), water vapor concentration difference between leaf and air (WD), the water stress in the plant (WS), and the phenological stage of leaf development (DAY) into account as input variables. The changes in the photosynthetically active organs of the plants with time (aging, phenology) have to be defined separately by the phenology and translocation submodel. The water stress in the plant is handled as an independent input variable until it is possible to connect this value to the soil and atmospheric conditions. Whenever possible, water stress is handled as a time function connected to the phenological stage of the plant.

The general form of the model is:

$$NP = (NPMAX)*F\ (L, TEMP, WD, WS, DAY)$$

The maximal rate of net photosynthesis (NPMAX) is defined to be the rate of $CO_2$ uptake at light saturation, optimal temperature and humidity conditions but at the water stress and phenological condition typical for the time of the year.

The effect of the different environmental factors F (L,TEMP,WD,WS,DAY) is scaled from 0-1. In the first approach the different factors are connected multiplicatively. It is subject to further sensitivity analysis and empirical tests to show if other and different connections of these factors will be more useful for prediction of gas exchange under certain conditions.

The light factor (FL) determines the increase on NP with increasing light intensity from 0 to 120 Klux. This increase is due to stomatal opening as well as to increasing rate of biochemical $CO_2$ uptake.

The temperature factor (FT) describes the optimum curve of NP at light saturation and optimal air humidity. This temperature factor also includes a stomatal and a biochemical effect.

The effect of the water vapor difference between the leaf and the air on $CO_2$ uptake (FW) works through stomatal reaction.

The water stress factor (FS) reduces NP through stomatal closure and also through an effect on mesophyll resistance.

All these processes change with time, aging and phenology. Therefore, they are expressed as a function of DAY.

A general flow diagram of the photosynthesis model is drawn in Figure 1. The model should finally operate on two different possible levels of resolution: (1) the greatest

---

*The field experiments were carried out in Avdat, Israel, 1971, by U. Buschbom, M. Evenari, L. Kappen, O. L. Lange, and E. D. Schultze. The methods used are described by Koch, Lange and Schultze (1971), Schultze, Lange and Lembke (1972) and Schultze (1972).

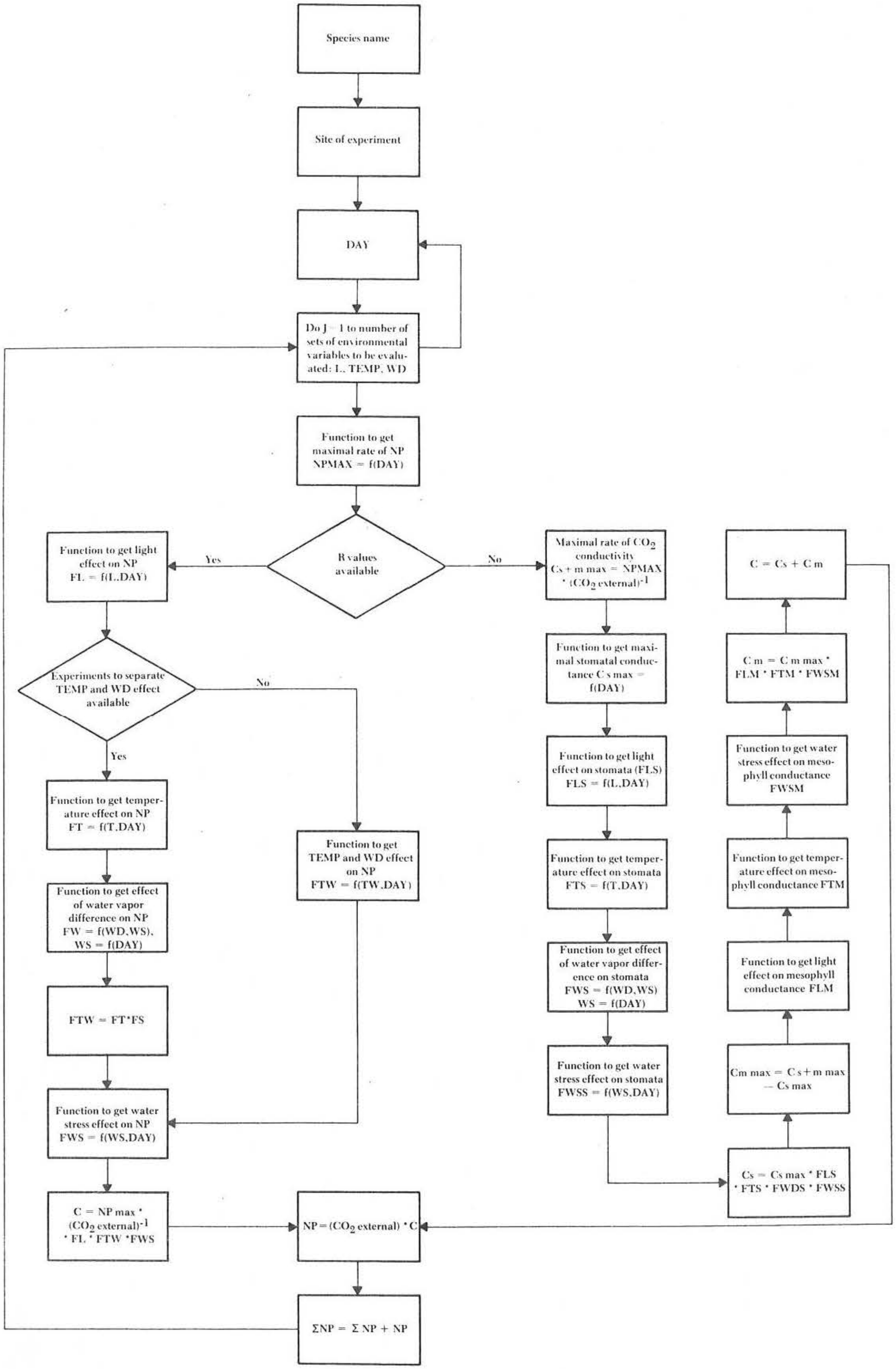


**Figure 1.** Flow diagram of the photosynthesis model.

refinement of the effect of environmental factors is obtained by separating the effects on stomatal and mesophyll resistance; (2) another level of refinement is obtained by calculating the influence of the environment on the gas exchange process as a whole. In the second case TEMP and WD can be handled separately or as a combined environmental stress factor. The decision as to which pathway is taken for a given species at a given site depends on the experimental data available. As long as mesophyll and stomatal resistance are not being measured separately, the accuracy of the predicted result is the same in both levels of resolution.

Since not all information on stomatal and mesophyll resistance can be worked up in the time available, most emphasis was placed on finding a mathematical resolution for the second level of refinement, taking TEMP and WD into account separately.

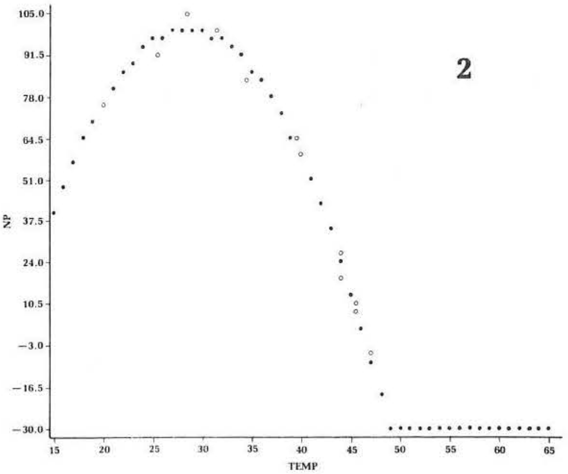
## THE FUNCTION (FT) OF THE EFFECT OF TEMPERATURE ON NP

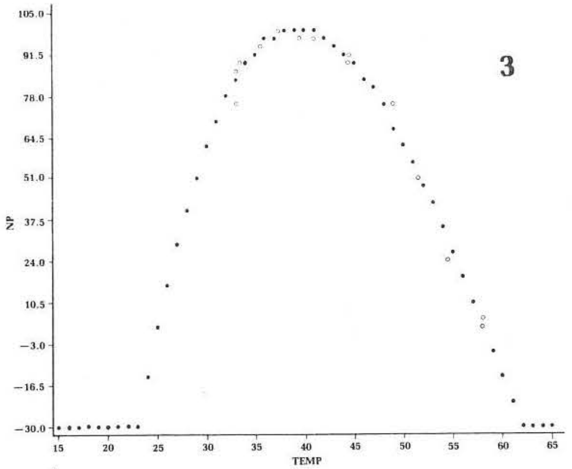
### The Temperature Response of Net Photosynthesis

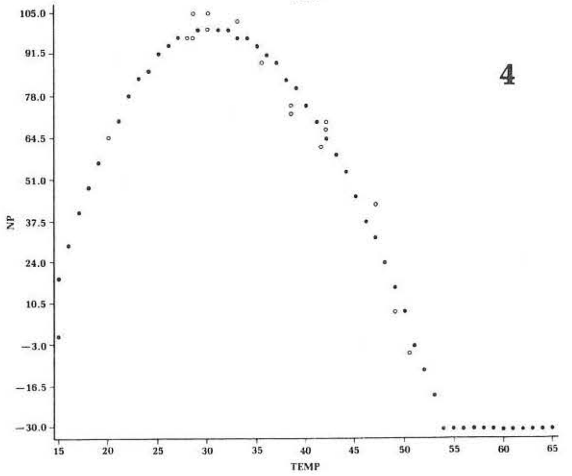
**Input**-Experiments measuring rates of $CO_2$ uptake at light saturation and at a high air humidity (WD almost 0) at varying temperatures during different times of the year.

Figure 2 shows a temperature response curve of net photosynthesis for *H. scoparia* in spring (March 28). Temperature optimum is at 28.6 C, the upper compensation point is at 46.3 C. The experimental data are not complete for a range of temperatures below the optimum of $CO_2$ uptake to the lower compensation point. This is because of the experimental difficulty of lowering temperatures in a cuvette in the field under desert conditions and in full sunlight to below the ambient air temperature. An important fact is that the temperature dependence of NP does not remain constant but changes throughout the year. This is demonstrated in Figure 3. It shows the same kind of response curve for July 19. The temperature optimum shifted up 10.7 C to 39.3 C. At the same time the upper compensation point shifted up 12.1 C to 58.4 C. Later in the season the temperature dependence of NP shifted back again to a range of lower temperatures (Fig. 4, September 22). The temperature optimum is at 30.5 C and the upper compensation point is 50.8 C. Maximal shift in the temperature optimum during the year was 13.6 C, taking the lowest spring value as a basis.

Figures 2-4 show that it is probably necessary for a model of NP to take the shift of the temperature curve into account as an adaptive feature of the plant to its environment. If all the experimental data of the year are plotted together to obtain a general temperature response curve for this species (without taking the shift in the temperature optimum and the temperature compensation point into account) and if these data points are fitted by a polynomial equation, the resulting $R^2$ is .70. This further suggests that the data of temperature-dependent NP are distributed on the temperature axis with enough scatter so that the application of a general temperature function for that species and that year is not useful.







**Figures 2, 3 and 4.** Percent photosynthesis (NP) of *H. scoparia* (unwatered) as related to leaf temperature (TEMP) on March 28, 1971 (Fig. 2), July 19, 1971 (Fig. 3) and September 22, 1971 (Fig. 4). Fitted curve based on a polynomial equation (●); points of measurement (○). Optimum of the polynomial curve is 100%.

## The Procedure to Calculate the Temperature Response of NP

It would be most desirable to apply a type of mathematical function which represents the process involved (Cunningham and Balding, 1972). The curve should show a variable optimum which originates from low temperatures assymptotically (dNP/dT, very small) and which drops to negative rates of gas exchange at high temperatures. Such a temperature function would provide the opportunity to extrapolate to a certain degree beyond the limits of experimental data, which would be advantageous for any predicting purpose. In this work we did not succeed in finding and applying a suitable non-polynomial function to the process of temperature-dependent net photosynthesis. Only polynomial equations were used, leaving this problem open for further photosynthesis modeling work. In applying polynomial equations, it is essentially necessary to plot the function with the data points. This is because at a high $R^2$ the least square fit might not represent the biological process one wants to simulate and predict.

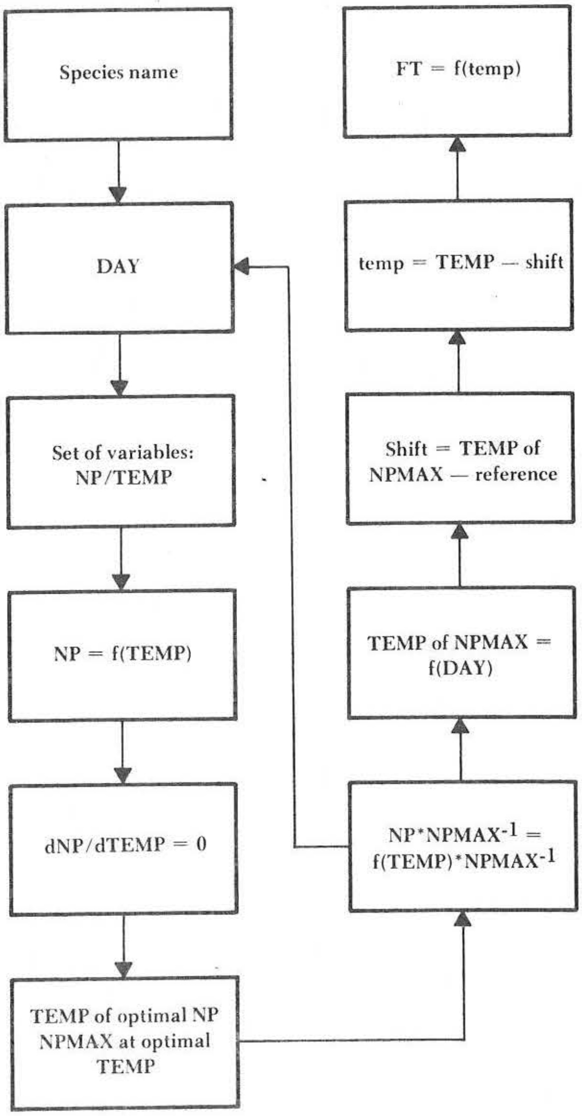


**Figure 5.** Flow diagram of the procedure to calculate the temperature effect on NP.

Figure 5 shows the flow diagram of the procedure to calculate the temperature response of NP used in the model:

1. Each set of data of one temperature experiment on a certain DAY is fitted with a third-degree polynomial (for 13 different temperature experiments, each having 8 to 16 measurements of temperature-dependent NP, the $R^2$ of the curve fit is .92 to .99).

2. The temperature optimum of each curve is the point at which the first derivative is zero. An iteration program determines the upper compensation point of NP.

3. Each parameter of the polynomial equations is divided by the maximal rate of NP at optimum temperature, so that the curves are scaled from 0 to 1.

4. The temperature of optimum NP versus time of year is fitted with a polynomial equation ($R^2$ = .65). This curve is shown in Figure 6.

5. Each value of temperature-dependent NP is shifted along the temperature axis to such a degree that all the optima of NP are the same and equal to the lowest temperature optimum as a reference (28.5).

6. One three-degree polynomial equation is fitted through all the shifted experimental data (for *H. scoparia*, $R^2$ of this equation is .86). Although this equation gives a high $R^2$, it was forced through some set-points to represent a biologically meaningful curve of predictive value. A four-degree polynomial equation should be considered instead. Figure 7 shows the measured values of the different temperature experiments being shifted to a common reference point and a polynomial equation fitted to these data. From the $R^2$ values of the curve fit, including the shift of the temperature curves compared to the $R^2$ before the shift, it is obvious that the shift of the temperature curves is significant. From Figure 7 it is obvious that the shape of the temperature response curve in the range from 10 C below the NP-optimum to the upper compensation point changes only to a small degree so that the temperature response is characterized with sufficient accuracy by a general equation and by the shift of the optimum. Major deviations from this general function will occur at temperatures of more than 15 C below the optimum, since the slope throughout this part of the curve will change with the value of the optimum. This deviation will be smallest if the temperature curves are not shifted to the lowest optimum as reference but to an average value of optimal temperature. For the purpose of this model, the range of temperature-dependent NP from 10 C below the optimum down to the lower compensation point was extrapolated linearly to a rate of NP of 0 at -5 C.

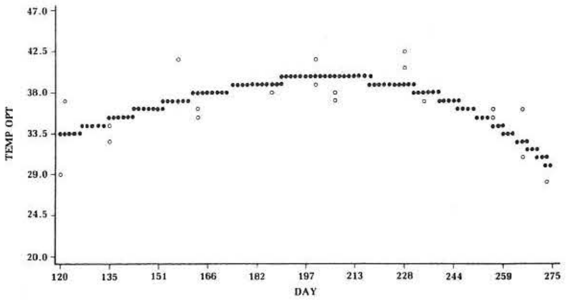


**Figure 6.** Change of the temperature optimum of net photosynthesis (TEMP OPT) with the time of year (DAY) for *H. scoparia* (unwatered).

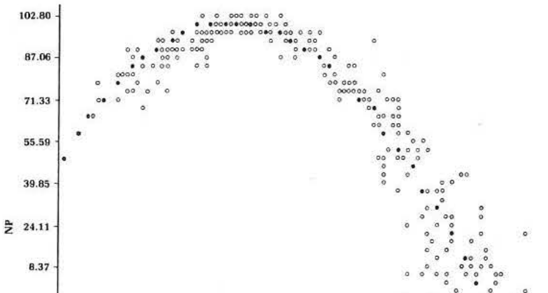


**Figure 7.** The measured values of percent net photosynthesis (NP) being shifted on the temperature axis to such a degree that all the optima of the single temperature curves of NP are the same and equal to the lowest temperature optimum as a reference as related to leaf temperature (TEMP) for *H. scoparia* (unwatered). Fitted curve based on a polynomial equation (●); points of measurement (○). Optimum of the polynomial curve is 100 %.

## THE FUNCTION TO OBTAIN THE EFFECT OF TEMPERATURE ON NP (FT) IN THE MODEL

```
MOD1:
  PROC OPTIONS(MAIN);
  ON ENDFILE(SYSIN) STOP;
TOP:
  GET LIST(DAY,TEMP);
  TEMPOPT=34.22297+DAY*(-0.2169415+DAY*(0.002518485-DAY*0.000006494)));
  PUT SKIP DATA(TEMPOPT);
  SHIFT=TEMPOPT - 27.34;
  TEMPIT=TEMP - SHIFT;
  IF TEMPIT > 19.0 THEN
   FACTOR=-161.6137+TEMPIT*(20.1694+TEMPIT*(-0.426328+TEMPIT*0.0014117)));
  ELSE
   FACTOR=4.08*TEMPIT;
  TEMPFACTOR=FACTUR/100;
  PUT SKIP DATA(DAY,TEMP,TEMPFACTOR,SHIFT);
  GO TO TOP;
END MOD1;
```

The change of the temperature optimum during the seasons was observed not only on *H. scoparia* but also on several other plant species (Lange et al., in preparation). It was observed on watered and non-watered plants of the same species. Figures 6 and 7 contain the values of watered and non-watered plants. It is obvious that there is no difference in temperature response due to water stress (for *H. scoparia* to a range of -86 bars). Furthermore, the watered plant was growing and producing new photosynthesizing organs throughout the year, which means that the change in the temperature optimum is not connected with a certain phenological stage. This response is probably an adaptive mechanism to the temperature, climate and the photoperiod of the habitat. This response, therefore, needs to be correlated to the EXOGEN submodel.

## THE FUNCTION OF THE EFFECT OF WATER VAPOR DIFFERENCE BETWEEN LEAF AND AIR ON NP (FW)

### THE RESPONSE OF NP TO CHANGES IN WD

**Input**-Experiments measuring rates of $CO_2$ uptake at light saturation and at a constant temperature at varying WD during different times of the year.

In a number of plant species WD has a direct and reversible effect on the stomatal diffusion resistance (Lange et al., 1971; Schultze et al., 1972). Figure 8 shows a linear decrease of NP at increasing WD for *H. scoparia* in the spring (April 28) at good soil water conditions (maximal water potential of the plant in the morning, -13 bars; minimal $\psi_p$ during the day, -31 bars). As the dry season proceeds this effect becomes more and more pronounced as shown in Figure 9 (June 2: $\psi$ max of the plant in the morning, -41 bars; $\psi_p$ min, -67 bars). An increasingly negative slope of the WD-dependent NP curve is obvious.

### THE PROCEDURE TO CALCULATE THE WD RESPONSE OF NP

Figure 10 shows a flow diagram of the procedure to calculate the WD response of NP used in the model:

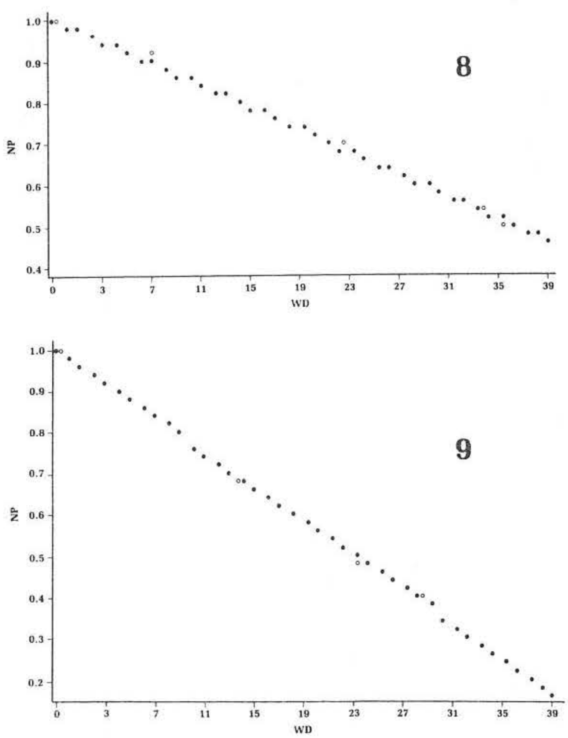
1. Each set of data of a humidity experiment on a certain DAY is fitted with a linear regression (for 13 different humidity experiments, each having 3-6 measurements of WD-dependent NP, the $R^2$ of the curve fit is .92 to .99).

2. The parameters of the equation are divided by the value of the y-axis intercept (NPMAX at WD=0), so that the regression lines are scaled from 0 to 1. It was tried to fit a time-dependent regression through the values of the slope of the WD-dependent NP (slope = f(DAY)). For any polynomial equation, $R^2$ remained very low (linear regression: $R^2$ = .02, second-degree polynomial regression: $R^2$ = .08, third-degree polynomial regression: $R^2$ = .11). This shows that there is no simple time function to calculate the seasonal change of the slope of the NP/WD experiments with sufficient accuracy.

3. From laboratory experiments it was obvious that the WD effect on the stomatal diffusion resistance is affected by water stress. Therefore, the slope of the NP/WD experiments is correlated to the minimal daily water potential of the plant during the day at that time of the year. Figure 11 shows this regression and the data points ($R^2 = .77$) for *H. scoparia*. The closing reaction of the stomata increases at increasing WD with decreasing water potential in the plant to a maximum value at about -65 bars. With a further decrease of water potential the reaction becomes smaller again, because of the overruling effect of internal water stress on the gas exchange process.

4. The change of the minimal daily water potential of the plants during the seasons is certainly dependent on the conditions in the atmosphere and in the soil. As a preliminary approach, a third-degree polynomial equation was fitted through the annual change of the daily minimal water potential of *H. scoparia* ($R^2 = .92$). Figure 12 shows a plot of this regression. It is obvious that the extremes are not covered by this regression (e.g., day 229), which certainly will cause an increased error in the overall photosynthesis model.

At large values of WD the stomata are expected to be closed, not allowing a positive uptake of $CO_2$. The experimental data do not show if the linear NP/WD relationship is valid under very dry air conditions (WD greater than 30 $mgH_20/1$), and it is very possible that in this range of WD the rate of $CO_2$ uptake does not decrease with the same slope. This effect was not taken into account in the first model test. This means, that at large WD the reduction of NP is probably overestimated with the linear regression.



**Figures 8 and 9.** Relative rate of net photosynthesis (NP) scaled from 0 - 1 as related to the water vapor concentration difference between leaf and air (WD) for *H. scoparia* (unwatered) at a low water stress of $\psi_p$ -31.5 bar(Fig. 8) and at a high water stress of $\psi_p$ -67 bar (Fig. 9).

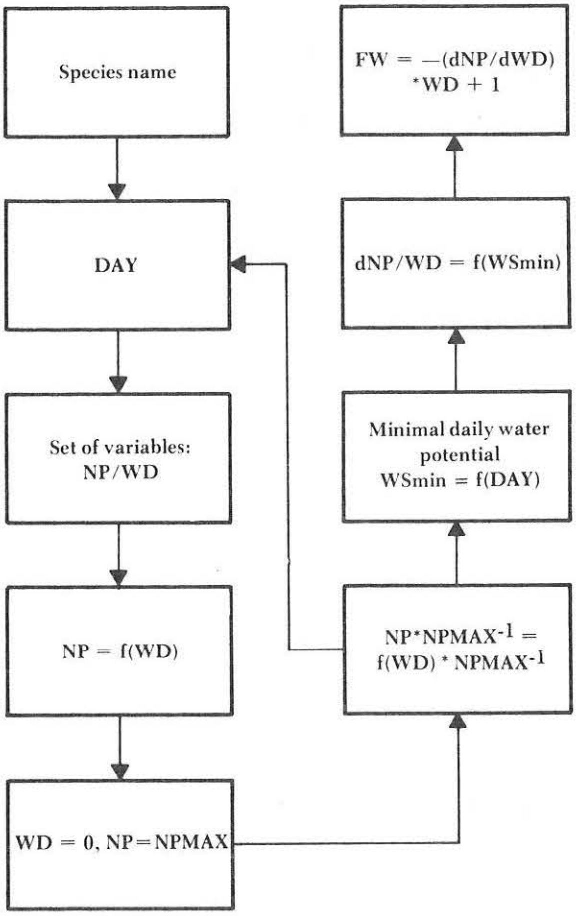


**Figure 10.** Flow diagram of the procedure to calculate the WD effect on NP.

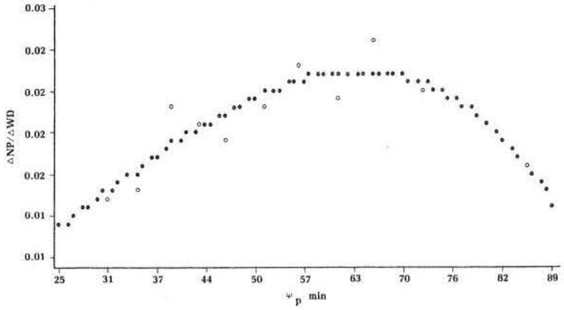


**Figure 11.** The change in net photosynthesis per 1 $mgH_2O/1$ increase of water vapor difference between leaf and air ($\Delta NP/\Delta WD$) as related to the minimal pressure potential in *H. scoparia* (unwatered) during the day ($\psi_p$ min).

This overestimatation of the humidity effect became obvious during the first model tests. An example is given in Figure 13, where the observed values of NP show a one-peaked daily course of $CO_2$ uptake whereas the predicted NP has a pronounced depression during noon and afternoon. The difference is caused by the linearly extrapolated humidity effect.

For selected days the change of $CO_2$ uptake with WD at low air humidity was plotted from the daily course of NP and from the deviation between predicted and observed values (Fig. 14). In this case the decrease of NP with WD changes the slope at about 30 mg $H_2O/1$. Stomata did not close as rapidly as had been assumed from the first experiments. In this range of stomatal closure, plant internal control mechanisms (i.e. the mesophyll internal $CO_2$ concentration) counterbalance the humidity-induced closing response.

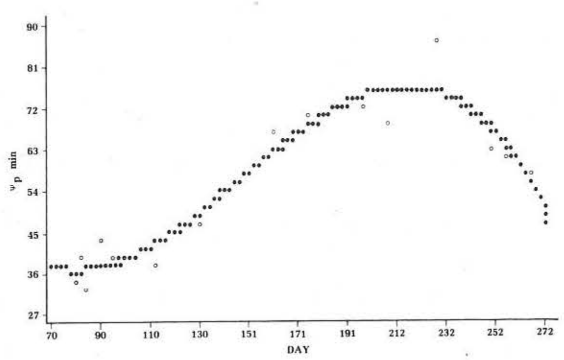


**Figure 12.** Change of the minimal pressure potential in *H. scoparia* (unwatered) during the day ($\psi_p$min) versus the time of year (DAY).

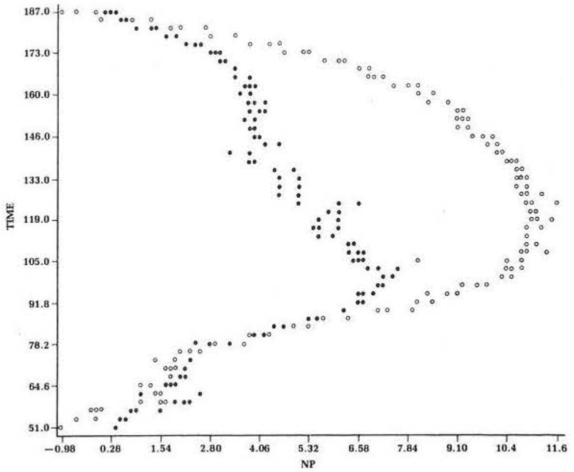


**Figure 13.** The daily course of net photosynthesis of *H. scoparia* (unwatered) on June 25, 1971. x-axis: rate of net photosynthesis per gram dry weight and hour (NP). y-axis: time of day in 1/10 of the hour (TIME). Predicted values (●); measured values (○).

For the purpose of this model, the deviation between the linear regression and the observed change of NP with WD was corrected for the first part of the year until July 16 (DAY 197) with a correction function of the type Y = A/X+B, where A and B are time-dependent parameters. In future applications of the model this correction should be included into a single humidity function. For this purpose, however, humidity experiments need to be carried out at very dry air conditions.

The effect of the applied correction according to Figure 14 is shown in Figure 15 for the same day as was presented in Figure 13. In this figure the observed and predicted values of WD match perfectly.

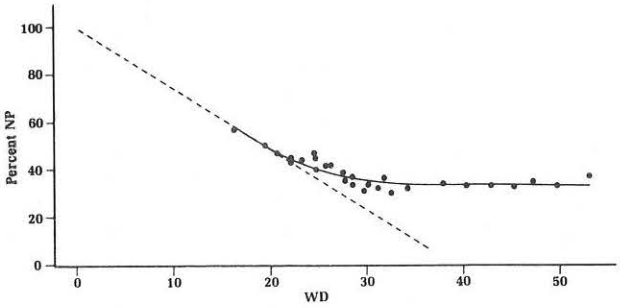


**Figure 14.** Percent net photosynthesis of *H. scoparia* (unwatered) as related to WD (mgH$_2$0/1) plotted from the daily course of NP (half hourly means) for the time of light saturation of $CO_2$ uptake on June 8-12, 1971. Linear NP-WD relationship (- - - - ); correction function (———).

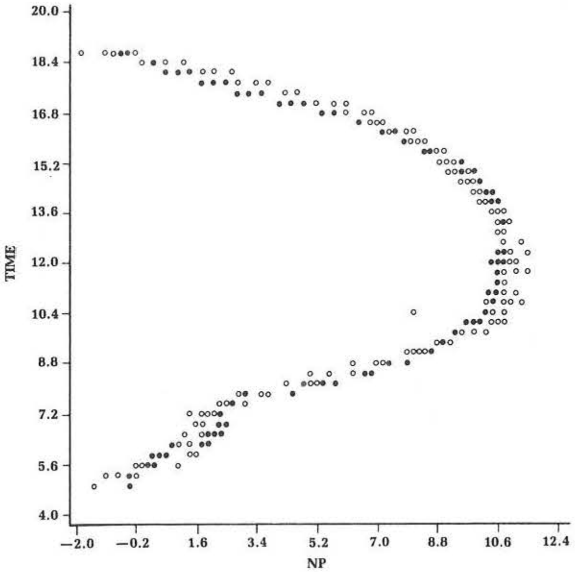


**Figure 15.** The daily course of net photosynthesis of *H. scoparia* (unwatered) on June 25, 1971, but calculated with the additional WD correction. x-axis: rate of net photosynthesis per gram dry weight and hour (NP). y-axis: time of day in 1/10 of the hour (TIME). Predicted values (●); measured values (○).

## THE FUNCTION (FW) TO OBTAIN THE EFFECT OF WD ON NP IN THE MODEL

**Original Function Used-**In the future, a similar function should be used after changing the equation of statement 8 to the non-linear relationship at high values of WD.

```
MOD2:
   PROC OPTIONS(MAIN);
   ON ENDFILE(SYSIN) STOP;
 TOP:
   GET LIST(DAY,WD);
   WSMIN=94.80794+DAY*(-1.648292+DAY*(0.0140833-DAY*0.00003169806)));
   FACTOR=0.003882364+WSMIN*(0.0001200639+WSMIN*(0.9728054E-05-WSMIN*
        0.1105827E-06)));
   FACTOR=-FACTOR;
8- FW=FACTOR * WD + 1;
   IF FW < 0.01 THEN
      FW=0.01;
   PUT SKIP DATA(DAY,WD,FW);
   GO TO TOP;
 END MOD2;
```

**Function Used in This Model, Containing the Correction for the Effect of Large Values of WD on NP-**

```
FW=FACTOR * WDI + 1.0
IF (FW .LE. 0) FW=0.01
FWCORR=FW
IF (FW .LT. 0.28) FWCORR=0.28
TEMP=A/FWCORR + B
IF (TEMP .GT. 1 .AND. DAY .LT. 197) FW=FWCORR * TEMP
```

where A and B are changing with DAY until July 16: A = .6177987E-04*DAY**2-.2787197E-01*DAY+.3445914E01 B=-.2558189E-03*DAY**2+.1056985E 00*DAY-.1643142E02

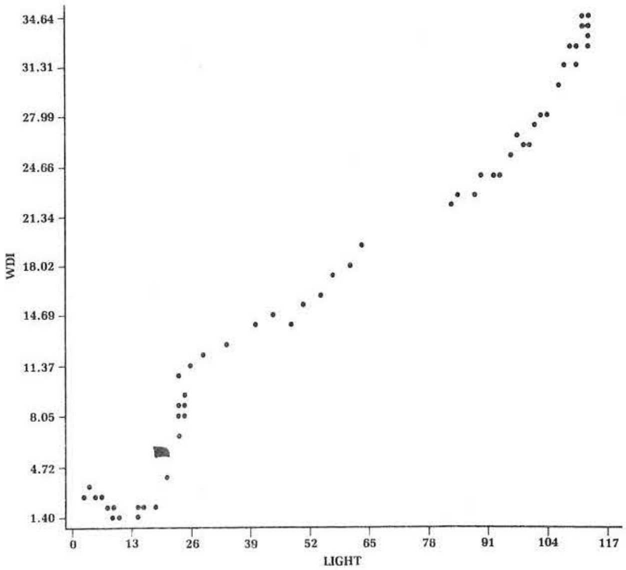


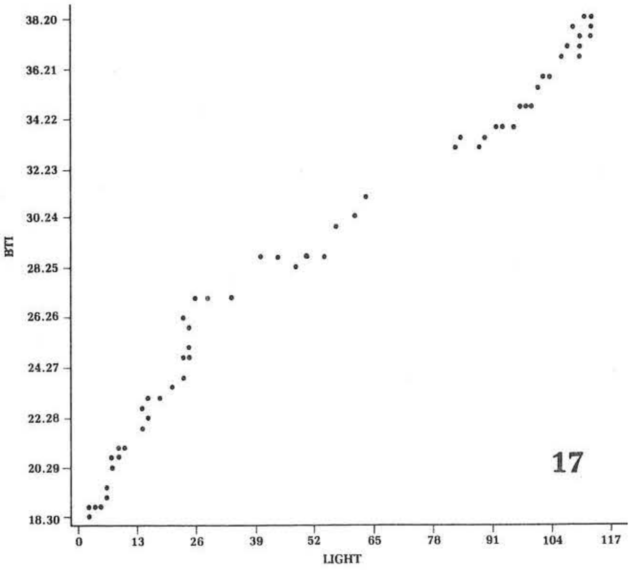
**Figure 16.** Change of the water vapor difference between the leaf and the air (WDI) throughout the day versus increasing light intensity (LIGHT) under natural conditions for *H. scoparia* (unwatered). (Avdat, July 28, 1971).

## THE FUNCTION OF THE EFFECT OF LIGHT INTENSITY AND THE FUNCTION OF NPMAX

### THE LIGHT RESPONSE OF NP

**Input-**Experiments measuring rates of $CO_2$ uptake during the course of a day from early morning until noon at varying light, temperature and humidity conditions.

Figures 16, 17 and 18 show the change of WD, temperature and NP with increasing light intensity during the course of a late summer morning until noon for *H. scoparià*. In the desert, as light intensity increases, the climate gets rapidly warmer and drier, which has a strong effect on NP at any time. The values of $CO_2$ uptake in the morning are measured when the air is moist but at temperatures far below the optimum. The values of NP at noon are measured at more favorable temperatures or at temperatures above optimum, but when the air is very dry. NP increases with light intensity to an optimum at 65-100 Klux. The rates decrease again at higher light intensities.



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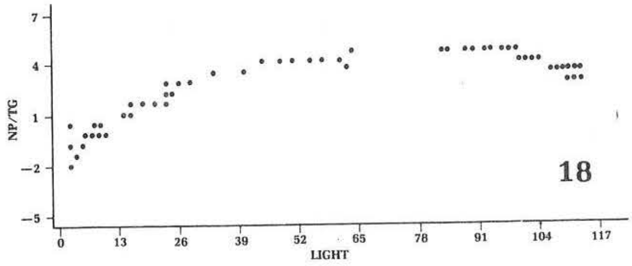

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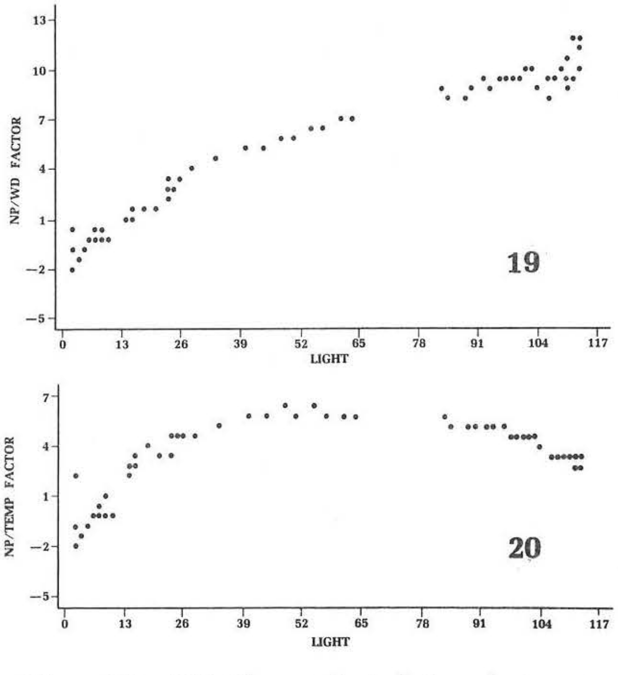
**Figures 17 and 18.** Change of leaf temperature (BTI) (Fig. 17) and change of net photosynthesis per gram dry weight and hour (NP/TG) (Fig. 18) throughout the day versus increasing light intensity (LIGHT) under natural conditions for *H. scoparia* (unwatered). (Avdat, July 28, 1971).

To attain the physiological light response curve the environmental factors TEMP and WD need to be optimized using the functions FT and FW. In a first step, the rates of NP were corrected for the effect of WD only. Figure 19 shows the same data as in Figure 18 only corrected for the effect of WD. The rates at light saturation increased more than two-fold by this correction. If the data are corrected only for TEMP, the rates of NP increase at low light intensities, making the noon depression of NP even more pronounced (Fig. 20). The light response corrected for TEMP and WD is shown in Figure 21. There is no recognizable depression of the rates of NP at high light intensities. For this species the drop in water potential from early morning to noon (-39 bars to -68 bars) has no additional effect on stomatal aperture other than the increased sensitivity to air humidity (the data were calculated with WD=f [water stress - 68 bars]). For other species it is possible that with the correction of WD and TEMP the rates of NP at a high light intensity at noon do drop. This would indicate an additional effect of water stress, which has to be taken into account in the model separately.

The data of light-dependent NP, which were corrected for TEMP and WD, are fitted with an assymptotic function:

$$f(x,a,b,c,) = a(1-e^{-bx}) + c,$$

in which 'a+c' is the asymptote f(x) approaches with increasing x, and 'b' is a parameter determining the rate of rise by which the curve approaches 'a+c'; 'c' is the intercept of the y-axis, which is negative and represents the respiration rate. This function was fitted with a non-linear regression program, which was especially adapted for this problem.



**Figures 19 and 20.** Change of net photosynthesis per gram dry weight and hour corrected for the effect of water vapor difference between leaf and air (NP/WD FACTOR) (Fig. 19) and for the effect of leaf temperature (NP/TEMP FACTOR) (Fig. 20) versus increasing light intensity (LIGHT) under natural conditions for *H. scoparia* (unwatered). (Avdat, July 28, 1971).

Figure 22 shows the flow diagram of the procedure to obtain the light response of NP from measurements of the daily course of gas exchange.

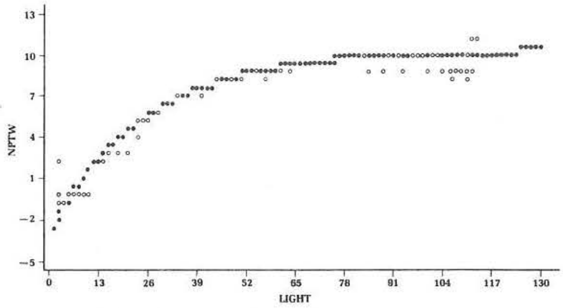


**Figure 21.** Change of net photosynthesis per gram dry weight and hour corrected for the effect of water vapor difference between leaf and air and corrected for the effect of leaf temperature (NPTW) versus increasing light intensity (LIGHT) under natural conditions. (●) calculated curve of the light equation; (o) points of measurement for *H. scoparia* (unwatered). (Avdat, July 28, 1971).

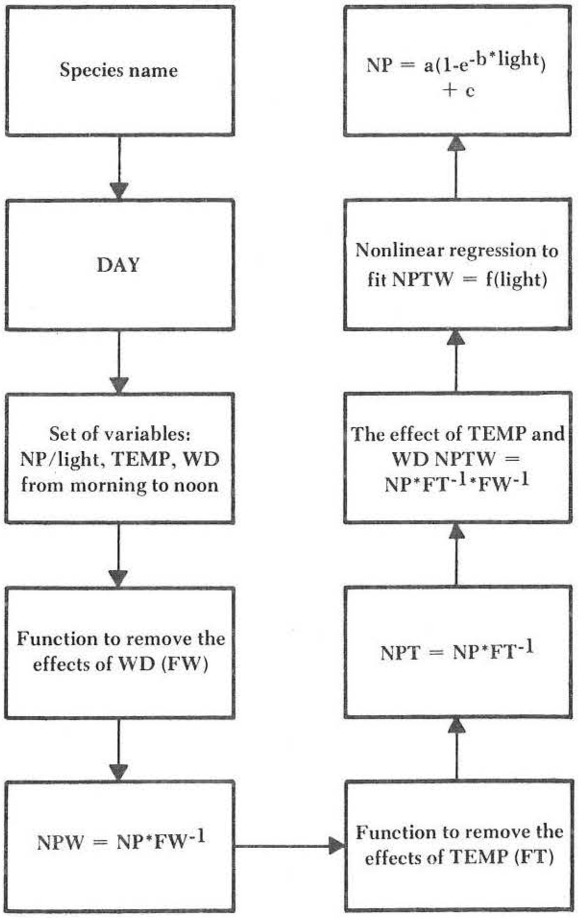


**Figure 22.** Flow diagram of the procedure to obtain the light response of NP.

### PROCEDURE TO OBTAIN THE LIGHT RESPONSE OF NP:

```
PLOTTER:
  PROC OPTIONS(MAIN);
  DCL I FLOAT,
      BB FIXED,
      (NPT,NPW,NPTW)(300) FLOAT,
      (A,X,C,D,E,FW,FT,FF,GG,XX)(300) FLOAT,
      STRINGS CHAR(25),
      B(2) FLOAT;
  ON ENDFILE(SYSIN)
      GO TO PART2;
  GET FILE(PARMS) LIST(DAY);
  STRINGS='DAY = '||DAY;
TOP:
  GET EDIT(AA,BB,CC,EE,DD)
  (COL(7),F(4,2),4F 6,2)));
  IF AA = 0 | BB = 0 | CC = 0 | DD = 0 | EE = 0 THEN
      GO TO TOP;
  COUNT=COUNT + 1;
  A(COUNT)=AA;
  X(COUNT)=BB;
  C(COUNT)=CC;
  D(COUNT)=DD;
  E(COUNT)=EE;
  GO TO TOP;
PART2:
  CALL PLOT(COUNT,'*',X,A);
  CALL GRAPH(0,1,3,0,0,'LIGHT','TIME',STRINGS);
  CALL PLOT(COUNT,'*',X,C);
  CALL GRAPH(0,1,3,0,0,'LIGHT','BTI ',STRINGS);
  CALL PLOT(COUNT,'*',X,D);
  CALL GRAPH(0,1,3,0,0,'LIGHT','WDI ',STRINGS);
  CALL PLOT(COUNT,'*',X,E);
  CALL GRAPH(0,1,3,-5,.8,'LIGHT','NP/TG',STRINGS);
  AMAT=94.80794+DAY*(-1.648292+DAY*(0.0140833-DAY*0.3169806E-04));
  FACTOR=0.003832364+AMAT*(0.0001200639+AMAT*(0.9728054E-05-AMAT*
      0.1105827E-06)));
  FACTOR=-FACTOR;
  PUT PAGE;
  DO I=1 TO COUNT;
      FW(I)=FACTOR * D(I) + 1.0;
      IF FW(I) < 0.01 THEN
          FW(I)=0.01;
      PUT SKIP DATA(DAY,D(I),FW(I));
      IF E(I) > 0 THEN
          NPW(I)=E(I)/FW(I);
      ELSE
          NPW(I)=E(I);
  END;
  CALL PLOT(COUNT,'*',X,NPW);
  CALL GRAPH(0,1,3,-5,.8,'LIGHT','NP/WD FACTOR',STRINGS);
  XMAX=34.22297+DAY*(-0.2169415+DAY*(0.002518485-DAY*0.000006494)));
  XMAX=XMAX - 27.34;
  DO I=1 TO COUNT;
      TEMPIT=C(I) - XMAX;
      COUNT1=COUNT1 + 1;
      IF TEMPIT < 7 THEN DO;
          FT(I)=1;
          GO TO ENDER;
      END;
      IF TEMPIT > 20 THEN
          FT(I)=-161.6137+TEMPIT*(20.1694+TEMPIT*(-0.426328+TEMPIT*
              0.0014117)));
      ELSE
          FT(I)=16.8 + 3.36*TEMPIT;
      FT(I)=FT(I)/100;

ENDER:
      PUT SKIP DATA(DAY,C(I),FT(I));
      IF E(I) > 0 THEN DO;
          NPT(I)=E(I)/FT(I);
          NPTW(I)=E(I)/FW(I)/FT(I);
      END;
      ELSE DO;
          NPT(I)=E(I);
          NPTW(I)=E(I);
      END;
  END;
  CALL PLOT(COUNT1,'*',X,NPT);
  CALL GRAPH(0,1,3,-5,.8,'LIGHT','NP/TEMP FACTOR',STRINGS);
  CALL PLOT(COUNT1,'*',X,NPTW);
  CALL GRAPH(0,1,3,-5,.8,'LIGHT','NPTW',STRINGS);
  DO I=1 TO COUNT1;
      PUT FILE(OUTPUT) EDIT(X(I),NPTW(I))
      (COL(1),2 (F(10,2),X(2)));
  END;
  CLOSE FILE(OUTPUT) OPTIONS(LOCK);
END PLOTTER;

EXPA:
  PROC OPTIONS(MAIN);
  DCL (XX,YY,X,Y)(300) FLOAT;
  GET FILE(OUTPUT) LIST(A,B,C);
  DO I=1 TO 130;
      XX(I)=I;
      YY(I)=A * (1.0 - EXP(-B*I)) + C;
  END;
  ON ENDFILE(OUTPUT) GO TO PART2;
TOP:
  GET FILE(OUTPUT) EDIT(D,E)
  (COL(1),2 F(10,2));
  COUNT=COUNT + 1;
  X(COUNT)=D;
  Y(COUNT)=E;
  GO TO TOP;
PART2:
  CALL PLOT(I - 1,'*',XX,YY);
  CALL PLOT(COUNT,'0',X,Y);
  CALL GRAPH(0,1,3,-5,.8,'LIGHT','NPTW',' ');
  PUT SKIP DATA(YY(120),YY(130));
END EXPA;
```

For this plant species, the above mentioned FW-correction was applied for calculating the light response of NP. This special procedure is included in the following FORTRAN program:

```
      REAL LIA(240),NPA(240),NPW(240),NPT(240),NPTW(240),NP,LI
      DIMENSION B(4)
      COMMON AA(867),XMIN,XMAX,YMIN,YMAX,FLG
      DATA FA1/94.80794/,FA2/-1.648292/,FA3/.0140833/,FA4/-.3169806E-04/
     1 ,FB1/.003832364/,FB2/.1200639E-03/,FB3/.9728054E-05/
     2 ,FB4/-.1105827E-06/,X1/6.88297/,X2/-.2169415/,X3/.002518485/
     3 ,X4/-0.6494E-05/,A1/3.445914/,A2/-0.02789179/,A3/.6177987E-04/
     4 ,B1/-10.4314/,B2/.1059985/,B3/-0.2558169E-03/,F1/-161.6137/
     5 ,F2/20.1694/,F3/-0.426328/,F4/.0014117/
      DO 3 I=1,867
    3 AA(I)='    '
      IDAY=101
      IDAY=JULIAN(IDAY) - 1
      READ(5,100) MON,LI,BTI,NP,WDI
    1 IMON=MON
      ICNT=0
      DAY=JULIAN(MON) - IDAY
      WRITE(6,300)
      FACTOR=FA1 + DAY * (FA2 + DAY * (FA3 + DAY * FA4))
      FACTOR=FB1 + FACTOR * (FB2 + FACTOR * (FB3 + FACTOR * FB4))
      FACTOR=-FACTOR
      XMAX=X1 + DAY * (X2 + DAY * (X3 + DAY * X4))
      A=A1 + DAY * (A2 + DAY * A3)
      BB=B1 + DAY * (B2 + DAY * B3)
    2 ICNT=ICNT + 1
      LIA(ICNT)=LI
      NPA(ICNT)=NP
      FW=FACTOR * WDI + 1
      IF (FW .LE. 0) FW=.01
      TEMP=A/FW + BB
      NPW(ICNT)=NP
      IF (TEMP .GT. 1) FW=FW * TEMP
      IF (NP .GT. 0) NPW(ICNT)=NP/FW
      TEMP=BTI - XMAX
      IF (TEMP .GT. 19) GO TO 8
      FT=3.36 * TEMP + 16.8
      GO TO 9
    8 FT=F1 + TEMP * (F2 + TEMP * (F3 + TEMP * F4))
    9 FT=FT * .01
      WRITE(6,200) MON,DAY,LI,BTI,NP,WDI,FW,FT
      IF (NP .LE. 0) GO TO 4
      NPT(ICNT)=NP/FT
      NPTW(ICNT)=NP/FW/FT
      GO TO 10
    4 NPT(ICNT)=NP
      NPTW(ICNT)=NP
   10 READ(5,100,END=5) MON,LI,BTI,NP,WDI
      IF (MON .EQ. IMON) GO TO 2
    5 WRITE(6,301)
      SYM='0'
      XMIN=0
      XMAX=130
      YMIN=-5.0
      YMAX=35
      CALL GRAPH(ICNT,SYM,LIA,NPA)
      WRITE(6,302)
      CALL GRAPH(ICNT,SYM,LIA,NPW)
      WRITE(6,303)
      CALL GRAPH(ICNT,SYM,LIA,NPT)
      CALL FNUN(LIA,NPTW,ICNT,B)
      DO 6 I=1,130
      NPA(I)=I
    6 NPW(I)=B(1) * (1.0 - EXP(B(2)*I)) + B(3)
      WRITE(6,304)
      DO 7 I=1,ICNT
      TEMP=B(1) * (1.0 - EXP(B(2) * LIA(I))) + B(3)
      FACTOR=NPTW(I) - TEMP
    7 WRITE(6,202) LIA(I),NPTW(I),TEMP,FACTOR
      WRITE(6,306)
      FLG=1
      CALL GRAPH(ICNT,SYM,LIA,NPTW)
      SYM='*'
      FLG=0
      ICNT=130
      CALL GRAPH(ICNT,SYM,NPA,NPW)
      WRITE(6,203) B
      IF (MON .NE. IMON) GO TO 1
      STOP
  100 FORMAT(4X,I4,4X,F3.0,1X,3F6.2)
  200 FORMAT(2I5,4F8.2,2F8.4)
  202 FORMAT(' ',4F8.2)
  203 FORMAT('0 COEFFIENTS :',3G15.6,'   RSQUARE :',F10.5)
  300 FORMAT('1MMDD  DAY        LI       BTI   NP/TP      WDI        FW
     1 'FT' / ' ',12('-----'))
  301 FORMAT('1                LI VERSUS NP/TP ')
  302 FORMAT('1                LI VERSUS NP/WD')
  303 FORMAT('1                LI VERSUS NP/TEMP')
  304 FORMAT('1          LI   NP/TG  ENP/TG    DEV.' / ' ',9('-----'))
  306 FORMAT('1                LIA VERSUS NP(3) AND ENP (*) ')
      END
```

### THE FUNCTION OF NPMAX

From the light curve of NP which is corrected for the effect of TEMP and WD, the maximal rate of NP (NPMAX) is defined as the rate of NP at high light intensity (120 Klux).

The asymptote of the exponential light function was not taken as NPMAX, since many desert plants reach light saturation only at a high light intensity (Schulze, Lange and Koch, 1972). In such cases there is danger that the calculated light curve does not reach an asymptote within the given range of data, but could increase to very high values of the parameter 'a'. This parameter, therefore, does not represent a physiological capability in all cases.

The seasonal change of NPMAX is fitted with a third-degree polynomial equation: NPMAX = f (DAY). This curve is shown in Figure 23 ($R^2$ = .89).

### THE FUNCTION (FL) OF THE EFFECT OF LIGHT INTENSITY

From the seasonal change of the light curves of NP it is obvious that the parameter 'a' of the exponential function has a high degree of variance. For this reason the seasonal change of the light curve is calculated from the function of NPMAX=f(DAY) and from the change of the parameter 'b'. The parameter 'c' is taken to be constant (average over the season) because of its low variability.

The procedure to calculate the effect of light (L) on NP(FL):

1. The seasonal change of the parameter 'b' is fitted with a third-degree polynomial equation: b=f(DAY). This curve is shown in Figure 24 ($R^2$=.59, the F-values show that all regression coefficients are highly significant).

2. The change of NPMAX with time is known from NPMAX=f(DAY).

3. The parameter 'a' is calculated from the exponential light functions: $a = (NPMAX-c)^*(1-e^{-b^*120})^{-1}$.

4. The light curve of NP for any DAY is:

$$NP = a^*(1-e^{-b^*L})+c$$

5. The effect of light intensity is scaled from 0 to 1 by division of NP by NPMAX:

$$FL = NP^*NPMAX^{-1} = (a^*(1-e^{-b^*L})+c)^*NPMAX^{-1}.$$

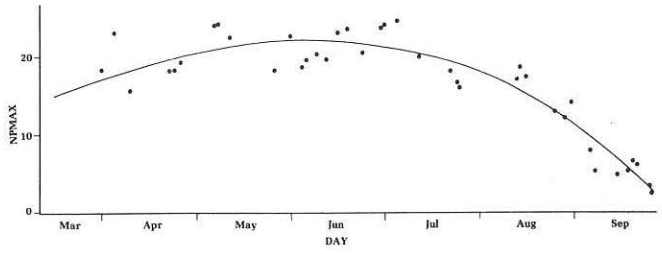


**Figure 23.** Change of the maximal rate of net photosynthesis (NPMAX) of *H. scoparia* (unwatered) versus the time of year (DAY).

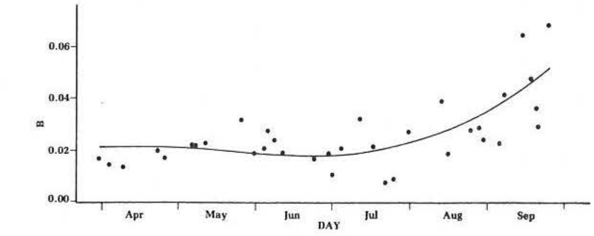


**Figure 24.** Change of the parameter "b" of the light equation (B) versus the time of year (DAY) for *H. scoparia* (unwatered).

### THE FUNCTION (FL) TO OBTAIN THE EFFECT OF LIGHT INTENSITY ON NP IN THE MODEL

```
MOD3:
  PROC OPTIONS(MAIN);
  ON ENDFILE(SYSIN) STOP;
TOP:
  GET LIST(DAY,LIGHT);
 XNPMAX=7.934179+DAY*(0.7454753+DAY*(0.7260825E-03+DAY*-0.4022865E-05)));
  BFACT=-0.02174363+DAY*(0.001041343+DAY*(-0.7986124E-05+DAY*
      0.1909426E-07)));
  AFACT=(XNPMAX - 0.141463)/(1.0 - EXP(-BFACT * 120));
  XL=AFACT*(1.0 - EXP(-BFACT*LIGHT)) - 2.24436;
  FL=XL/XNPMAX;
  PUT SKIP DATA(DAY,LIGHT,FL);
  GO TO TOP;
END MOD3;
```

### THE WATER STRESS FACTOR (FS)

An increase in plant water stress during the day is expected to reduce the TEMP and WD corrected rates of NP, especially at a high light intensity at noon. In this case the correction for the effect of TEMP and WD would not compensate for the noon depression. The decrease of the corrected NP values with increasing light would be a measure of the stress effect.

For *H. scoparia* the curves of light-dependent NP either level off or show an increasing rate of $CO_2$ uptake until high light intensity. Therefore, in this case, the development of a separate stress function was not possible. This, however, might be necessary for other desert species.

## THE MODEL TO CALCULATE NP FROM THE TIME OF YEAR (DAY) AND FROM THE CLIMATIC DATA: LIGHT, TEMPERATURE AND DEWPOINT

**Input**-The climatic data (light, temperature and dewpoint) are obtained from the METEOR common block which contains the output of the EXOGEN program. The WD value is calculated from the temperature and the dewpoint data. For each species the following parameters must be determined:

1. parameters for the correction of the effect of TEMP (TEMPC1-TEMPC8)
2. parameters for the correction of the effect of WD (WDC1-WDC8)
3. parameters for the correction of the effect of L including the calculation of NPMAX (XLIC1-XLIC8)
4. constant for conversion of the output from $mgCO_2{}^*gdw^{-1}{}^*time^{-1}$ to $mgC^*gC^{-1}{}^*time\ span^{-1}$ (Const).

The model calculates NPMAX = f(DAY) and corrects this value for the effect of L, TEMP, WD multiplicatively (see Fig. 1). An effect of water stress still needs to be included if necessary.

The output of the model is $mg\ C^*\ gC^{-1}{}^*time\ span^{-1}$

The FORTRAN program interfaces with the Desert Biome "General-purpose" Model. It is as follows:

```
      SUBROUTINE PHOTOS

      COMMON /PARM/
     1 TEMPC1(15),TEMPC2(15),TEMPC3(15),TEMPC4(15),TEMPC5(15),TEMPC6(15)
     2,TEMPC7(15),TEMPC8(15),WDC1(15),WDC2(15),WDC3(15),WDC4(15),
     3 WDC5(15),WDC6(15),WDC7(15),WDC8(15),XLIC1(15),XLIC2(15),
     4 XLIC3(15),XLIC4(15),XLIC5(15),XLIC6(15),XLIC7(15),XLIC8(15)
     5 ,CONST(15)

      COMMON/INCOMV/I,IL,IR

      COMMON/STAT/CVEG(15,10,6)

      COMMON /CHANGE/CVEGQQ(15,10,6)

      COMMON/METEOR/EVAP,TDAY,TNIGHT,DAYWVP,DWINAV,DWINMX,DAPHOT,
     1 DAYRAD,DUST,DUSCOM(6),RAINCO(6),ERODE,DAYRUN,DRUNMI(6),DRUNUR(6)
     2 ,DRUNLT(5,6), DASNOW, DARAIN,HTEMP(24),HLIGHT(24),HRELHU(24)
     3 HDEWPT(24),HWIND(24),HEVAP(24)

      COMMON/SPEC/DUM(30),IYRDAY,D1(20),NDEBUG,D2(XX),NUNIT

      COMMON/TOTALS/D4(237),AVEG(15,10)

      NUNIT=NUNIT/1000
      DO 11 K=1,NUNIT
      DAY=IYDAY+K-1
      DO 11 J=1,24
      IF (HLIGHT(J).LT.2.)GO TO 11

C     CORRECTION FOR THE EFFECT OF TEMPERATURE

      TEMPCP =TEMPC1(I)*DAY**3+TEMPC2(I)*DAY*DAY+TEMPC3(I)*DAY+TEMPC4(I)
      SHIFT=TEMPCP -27.34
      TEMPIT=HTEMP(J)-SHIFT
      IF (TEMPIT.LT.7.)GO TO 20
      IF (TEMPIT.GT.20.)
     *TF=(TEMPC5(I)*TEMPIT**3+TEMPC6(I)*TEMPIT**2+TEMPC7(I)*TEMPIT
     1 +TEMPC8(I))/100
      IF (TEMPIT.LT.20.) TF=(3.36*TEMPIT+16.8)/100
      GO TO 30
20    TF=1
30    CONTINUE

CORRECTION FOR THE EFFECT OF WATER VAPOUR DIFFERENCE BETWEEN LEAF AND AIR

      WSMIN=WDC1(I)*DAY**3+WDC2(I)*DAY**2+WDC3(I)*DAY+WDC4(I)
      WDF=-(WDC5(I)*WSMIN**3+WDC6(I)*WSMIN**2+WDC7(I)*WSMIN+WDC8(I))
     1 *((.257827E-5*HTEMP(J)**4+.152719E-3*HTEMP(J)**3
     2 +.103302E-1*HTEMP(J)**2+.333707*HTEMP(J)+4.84756)
     3 - (.257827E-5*HDEWPT(J)**4+.152719E-3*HDEWPT(J)**3
     4 +.103302E-1*HDEWPT(J)**2+.333707*HDEWPT(J)+4.84756))+1
      IF (WDF.LT..01)WDF=.01
      FS=1

 CALCULATION OF MAXIMAL RATE OF NET PHOTOSYNTHESIS

       XNPMAX=XLIC1(I)*DAY**3+XLIC2(I)*DAY**2+XLIC3(I)*DAY+XLIC4(I)

 CORRECTION FOR THE EFFECT OF LIGHT

       BFACT=XLIC5(I)*DAY**3+XLIC6(I)*DAY**2+XLIC7(I)*DAY+XLIC8(I)
       AFACT=(XNPMAX-.141463)/(1-EXP(-BFACT*120))
       FL=AFACT*(1-EXP(-BFACT*HLIGHT(J)))-.141463
       FL=FL/XNPMAX

 CALCULATION OF ACTUAL RATE OF NP

       XNP=XNPMAX*FL*WDF    *TF*FS
10     TOTNP=TOTNP+XNP
11     CONTINUE
       TOTNP=TOTNP*CONST(I)
       PSATE=TOTNP*AVEG(I,IL)
       CVEGQQ(I,IL,IR)=CVEGQQ(I,IL,IR)+PSATE
       RETURN
       ENTRY INPHOS
       DO 15 J=1,I
15     READ(5,/)TEMPC1(J),TEMPC2(J),TEMPC3(J),TEMPC4(J),TEMPC5(J),
      1 TEMPC6(J),TEMPC7(J),TEMPC8(J),WDC1(J),WDC2(J),WDC3(J),WDC4(J),
      2 WDC5(J),WDC6(J),WDC7(J),WDC8(J),XLIC1(4),XLIC2(J),XLIC3(J)
      3 XLIC4(J),XLIC5(J),XLIC6(J),XLIC7(J),XLIC8(J),CONST(J)
       RETURN
       END
```

## THE TEST OF THE MODEL

The model was tested against NP measurements which were taken under natural conditions in the field but were not incorporated during building of the model. For the period from April to September, 104 days were chosen. For these days, NP was predicted on a 6-min time step. The result was compared with the actual measured rates of gas exchange. The test program worked on a 6-min time step, with only one species, taking WD as an input variable. The test program is as follows (for this species, the NP-WD relationship was corrected for the non-linearity in the range of large values of WD):

```
FILE  4=FILE4,UNIT=READER,RECORD=14
FILE  5=FILE5,UNIT=DISKPACK,RECORD=14,BLOCKING=30
FILE  6=FILE6,UNIT=PRINTER,RECORD=22
FILE  7=FILE7,UNIT=PRINTER,RECORD=22
```

```
      REAL LI,HR,HRA(240),NP,NPA(240),NPMAX
      DIMENSION FWA(240),FTA(240),FLA(240),ENPA(240),ABC(8),XC(8),FC(8)
     1 ,FACT(8),ENPB(240),FWO(240)
      COMMON AA(867),XMIN,XMAX,YMIN,YMAX,FLG
      DATA AA/867*'      '/
      IDAY=101
      IDAY=JULIAN(IDAY) - 1
      READ(4,/) ABC,XC,FC,FACT
      CLOSE 4
      WRITE(6,201) ABC,XC,FC,FACT
      READ(5,100) MON,HR,LI,BTI,NP,WDI
1     IMON=MON
      ICNT=0
      DAY=JULIAN(MON) - IDAY
      FACTOR=FC(4) + DAY * (FC(3) + DAY * (FC(2) + DAY * FC(1)))
      FACTOR=FC(8) + FACTOR *(FC(7) + FACTOR *(FC(6) + FACTOR * FC(5)))
      FACTOR=-FACTOR
      XMAX=XC(4) + DAY * (XC(3) + DAY * (XC(2) + DAY * XC(1)))
      A=ABC(4) + DAY * (ABC(3) + DAY * (ABC(2) + DAY * ABC(1)))
      B=ABC(8) + DAY * (ABC(7) + DAY * (ABC(6) + DAY * ABC(5)))
      NPMAX=FACT(4) + DAY * (FACT(3) + DAY * (FACT(2) + DAY * FACT(1)))
      BFACT=FACT(8) + DAY * (FACT(7) + DAY * (FACT(6) + DAY * FACT(5)))
      BFACT=-BFACT
      AFACT=(NPMAX + 2.24436)/(1.0 - EXP(BFACT * 120))
      WRITE(6,300)
      SNP=0
      SENP=0
      SENP1=0
2     ICNT=ICNT + 1
      HR=IFIX(HR/100) + MOD(HR,100)/60.0
      HRA(ICNT)=HR
      NPA(ICNT)=NP
      TEMP=BTI - XMAX
      IF (TEMP .GT. 19) GO TO 3
      FT=3.36 * TEMP + 16.8
      GO TO 4
3     FT=XC(8) + TEMP * (XC(7) + TEMP * (XC(6) + TEMP * XC(5)))
4     FT=FT * .01
      FL=AFACT * (1.0 - EXP(BFACT * LI))  - 2.24436
      FL=FL/NPMAX
      FW=FACTOR * WDI + 1.0
      IF (FW .LE. 0) FW=.01
      FWOLD=FW
      FWCORR=FW
      ENP1=NPMAX * FL * FW * FT
      IF (FW .LT. 0.28) FWCORR=0.28
      TEMP=A/FWCORR + B
      IF (TEMP .GT. 1) FW=FWCORR * TEMP
      ENP=NPMAX * FL * FW * FT
      IF (NP .EQ. 0) NP=.01
      QUOT=ENP/NP
      WRITE(6,200) MON,DAY,HR,LI,BTI,WDI,FWOLD,FW,TEMP,FT,FL,ENP,ENP1,NP
     1 ,QUOT
      SNP=SNP + NP
      SENP=SENP + ENP
      SENP1=SENP1 + ENP1
      FWO(ICNT)=FWOLD
      FWA(ICNT)=FW
      FTA(ICNT)=FT
      FLA(ICNT)=FL
      ENPB(ICNT)=ENP1
      ENPA(ICNT)=ENP
      READ(5,100,END=6) MON,HR,LI,BTI,NP,WDI
      IF (MON .EQ. IMON) GO TO 2
6     WRITE(6,203) SENP,SENP1,SNP
      SNP=100.0/SNP
      SENP=SENP * SNP
      SENP1=SENP1 * SNP
      WRITE(6,204) SENP,SENP1
      WRITE(6,202) MON,DAY,FACTOR,XMAX,A,B,NPMAX,BFACT,AFACT
      SYM='*'
      XMIN=4
      XMAX=20
      YMIN=0
      YMAX=1
      WRITE(6,307)
      CALL GRAPH(ICNT,SYM,HRA,FWO)
      WRITE(6,301)
      CALL GRAPH(ICNT,SYM,HRA,FWA)
      WRITE(6,302)
      CALL GRAPH(ICNT,SYM,HRA,FTA)
      YMIN=-0.2
      WRITE(6,303)
      CALL GRAPH(ICNT,SYM,HRA,FLA)
      WRITE(6,304)
      XMAX=16
      XMIN=-2
      YMAX=20
      YMIN=4
      FLG=1
      CALL GRAPH(ICNT,SYM,ENPA,HRA)
      FLG=0
      SYM='O'
      CALL GRAPH(ICNT,SYM,NPA,HRA)
      WRITE(6,306)
      FLG=1
      CALL GRAPH(ICNT,SYM,NPA,HRA)
      FLG=0
      SYM='*'
      CALL GRAPH(ICNT,SYM,ENPB,HRA)
      IF (IMON .NE. MON) GO TO 1
      STOP
100   FORMAT(4X,2I4,F4.0,3F6.2)
200   FORMAT(2I5,F6.2,I5,11F8.2)
201   FORMAT(4(5X,E15.7))
202   FORMAT('0MMDD  DAY   FACTOR(WD)           SHIFT            A(WDCORR)  '
     1 ,'        B(WDCORR)   NPMAX             BFACT(FL)        AFACT(FL)' /
     2 21('-----') / 2I5,7G15.6)
203   FORMAT('0TOTALS',70X,3F8.2)
204   FORMAT(' PERCENTS',68X,2F8.2)
300   FORMAT('1MMDD  DAY  TIME   LI      BTI      WDI   FWOLD       FW    '
     1 ,'TEMP       FT       FL      XNP     XNP1    NP/TR   QUOT.' / ' ',
     2 21('-----'))
301   FORMAT('1                FW VERSUS TIME    ')
302   FORMAT('1                FT VERSUS TIME')
303   FORMAT('1                FL VERSUS TIME')
304   FORMAT('1                XNP (*) AND NP/TR (O) VERSUS TIME WITH FW ',
     1 'CORRECTION ')
306   FORMAT('1                XNP (*) AND NP/TR (O) VERSUS TIME WITHOUT ',
     1 'FW CORRECTION ')
307   FORMAT('1                FW WITHOUT CORRECTION  VERSUS TIME')
      END
```

Figure 25 shows the test result in a drawing, in which the measured and predicted daily sums of $CO_2$ uptake are plotted as a function of DAY. The scatter of the observed values (o) is greater than that of the predicted (●) values. Extreme high and low observed values (i.e. DAY 129, 141 and 142) should be checked on the original recordings of the raw data. The average deviation of the predicted and the observed values of the daily sum of $CO_2$ uptake is -18 to +14 mg $CO_2$*gdw$^{-1}$ *DAY$^{-1}$, which is on the total average, an error of -8%. It is important that the scatter of the predicted and observed values seems to be random. There is no systematic over- or under-estimation of the predicted NP at any time of the year.

A great number of daily courses of NP is predicted very closely. An example is given for a day in spring (April 22) in Figure 26; for a day in summer (June 17) in Figure 27; and for a day in late summer (September 17) in Figure 28. The predicted values (●) match the observed ones (o) for all conditions throughout the day.

The limitations of the model are obvious from days with extreme climatic conditions and from days where production is systematically over- or under-estimated. Figure 29 (July 28) shows an example, where the predicted values (●) are much higher than the observed values (o). The reason for such an over-estimation of production is mainly due to a wrong estimation of NPMAX at that point of the annual curve. For long-term prediction of $CO_2$ uptake, for instance the NP estimation of a whole growing season, such errors should equilibrate. For extreme climatic conditions, however, there is still a need to test whether the approach of handling the effect of various factors multiplicatively is correct. In some situations an average effect of the various factors, or the effect of the minimum factor only, might lead to a better result.

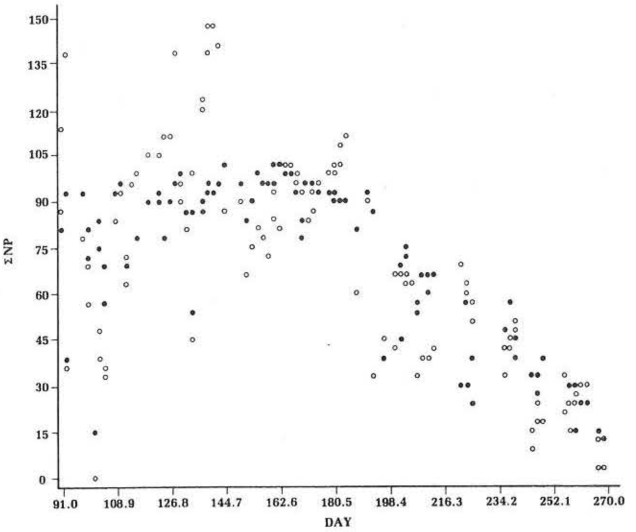
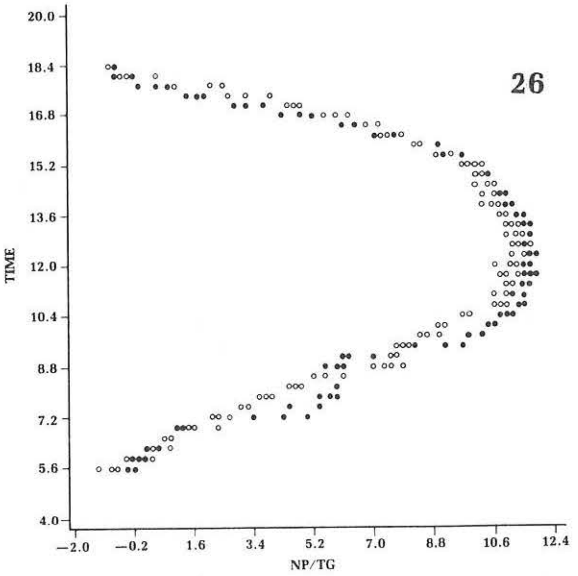
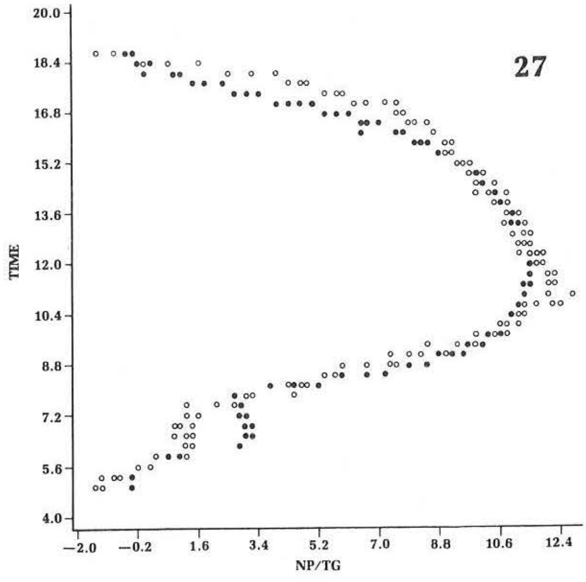


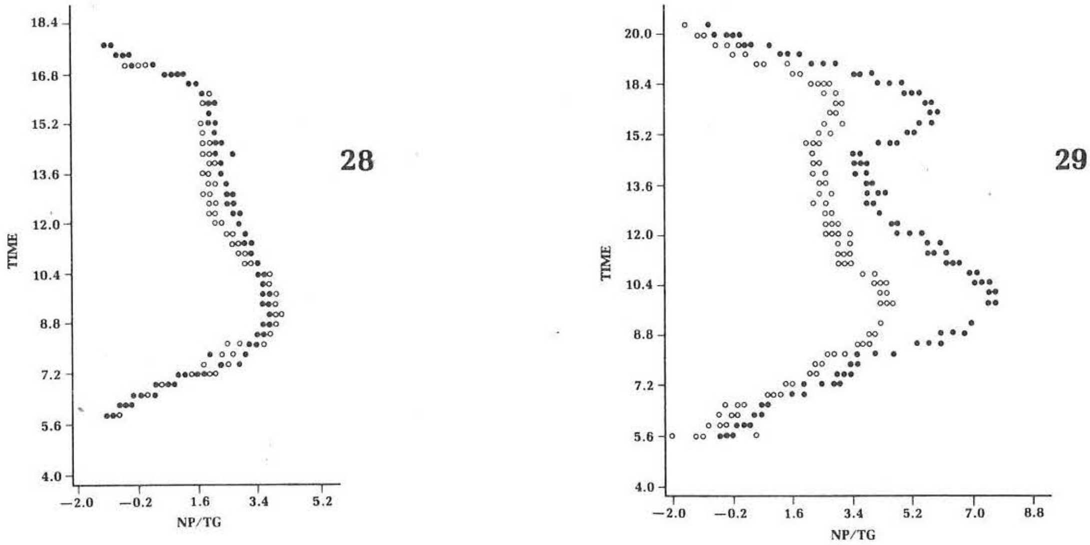
**Figure 25.** Daily sum of $CO_2$ uptake (ΣNP) as related to the time of year (DAY) for *H. scoparia* (unwatered). Predicted values (●): measured values (o).

For the ecosystem model the sum of $CO_2$ uptake over the season is the most important result of the photosynthesis model. During the time from April 1 to September 30, for 104 test days from a total of 183 days, the total sum of $CO_2$ uptake is calculated. The predicted sum of $CO_2$ uptake is 7063.54 mg$CO_2$*gdw$^{-1}$, whereas the measured rate is 7078.22 mg $CO_2$*gdw$^{-1}$. The difference between the measured and the predicted result over this period of time is only -14.69 mg $CO_2$*gdw$^{-1}$. Thus the final error of this model test is in this case less than -1%





**Figures 26 and 27.** The daily course of net photosynthesis of *H. scoparia* (unwatered) on April 22, 1971 (Fig. 26) and June 17, 1971 (Fig. 27) with FW correction. x-axis: rate of net phosynthesis per gram dry weight and hour (NP/TG). y-axis: time of day in 1/10 of the hour (TIME). Predicted values (●); measured values (o).



**Figures 28 and 29.** The daily course of net photosynthesis of *H. scoparia* (unwatered) on September 17, 1971 (Fig. 28) and July 28, 1971 (Fig. 29) without FW correction. x-axis: rate of net photosynthesis per gram dry weight and hour (NP/TG), y-axis: time of day in 1/10 of the hour (TIME). Predicted values (•); measured values (o).

### CONCLUSIONS

When we began to build the model it was not known if this approach would lead to a reasonable result. Especially, it was not known whether the function of the effect of L, TEMP and WD would be sufficient to predict NP under natural conditions in the field. For *H. scoparia* this approach seems to be sufficient and correct. For other species, however, other mechanisms may be of more importance, and may be added in a similar approach to the existing model.

For the application of this approach to other species, all the parameters of the different equations have to be determined from field data. If no data are available, new experiments should be carried out. For species comparison, it would be most desirable if similar sets of experiments could be performed.

## SENSITIVITY ANALYSIS OF THE MODEL AND AN APPLICATION

A model gives the opportunity to test single factors in their effect on the system as a whole which usually cannot be accomplished by the original data set. Such an extrapolation is certainly possible only within a limited range given by the experiment.

In the following, an attempt is made to solve a specific problem taking the primary production of *H. scoparia* as an example. From the SST project the question has been asked, What effect has a certain change in climate on plant production? For 40°-60° latitude the following cases ought to be tested:

1. change in mean temperature °C: -3, -1.5, -.75, + .75
2. change in wind and precipitation: -10%, -5%, -2.5%, 0
3. change in radiation: -3.1%, -1.6%, -.8%, 0

These changes should occur over a three-year period.

In solving this problem the following restrictions have been made:

1. The model was run for 104 out of 180 days ranging from April 1 to September 30. This is the main growing season of *H. scoparia* in the Negev desert. The last heavy rains occurred in mid-April. There is no rain until the end of October. The percentage change of each case is calculated.
2. The mean change of any parameter was accomplished by subtracting this change from the original field data. This is certainly not correct, since a mean change has a certain statistical variation. A 3° change in mean temperature means that also a change of 10° and more is possible. Such episodial events have a drastic influence on plant distribution. They are not covered here.
3. The model does not account for any acclimation, which certainly will occur in a plant if conditions change over a period of time.
4. A change in climate might reach certain physiological threshold values (e.g., temperature induction of enzymes, influence of photoperiod, etc.) which again have a feedback on net photosynthesis and which are not covered by the model.

5. A change in climate will influence many other physiological processes besides photosynthesis and respiration, which in a feedback loop influence NP again. The model does not account for such indirect effects.

6. Long-term changes of climate will certainly influence the competition between plant species and induce a new succession. Also this problem cannot be solved by a photosynthesis model.

The model determines the relative importance of certain factors for this special plant in its habitat. It also will show, under certain changing conditons, if new factors and functions have to be considered as important for the model.

*H. scoparia* shows the following responses in NP at the proposed changes in external conditions:

1. Influence of a change in leaf temperature **without** taking a change in WD into account: a change in leaf temperature will certainly affect NP differently during the cold temperatures in spring as compared to the hot summer. Figure 30 shows the result of a temperature change on the total rate of $CO_2$ uptake over the season.

| Change in TEMP | Rel. rate of $CO_2$ gain |
|---|---|
| -5.0 C | 85.77% |
| -3.0 C | 92.13% |
| -1.5 C | 96.43% |
| 0 | 100.00% |
| +1.5 C | 102.76% |
| +3.0 C | 104.47% |
| +5.0 C | 104.97% |

For a desert plant adapted to a hot desert climate, a temperature drop of -3 C would decrease production by 7.9%. This change will certainly be smaller if this temperature change occurs over a long period of time, since *H. scoparia* shows a great adaptation in its temperature response (see Fig. 6). It is a remarkable result that if WD is not changed, production of *H. scoparia* will increase 4-5% with a temperature rise of 3-5 C.

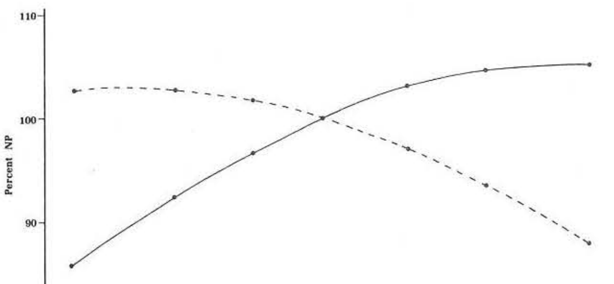


**Figure 30.** Relative change of the photosynthetic gain (percent NP) for *H. scoparia* (unwatered) at a certain change in mean temperature (ΔTEMP) **without** taking a change in WD into account. Constant WD (——): changing WD with TEMP (----).

2. Influence of a change in leaf temperature **with** taking a change in WD into account: a change in leaf temperature has a large effect on WD if the dew point is constant especially at high temperatures typical for a desert day. Figure 30 shows also the result of a TEMP and WD change on the total rate of $CO_2$ uptake over a growing season.

| Change in TEMP | Rel. rate of $CO_2$ gain |
|---|---|
| -5.0 C | 102.56% |
| -3.0 C | 102.85% |
| -1.5 C | 101.99% |
| 0 | 100.00% |
| +1.5 C | 97.26% |
| +3.0 C | 93.23% |
| +5.0 C | 88.08% |

The result shows that in contrast to case (1), NP increases 2-3% with decreasing temperature. This increase is terminated at a temperature change of -3 to -5 C because of the great effect of the unfavorable cool temperatures. Although a pure temperature increase will increase production, rising temperatures with a simultaneous change in WD will decrease total production 12% at +5 C by humidity-induced stomatal closure.

3. Influence of a change in rainfall: a change in rainfall in a desert area could have severe effects on plant growth. All the cumulative effects on phenology will mainly change the NPMAX curve. At decreasing rainfall the maximal rates of $CO_2$ uptake will be lower. However, since the effect of phenology on NPMAX is not modelled yet, the effect of decreasing rainfall cannot be handled properly by the model.

4. Influence of a change in radiation: the influence of light intensity on the gain of $CO_2$ uptake is expected to be small in the desert (Fig. 31). It might have an additional effect on a change in leaf temperature and WD which is not accounted for.

| Change in light | Rel. rate of $CO_2$ gain |
|---|---|
| +10% | 105.00% |
| + 5% | 102.58% |
| + 3% | 101.57% |
| 0 | 100.00% |
| - 3% | 98.37% |
| - 5% | 97.25% |
| -10% | 94.33% |

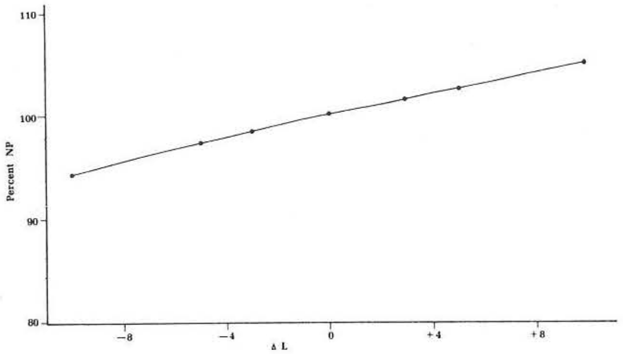


**Figure 31.** Relative change of the photosynthetic gain (percent NP) at a change in light intensity (Δ L) for *H. scoparia* (unwatered).

The results show the dominating effect of WD and TEMP on the rate of NP of *H. scoparia*. The effect of changing water stress still needs to be investigated. The changing light intensity will influence NP in the given range only insignificantly.

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1973 PROGRESS REPORT

# A PRELIMINARY SUBMODEL OF CARBON TRANSLOCATION

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**in**

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## INTRODUCTION

The aim of this report is to present a simple version of the translocation submodel which may serve as a focal point for discussion on the development of a series of submodels of differing complexities.

In constructing this preliminary submodel, we have set forth four questions to be answered in sequence: (a) What compartments should be included in this submodel? (b) What flows between compartments should be considered? (c) What factors control the rates of these flows? and (d) What are the mathematical forms of the equations relating flow rates to the factors affecting them? Our answers to these questions have been based on a combination of the results of the two previous meetings of the translocation committee, available information from the literature, and informed guesses. We have been guided by a desire to build a submodel in the short time available prior to subsequent meetings, in order to crystallize the problems which we have to confront.

## ASSUMPTIONS

The following major simplifying assumptions have been made in order to facilitate the construction of the present preliminary submodel:

1. The compartments (plant organs and carbon fractions) and flows in the submodel are shown in Figure 1 (a and b). The vertical line in Figure 1a separates flows which take place at the beginning of the growing season (right side) from those which occur later (left side). The flows at the beginning of the season are distinguished into three different life forms considered in this submodel. After the beginning of the growing season, it is assumed that the only carbon translocation occurring is that from photosynthetic to other organs, and distinction among life forms is then unnecessary.
2. The carbon fixed during each time step is put directly into the reserve carbon fraction of the photosynthetic organ.
3. All carbon translocations among organs involve the reserve fraction only; such translocations are performed prior to any transfers between different carbon fractions.
4. Growth is defined as an increase in structural carbon. Therefore, the model deals with two related but different processes, viz. growth, and fluctuation of the relative amounts of reserve carbon and protein carbon.

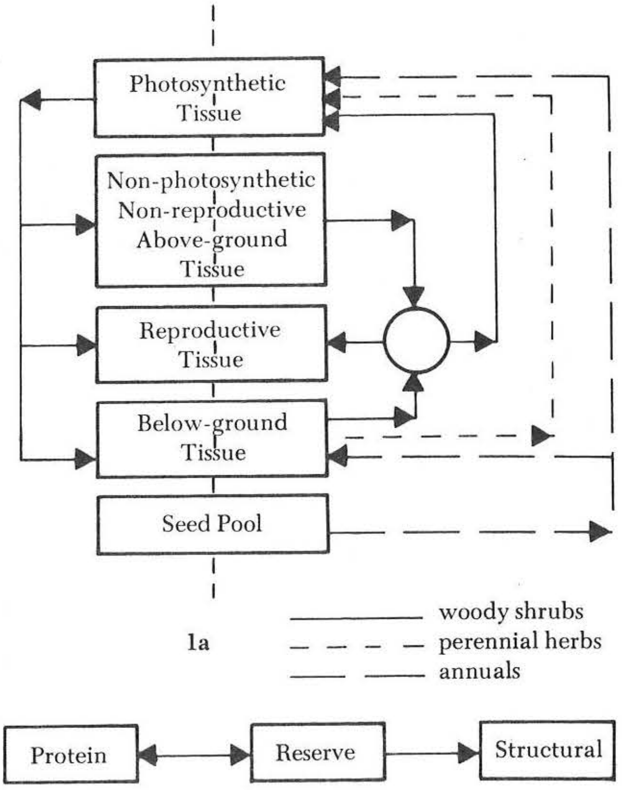
Assumptions concerning the factors affecting the flows, and the mathematical forms of the equations expressing the rates of flows as functions of these factors are explained in the following section.

## REMARKS ON THE FORTRAN IMPLEMENTATION OF THE WHOLE-SYSTEM MODEL

Before describing the translocation submodel, the overall structure of the whole-ecosystem model (Fig. 2) and the manner in which information is passed among submodels (Fig. 3) will be briefly reviewed.

The boxes in Figure 2 represent subroutines in the FORTRAN implementation of the whole-ecosystem model. Subroutines above the broken line do not model any biological processes. The main program reads initial values of the state variables, calls some of the subroutines, and handles various bookkeeping chores. The subroutine EXOGEN provides exogenous data such as air temperature, precipitation, irradiation, etc. Tabular and graphical print-out are provided by the subroutines REPORT and GRAF, respectively. Sensitivity analysis is performed by SENSIT, SENOUT and DERIVD. The subroutines VEGET, ANIMAL and SOILS either model the plant, animal and soil subsystems or call other subroutines which model separate processes of these subsystems. The processes considered in the plant subsystem are phenology (PHENOL), photosynthesis (PHOTOS), respiration of non-photosynthetic organs during dark hours (RESPIR), translocation of carbon among organs and changes in the amounts of different classes of carbon compounds (TRANSL), uptake of nitrogen and minerals from the soil and their distribution to each of the organs (MINUPT), and organ abscission and death (VDEATH). The subroutine KOVER calculates the fraction of ground covered by each species. The subroutine VSTVAR handles miscellaneous bookkeeping chores.

The common block /INCOMV/ contains variables and switches generated by the various plant submodels and required by more than one of these submodels. For example, the one-dimensional array "PHENST(I)" which is an output from the phenology submodel, and an input to the translocation submodel, indicates the current phenological state of the *i*'th species age class. Inputs required by the submodel which are read in at the start of simulation are placed in the common block /PARAM/ if they are real numbers, and in the common block /IPARAM/ if they are integers. The common block /SPEC/ contains specifications required by all of the programs such as the number of species, the number of organs, etc. The common block /METEOR/ contains exogenous variables (mostly meteorological). State variables are contained in the common block /STAT/, and increments to the state variables in the common block /CHANGE/. The common block /TOTALS/ contains summations of various combinations of state variables. Selected state variables and output variables not contained in the previously mentioned common blocks are included in the common block /OTHER/.



1a

1b

Figure 1. Compartments in translocation model.

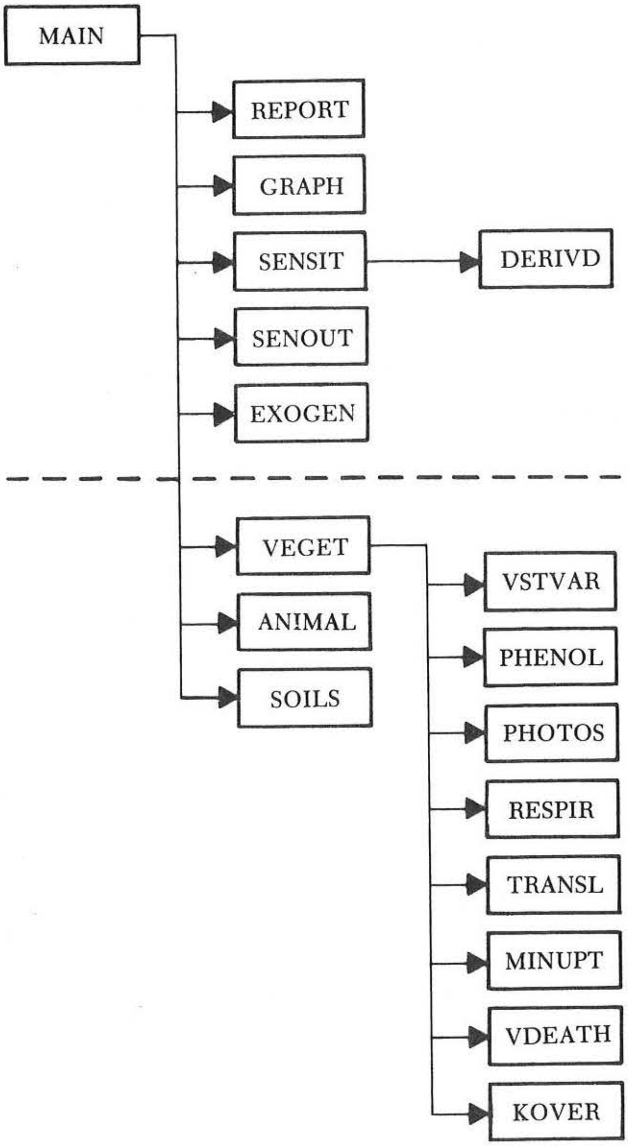


**Figure 2.** Procedures in FORTRAN implementation of whole-ecosystem model.

/INCOMV/
/PARAM/
/IPARAM/

/SPEC/
/METEOR/
/STAT/

/CHANGE/
/TOTALS/
/OTHER/

**Figure 3.** Common blocks used by translocation model.

# DESCRIPTION OF THE TRANSLOCATION SUBMODEL*

## GERMINATION AND LEAFING-OUT

Germination and leafing-out are considered to be affected by soil water potential in bars (SWP), soil temperature (ST), and the ratio of the amounts of reserve to total carbon (RC:TC). The translocation rate is related to SWP by a modified Mitscherlich function (equation 1 and Figure 4), to ST by a fourth-order polynomial (equation 2 and Figure 5), and to RC:TC by an exponential function (equation 3 and Figure 6). In these and subsequent equations, lower case letters represent parameters. RTR1 and RTR2 are relative rates varying from zero to one, and the overall rate equals the product of TR, RTR1 and RTR2. In equation 1, c and SWP are negative numbers.

The reserve carbon translocated during germination is distributed to roots and shoots according to read-in ratios. In perennial grasses and herbs, the translocation during leafing-out occurs from a single donor organ (below-ground) to a single recipient organ (above-ground photosynthetic). In woody shrubs, translocation occurs from two donor organs (stems and roots) to one or both of two recipient organs (leaves and fruits). In the latter case, the amounts translocated from each of the donor organs are summed and the resulting amount is distributed between leaves and fruits according to read-in ratios.

## VEGETATIVE AND FRUITING STAGES

The rate of translocation from the photosynthetic organ to other organs is a function of water potential (WP), temperature and RC:TC in leaves. The value used for WP is the SWP of each soil horizon weighted by the root biomass in the respective horizon. For above-ground organs the translocation rate depends on air temperature, and for below-ground organs it depends on the temperature of the respective soil horizon. The relationships between the translocation rate and each of these three variables are as indicated in equations 1, 2 and 3 and Figures 4, 5 and 6 respectively.

If the species is fruiting the fraction of the translocate that goes to fruits is an exponential function of RC:TC (Fig. 7). The fraction of the remaining amount of translocate which is transferred to below-ground organs is also an exponential function of RC:TC; the rest is transferred to stems. This manner of distribution is based on the assumption that as conditions become more favorable, fruits receive a progressively larger proportion of the translocate, and stems a progressively smaller proportion.

## CARBON FRACTION DYNAMICS

The ratio of reserve to protein carbon (RC:PC) at which no flow occurs between these two fractons (CR = critical ratio) is a negative exponential function of WP (equation 4 and Fig. 8), and the nitrogen to protein carbon ratio (N:PC; Fig. 9). For above-ground organs the value used for WP is the weighted SWP described in the previous section, and for below-ground organs, it is the unweighted SWP. The dependence on N:PC ensures that if nitrogen uptake is low, protein synthesis will be depressed.

If the actual current RC:PC is greater than the critical ratio, carbon flows from the reserve fraction to the protein and structural fractions. The rates of these two flows are exponential functions of RC:PC and RC:SC (where SC= structural carbon) respectively. On the other hand, if the actual value of RC:PC is below the critical ratio, then there is only one flow; from protein to reserve carbon. The rate of this flow is a negative exponential function of RC:PC.

# FINAL REMARKS

In order to fulfill our ultimate objective of building a series of translocation submodels, and to improve the above submodel, which may be considered the simplest of this series, we need to address ourselves to the questions below. It is expected that each submodel of the series will have a different set of answers to these questions:

1. Are there any compartments and flows that should be added to and/or deleted from the present submodel?
2. Are there any data available bearing on the relationship between the flows and the factors influencing them which are assumed in the above submodel, or is there any information indicating that there are better choices of factors?
3. Are there time series data available providing the relative amounts of protein, reserve and structural carbon present in each organ of representative species?
4. Should any of the mathematical equations expressing the rates of flow be modified or replaced by others?

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*A flow chart of the submodel is provided in Figure 10.

$$RTR1 = 1 - \exp(-b(SWP - c)) \qquad (1)$$

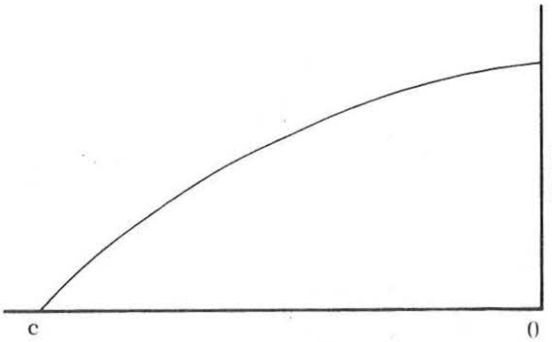

Figure 4

$$RTR2 = b \cdot ST + c \cdot ST^2 + d \cdot ST^3 + f \cdot ST^4 \qquad (2)$$

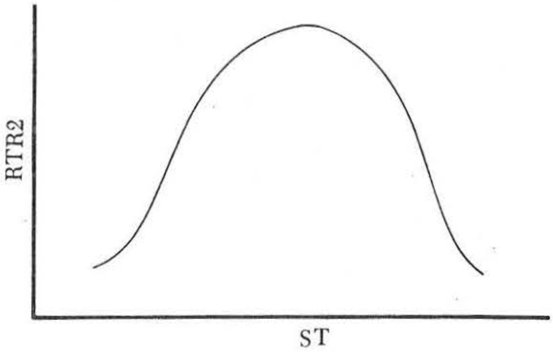

Figure 5

$$TR = a + b \cdot \exp(c \cdot RC{:}TC) \qquad (3)$$

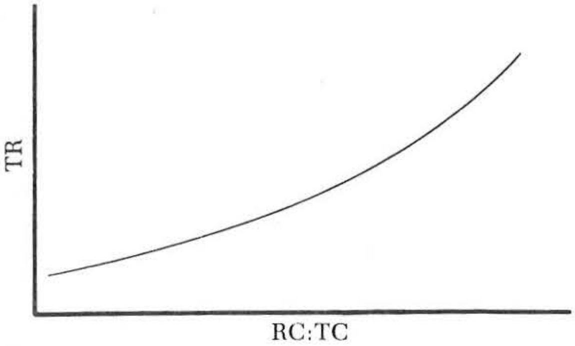

Figure 6

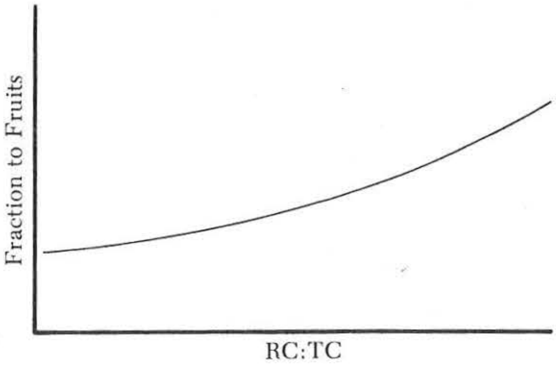

Figure 7

$$CR = a + b \cdot \exp(-c \cdot WP) \qquad (4)$$

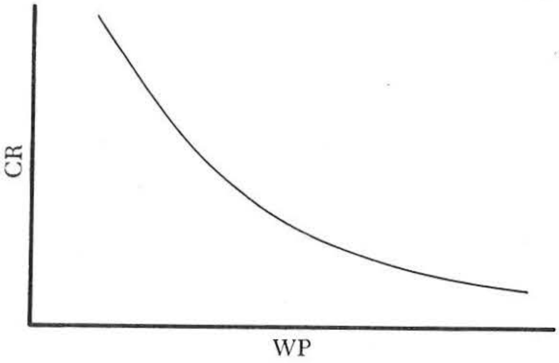

Figure 8

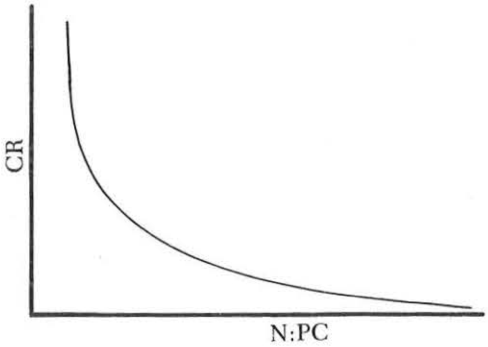

Figure 9

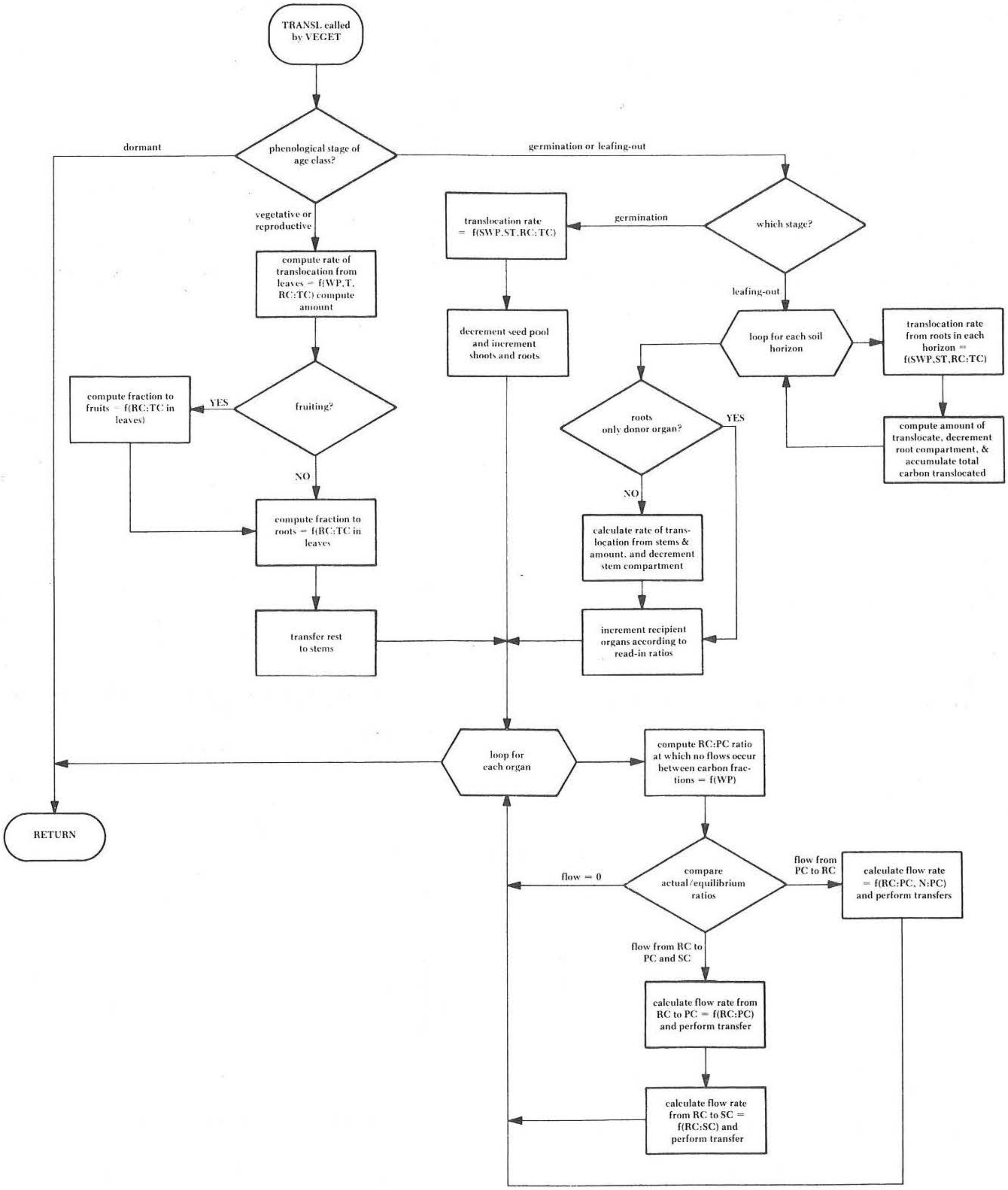

**Figure 10.** Flow chart of the translocation submodel.

**1973/74 PROGRESS REPORT**

# A GENERALIZED PHENOLOGY SUBMODEL FOR DESERT PLANTS

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**US/IBP DESERT BIOME**
**RESEARCH MEMORANDUM 74-59**

**in**

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**MAY, 1974**

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## INTRODUCTION

One of the major objectives of the International Biological Program (IBP) is to develop large-scale systems models to simulate carbon flow through natural ecosystems. Research emphasis toward this end has focused on many important ecosystem processes, e.g., primary productivity, population dynamics, nutrient cycling, etc., all of which must be incorporated into the models. In order to predict the activities of the different trophic levels in an ecosystem, temporal realism for ecosystem phenomena must be achieved. Because of this need, it has been recognized from the outset that phenological information would be an integral part of any large systems model. Consequently, there has been considerable interest in phenology within the representative biomes of the US/IBP in both field studies (US/IBP Phenology Committee, 1972) and mathematical modeling (Lieth, 1974). A Desert Biome approach developed for modeling phenology will be presented in this paper.

The response of plants to environmental stimuli is reflected in a change in their activity. This could involve, for example, the initiation of flowering buds, the germination of seeds, or the onset of senescence. These changes, or phenophases (Lieth, 1970), within the life cycles of plants are important in delimiting many ecosystem events such as the beginning and end of growing seasons and energy transfers between trophic levels (Bliss, 1967; Lieth, 1970, 1971). The use of meteorological data to predict some of these phenological changes has been practiced for many years where, in general, correlations between certain phenophases and specific environmental triggers are sought. Probably the most well-known example is the concept of heat-units or degree-days (Wang, 1960) which characterizes plant development as a function of its thermal environment. Other factors, such as the cumulative sum of air temperature (Jackson, 1966) and the cumulative sum of the product of daily air temperature and insolation (Capiro, 1971), have also been used to predict flowering time in certain species of plants with varying degrees of success.

It is clear that the seasonal and yearly stochastic variations in the physical environment to which plants are coupled make prediction of phenophases based solely on calendar dates unsatisfactory. This is especially true in desert ecosystems where extreme conditions prevail. Consequently, it is necessary to have phenology as a variable which can be determined as a function of current environmental conditions. The role of a phenology submodel in an ecosystems model is to provide current information on the phenological status or developmental stage of each primary producer. This information will, in turn, be used to regulate other activities in the model, e.g., photosynthesis, carbohydrate translocation, etc., thereby obtaining realistic simulations of biomass dynamics.

## MODELING PHENOLOGY IN DESERT ECOSYSTEMS

Deserts are essentially "water-controlled" ecosystems because of the infrequent, discrete and unpredictable inputs of water (Noy-Meir, 1973) and the tight coupling of the organisms to this available moisture. For example, creosotebush (*Larrea divaricata*) in the Colorado Desert in southern California was found to flower any time of the year in response to increased soil moisture (Oechel et al., 1972), and Brum (1973) has documented the importance of spring and summer rainfall in the germination and establishment of saguaro (*Carnegiea gigantea*). Probably few exceptions exist where major plant activities are not a direct response to soil moisture levels. This concept is examined in depth by Noy-Meir (1973). Of course, in spite of the importance of water, other environmental variables can have a modifying effect on the physiological response of a plant. In fact, *Larrea* would not have exhibited a year-around flowering capacity had air temperature been limiting at the time of water influx (Oechel et al., 1972).

Bridges et al. (1972) have proposed modeling phenology in deserts using a "pulse-reserve" paradigm in which various qualitative phenological states of plants are triggered by different combinations of environmental variables -- water being the most important. If the relationships between phenological events and environmental triggers are known, as Beatley (1974) has worked out in great detail for Mojave Desert plants, this approach may prove to be useful, at least where such detailed data are available. As yet, however, it appears that this method would not provide the resolution necessary in a systems model (Reynolds, 1974). However, a phenology model for desert plants should ideally include the flexibility which would allow the inclusion of any threshold trigger that has been defined for certain phenophases in a species as well as quantitatively tracking phenological progression. In this paper a generalized phenology submodel is presented for desert plants. This submodel was developed to provide a framework for utilizing a variety of environmental data (e.g., soil moisture status, air temperatures, heat-sums, etc.) to simulate phenology and, in addition, provide for internal plant thresholds (e.g., carbon fraction ratios) which can further regulate the phenological status of a plant.

# MODEL DESCRIPTION

## SELECTION OF LIFE-FORMS AND PHENOPHASES

A balance must be made in any modeling attempt with regard to the detail needed to accurately represent important biological phenomena and the complexity of the model which can limit its understanding and usefulness. Thus, in addition to obtaining a realistic representation, a minimum level of complexity was sought in formulating the submodel.

The submodel was structured to handle two functional plant groups; perennials (including grasses, forbs, succulents, evergreen shrubs, winter- and drought-deciduous shrubs), and annuals (grasses and forbs). Although the division of all plants into an annual or perennial distinction is broad, it was justified on the basis of the closer functional similarity of, for example, the life cycle of a perennial grass and a perennial shrub than that of a perennial grass and an annual grass. Phenophases were selected to cover the general spectrum of morphological development of plants during their life cycles, from germination to vegetative growth (e.g., swelling leaf buds, emergent leaves, twig elongation, etc.) and reproductive growth (e.g., floral bud development, flowering, fruiting, etc.) to, finally, dormancy and/or senescence. Six phenophases were defined for annuals and five for perennials, as listed below:

| **Annuals** | **Perennials** |
|---|---|
| 1. Seed dormancy | 1. Dormancy |
| 2. Seedling | 2. Leafing-out |
| 3. Vegetative growth | 3. Vegetative growth |
| 4. Flowering | 4. Flowering |
| 5. Fruiting | 5. Fruiting |
| 6. Senescence/death | |

In addition, perennial seed germination was simulated, corresponding to the first three phenophases of the annuals listed above.

Dormancy was selected to represent a seed phase in annuals and winter- and/or drought-induced dormancy in perennials. Some evergreen desert shrubs remain metabolically active throughout the year (Chew and Chew, 1965; Oechel et al., 1972); thus the dormant stage actually represented a "quiescent" stage for certain plants in that a relatively fast response to increased levels of soil moisture and favorable soil and air temperatures was possible as reported for *Larrea* and *Ambrosia* (Ackerman and Bamberg, 1972).

The seedling phenophase for annuals was distinguished since the process of establishment must be achieved before vegetative growth was permitted. Leafing-out was an arbitrary term selected to represent the period immediately following the breaking of dormancy in perennials; for evergreens it may simply be an increased level of photosynthetic activity and greening of leaves, whereas for deciduous shrubs it would be the initial production of new leaves from internal reserves before active photosynthetic growth resumes.

The reproductive phase is important for consumer sections in the other portions of the ecosystem model; thus a separation was made into flowering and fruiting states. The eventual senescence and death of annuals were also separated into a distinct phenophase to complete their life cycle, whereas for perennials, a return to dormancy followed the reproductive phase.

# MODEL STRUCTURE

Plant development was viewed as a continuous phenomenon; i.e., the within-population variability in phenological progression rates was taken into account. To achieve this, the percentage of the population of a species in each phenophase at any given time was simulated, a technique used in a grassland phenology model (Sauer, 1973). This was also desirable in that much of the Desert Biome phenology data exists in this form (West and Fareed, 1973).

The phenophases are shown as compartments in Figure 1, where the interconnecting arrows indicate the natural progression of plant development. It was assumed that phenological progression, i.e., the transfer of the percentage of the population between the "compartments," could be predicted by empirical relationships between each phenophase of the certain endogenous and exogenous variables. These relationships took the form of rate coefficients which govern the magnitude of all transfers between compartments, or phenophases. The general form of a flow rate between two phenophases was:

$$F_{ij} = f(X_1, X_2, \ldots, X_n, \mathrm{RATMX})$$

where

$F_{ij}$ = the flow rate from phenophase $i$ to $j$

$X_i$ = the environmental or endogenous parameters involved in this flow

RATMX = the maximum allowable rate of flow under optimum conditions

The flow rates were time-varying and were calculated on the basis of an interacting factor approach common in photosynthesis models (e.g., Brittain, 1974; Cunningham and Balding, 1972; Hari and Luukkanen, 1973; and Schultze et al., 1974). For example, the effect at time $t$ of soil water potential and air temperature on a certain physiological activity (e.g., vegetative growth) would each vary between 0 (no growth) and 1 (optimum growth), depending on the functional relationship involving the current measured values of soil water potential and air temperature and vegetative growth. The resultant overall flow rate ($F_{ij}$) would be the product of the two values and RATMX. A comparison of this technique to the limiting factor approach is given in Cunningham and Balding (1972).

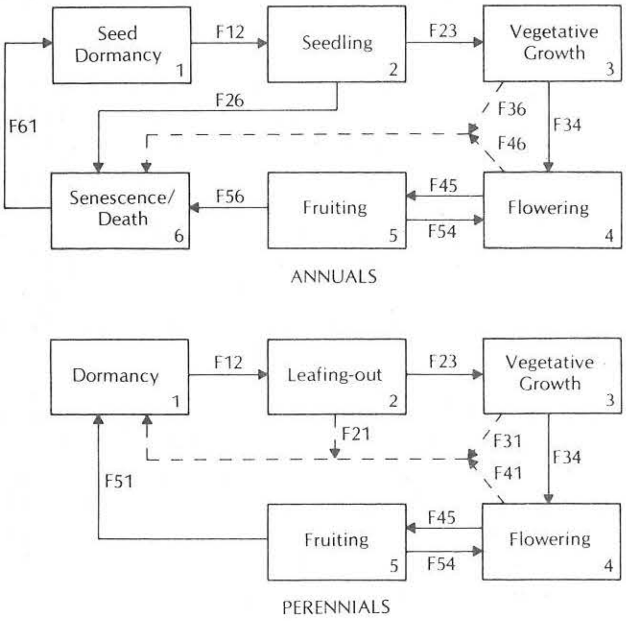

**Figure 1.** Annual and perennial phenophases represented as compartments. Arrows indicate the natural progression of plant development.

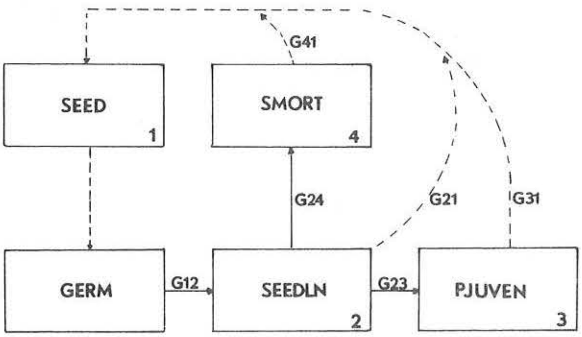

**Figure 2.** Compartmental representation of phenophases in perennial germination.

Computationally, the percentage of biomass in phenophase $i$ ($X_i$) at time $t$ is as follows:

$$X_i(t) = X_i(t\text{-}1) + \Sigma\, F_{ji}(t\text{-}1)\, X_j(t\text{-}1) - \Sigma\, F_{ij}(t\text{-}1)\, X_i(t\text{-}1)$$

where $F_{ij}(t\text{-}1)$ represents the flow rate coefficient from phenophase $i$ to $j$ at time $t$-1. This representation was simply a donor-controlled system of first-order difference equations. With this approach, the changing distribution of the percentage of the population between compartments represented phenological progression or plant development (Sauer, 1973).

## FLOW RATES

In this section each flow rate will be described with respect to specific phenological states. All flows are written as $F_{ij}$ (Fig. 1) or, in the case of perennial germination, $G_{ij}$ (Fig. 2). For convenience, associated FORTRAN names are given throughout for easy reference to the computer listing in Appendix 1 (e.g., the FORTRAN equivalent for the percentage of the population of the $i$th species in the $j$th phenophase is PHASE(I,J)).

### GERMINATION AND ESTABLISHMENT

*Annuals*

Germination ($F_{12}$) was simulated by predicting the percentage of total carbon in all shed seeds, PHASE(I,1), that became above-ground biomass. This percentage, GERM, was given by PREDGM x PHASE(I,1), where PREDGM was determined from a functional relationship which related soil water potential to germination response (Fig. 3a). Under optimum soil moisture conditions, a large percentage of the total seed reserve in the soil will germinate; under poor conditions, an increasingly smaller percentage germinates. Before germination can occur, however, soil temperature (SOILTE) must be above a certain threshold value (SOILTH) and coldhardening requirements, if any, must be satisfied. Germination can occur more than once during the growing season, which is directly dependent on influxes of soil moisture from rainfall.

For the coldhardening requirement to be satisfied, soil temperature must be less than a certain threshold (COLDT) for a predetermined number of days (COLDTH). In the model, a counter (ICOLDS) is used to register the number of days this threshold has been met within the preceding $n$th days. Elaboration of this is possible, e.g., combinations of high and low soil temperatures, which appear to be important for some desert annuals in New Mexico (Whitson, pers. comm.).

The general form for germination is:

$F_{12}$ = f(PREDGM, ICHARD, IGTEMP, RATMX) where

$$\text{PREDGM} = \alpha + \beta \exp(\xi \cdot \text{soil water potential})$$

$$\text{ICHARD} = \begin{cases} 0 \text{ if ICOLDS} < \text{COLDTH} \\ 1 \text{ if ICOLDS} \geqslant \text{COLDTH} \end{cases}$$

$$\text{IGTEMP} = \begin{cases} 0 \text{ if SOILTE} < \text{SOILTH}, \\ 1 \text{ if SOILTE} \geqslant \text{SOILTH} \end{cases}$$

RATMX = the maximum rate of germination (percent $\text{day}^{-1}$)

Immediately following germination, establishment ($F_{23}$) is considered. It is assumed that soil moisture is the most significant variable affecting establishment success. The functional relationship used is shown in Figure 3b, relating soil moisture (SM23E) to the interphenophase flux. Note that a change in soil moisture near the drier portion of the range of soil water potential values is more significant in terms of the flow rate coefficient (SM23E) than when occurring near the wet end. Under moist conditions a large portion of the percentage ends in the vegetative growth stage ($F_{23}$; Fig. 1), whereas under dry conditions, mortality is high ($F_{26}$; Fig. 1). The flows are:

$$F_{23} = f(\text{SM23E, RATMX}) \text{ and}$$
$$F_{26} = f(\text{SM26E, RATMX})$$

where

$$\text{SM23E} = \alpha\,(1. - \exp(-\beta \cdot (\xi - \text{soil water potential})))$$

$$\text{SM26E} = 1. - \text{SM23E}$$

RATMX = the maximum rate of interphenophase transfer (percent $\text{day}^{-1}$)

*Perennials*

For perennials, the simulation of germination ($G_{12}$; Fig. 2) is essentially the same as discussed above for annuals. For each species a seed reserve exists (SEED), of which a certain percentage (GERM) will germinate in response to suitable conditions. Soil moisture determines the percent survival (SEEDLN to PJUVEN) or death (SEEDLN to SMORT), once germination has occurred. Once the growing season has passed, the total percentage that is distributed among the compartments is shunted back to SEED to represent the total seed reserve for the next season (the absolute value of which is determined by other submodels). In general, perennial germination and establishment are as follows:

$$G_{12} = f(\text{PREDGM, ICHARD, IGTEMP, GERMRX})$$

$$G_{23} = f(\text{SM23E, GERMRX})$$

$$G_{24} = f(\text{SM24E, GERMRX})$$

where

PREDGM, ICHARD, IGTEMP, SM23E are as defined for annuals

SM24E = SM26E, where SM26E is as defined for annuals

GERMRX is the maximum rate of each interphenophase flux (percent $\text{day}^{-1}$)

### BREAKING DORMANCY

Perennials break winter dormancy ($F_{12}$; Fig. 1) as a response to various environmental variables. The thermal environment is assumed to be important in this respect (Jackson, 1966; Taylor, 1969). The concept of degree-days is used, as in Waggoner (1974), to predict the appearance of the leafing-out phenophase:

$$\text{Heatsum} = \int_{t_o}^{t} (T - T_h)\,dt$$

where

$T$ = current air temperature
$T_h$ = the threshold air temperature
$t$ = current time
$t_o$ = arbitrarily taken as t-60

When the heatsum (SMHEAT) has reached a specified critical level (THHEAT), leafing-out will occur. Other parameters can modify the response of the plant, e.g., soil moisture (SM12; Fig. 3c) and photoperiod (IPHOT1). The general form for leafing-out is:

$$F_{12} = f(\text{IDTEMP, SM12, IPHOT1, RATMX})$$

where

$$\text{IDTEMP} = \begin{cases} 0 \text{ if SMHEAT} < \text{THHEAT} \\ 1 \text{ if SMHEAT} \geqslant \text{THHEAT} \end{cases}$$

$$\text{SM12} = \alpha + \beta \exp(\zeta \cdot \text{soil water potential})$$

$$\text{IPHOT1} = \begin{cases} 0 \text{ if daylength} < \text{specific photoperiod (PHOTOR)} \\ 1 \text{ if daylength} \geqslant \text{specific photoperiod (PHOTOR)} \end{cases}$$

RATMX = the maximum rate of leafing-out (percent $\text{day}^{-1}$)

## Vegetative Growth and Flowering

Once perennial dormancy has been broken, transfer from the leafing-out phenophase to vegetative growth ($F_{23}$; Fig. 1) is related to the increase in physiological activities of the plant. It is assumed that this is reflected in the respiration:photosynthesis ratio (CR23) in that, before the breaking of dormancy, respiratory losses and photosynthetic gains probably balance each other ($R=P$) in evergreen shrubs, whereas in other perennials, respiratory losses are probably higher ($R > P$). The functional relationship between R:P and CR23 is shown in Figure 4 where, as the ratio decreases, the transfer to vegetative growth increases. In addition, soil water potential is employed as a rate-determining factor (SM23; Fig. 3c). The flux to vegetative growth is given as:

$$F_{23} = f(\mathrm{CR23}, \mathrm{SM23}, \mathrm{RATMX})$$

where

$$\mathrm{CR23} = a + \beta \exp(\xi \cdot \mathrm{R{:}P}))$$

$$\mathrm{SM23} = a + \beta \exp(\xi \cdot \text{soil water potential})$$

RATMX = the maximum rate of transfer (percent $\mathrm{day}^{-1}$)

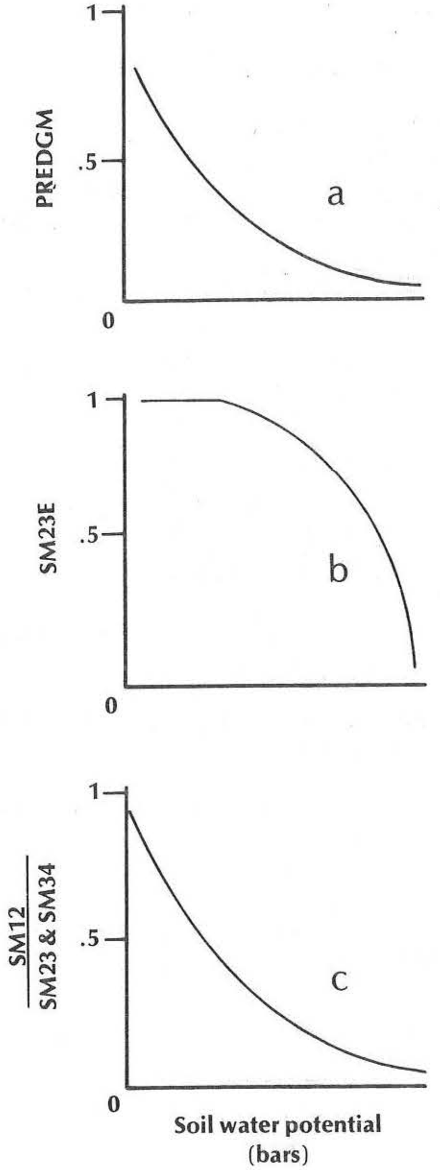

**Figure** 3. Functional relationship of soil water potential to: (a) percent seed reserve germination; (b) effect of soil moisture on establishment success; and (c) effect of soil moisture on interphenophase flows (1,2), (2,3) and (3,4).

## Flowering and Fruiting

The criteria used in determining the flowering phenophase ($F_{34}$; Fig. 1) are photoperiod (IPHOT2), soil moisture (SM34; Fig. 3c) and flower development (CR34; Fig. 5), in the form of the ratio of reserve carbon in all organs (CVEGO(I,IR)) to the total carbon in the plant (AVEGO(I)). The carbon ratio was chosen on the basis of the results of earlier executions of the photosynthesis and translocation submodels, where this ratio was highly correlated to flowering. The flow rate is given by:

$$F_{34} = f(\mathrm{IPHOT2}, \mathrm{SM34}, \mathrm{CR34}, \mathrm{RATMX})$$

where

$$\mathrm{IPHOT2} = \begin{cases} 0 \text{ if daylength} < \text{specific threshold (PHOTOF)} \\ 1 \text{ if daylength} \geqslant \text{specific threshold (PHOTOF)} \end{cases}$$

$$\mathrm{CR34} = a\,(1. - \exp(\beta \cdot \text{carbon ratio})$$

$$\mathrm{SM34} = a + \beta \exp(\xi \cdot \text{soil water potential})$$

RATMX = the maximum rate of flux (percent $\mathrm{day}^{-1}$)

Soil moisture (SM45) is probably the determining factor as far as the allocation of carbon to flowers and/or fruits. Under moist conditions, continuous flowering and fruiting are common for many desert plants (as reported for grassland plants; Sauer, 1973), although the total energy allocated to reproduction may be less than that under drier moisture regimes, at least for some plants (Cunningham et al., 1974). Consequently, as shown in the relationship between soil moisture and flowering-fruiting (Figs. 6-7), as the soil dries there is a rapid transfer to fruiting; under moist conditions flowering will continue, with a certain percentage transferred to fruiting at all times. Plant water potential might be a better parameter in some plants, e.g., cacti. The rates are given by:

$$F_{45} = f(\mathrm{SM45}, \mathrm{RATMX})$$

$$F_{54} = f(\mathrm{SM54}, \mathrm{RATMX})$$

where

$$\mathrm{SM45} = a\,(1. - \exp\,(\,\beta \cdot \text{soil water potential})$$

$$\mathrm{SM54} = 1. - \mathrm{SM45}$$

RATMX = the maximum rate of flowering and fruiting (percent day$^{-1}$)

### SENESCENCE AND DORMANCY

*Annuals*

Senescence ($F_{56}$; Fig. 1) is generally keyed to an internal depletion of carbon when physiological activity is reduced. Therefore, a carbon ratio (CR56 -- fruit carbon:total plant carbon; Fig. 8) was used to simulate senescence. Freezing air temperatures will result in a rapid transfer from all compartments to senescence ($F_{i6}$; Fig. 1). Once this occurs the percentage is distributed back to seed dormancy as a mechanical process to be used to simulate the start of the life cycle for the next occurrence. The general forms of the rates are:

$$F_{56} = f(\mathrm{CR56}, \mathrm{RATMX})$$

$$F_{61} = f(\mathrm{RATMX})$$

where

$$\mathrm{CR56} = a + \beta \exp\,(\text{carbon ratio})$$

RATMX = the maximum rate of flux (percent day$^{-1}$)

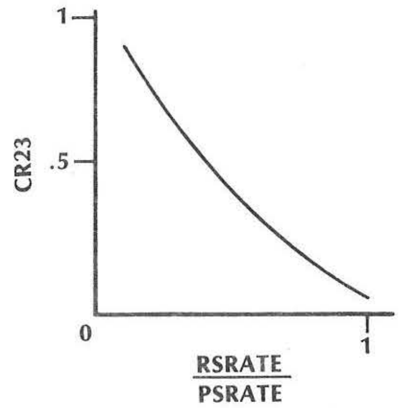

**Figure 4.** Effect of respiration: photosynthesis ratio on interphenophase flow (2,3).

*Perennials*

For perennials, as the ratio of reserve carbon in the leaf to total plant carbon decreases, the plant rapidly becomes dormant ($F_{51}$; Fig. 1). The form of this relationship is shown in Figure 7. If freezing air temperatures (a species-specific value -- FREEZE) occur, rapid transfer of all percentage of the population is made to the dormant state (Fig. 1). In general:

$$F_{51} = f(\mathrm{CR51}, \mathrm{RATMX})$$

$$F_{i1} = f(\mathrm{FREEZE}, \mathrm{RATMX})$$

where

$$\mathrm{CR51} = a + \beta \exp\,(\text{carbon ratio})$$

RATMX = the maximum rate of flux (percent day$^{-1}$)

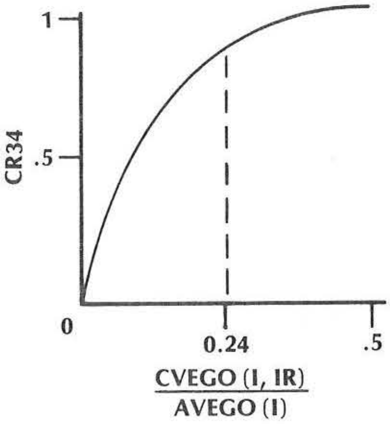

**Figure 5.** Effect of the ratio of reserve carbon in all organs to the total carbon in the plant on interphenophase flow (3,4).

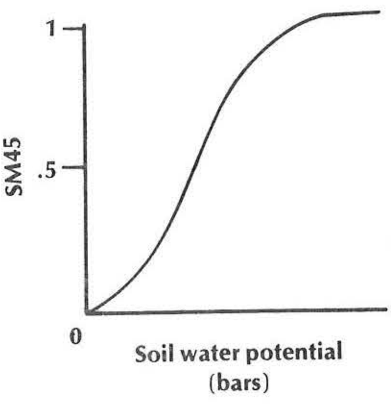

**Figure 6.** Effect of soil water potential on flowering and fruiting -- interphenophase flows (4,5) and (5,4).

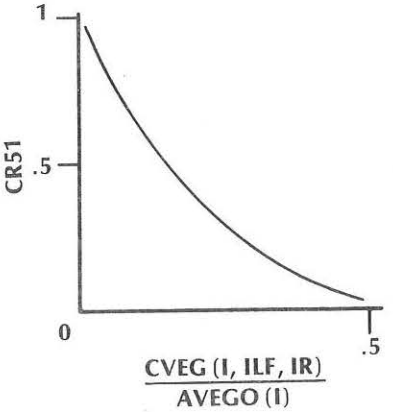

**Figure 7.** Effect of ratio of reserve carbon in the leaf to total plant carbon in interphenophase flow (5,1).

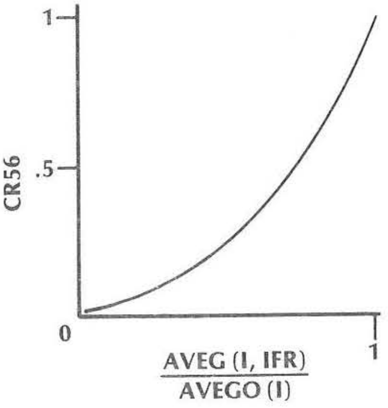

**Figure 8.** Effect of fruit carbon:total plant carbon on interphenophase flow (5,6).

# MODEL BEHAVIOR

To illustrate the output of this submodel, the general phenological responses of *Hilaria mutica* will be discussed and compared to the simulated model output. *Hilaria* is a large perennial bunchgrass occurring on the west and east edges of the playa bottom at the Jornada Validation Site. It generally begins growth in the early spring as soil and air temperatures increase -- the rate of growth being limited by soil moisture. A rapid flush of growth often occurs in late summer in response to increased soil moisture and higher air temperatures near the optimum for photosynthesis (Cunningham et al., 1974). *Hilaria* has a small amount of green material at the base of the large clumps throughout the winter months, but this is probably insignificant in terms of photosynthetic gains and is not considered in the submodel (i.e., the plant is considered to be completely dormant during certain periods).

In Figure 9 the four-year model simulation of *Hilaria* phenology is shown. The percentage of the population biomass in either a vegetative (VEG) or a dormant stage (DOR) was plotted, where values of VEG less than 100%, when DOR was 0%, represented the percentage of the population biomass which was in the reproductive phenophases of flowering and/or fruiting. The rainfall events which occurred during the years 1971-72 and 1972-73 (March 20 to March 20; Fig. 9) provide excellent contrasts for examining the simulated phenological responses of this species. For reference, specific events referred to in Figure 9 are labeled e1, e2, etc. In the simulation, *Hilaria* broke winter dormancy both years at approximately the same time (March 7-14, e1 and e6) in an apparent response to warmer temperatures. However, the subsequent phenological events were quite different during these two years.

In 1971-72, breaking of dormancy occurred slowly over a period of about 11 weeks (e1 to e2). The first reproductive growth occurred in late July, 18 weeks after breaking dormancy as indicated by the drop in the percentage of the population which was solely in a vegetative state (e3). This corresponded to the first significant rainfall during that summer. Reproductive growth occurred in various magnitudes in response to rainfall up to late November (e4). At this time, the plant species went completely dormant in response to freezing soil and air temperatures (e5).

In 1972-73, the first reproductive pulse (e7) was seven weeks after the breaking of dormancy (e6), which was followed by three large pulses (e8-e10). This was apparently in response to optimal soil moisture conditions since precipitation occurred throughout the summer starting in mid-June (week 116) and continued into late fall. This unusually wet summer resulted in the simulation of reproductive growth throughout the entire summer as evidenced by the absence of a 100% vegetative population.

Although field data for *Hilaria* phenology do not exist to validate this four-year simulation on a week-to-week basis, field observations and standing crop estimates from 1970 to 1972 (Fig. 10) provide a basis for evaluation. The submodel adequately simulated the periods of *Hilaria* dormancy. This can be seen by comparing the weeks of absolute dormancy simulated in Figure 9 to the absence of live green material in Figure 10. The simulation of reproductive phenology is not as easily evaluated, but the submodel did produce the general observed trends. For example, the greatest reproductive biomass was produced during the wettest summer (Fig. 10; 1972) while the submodel predicted substantial reproductive phenology for this summer (1972-73 simulation year) as discussed earlier.

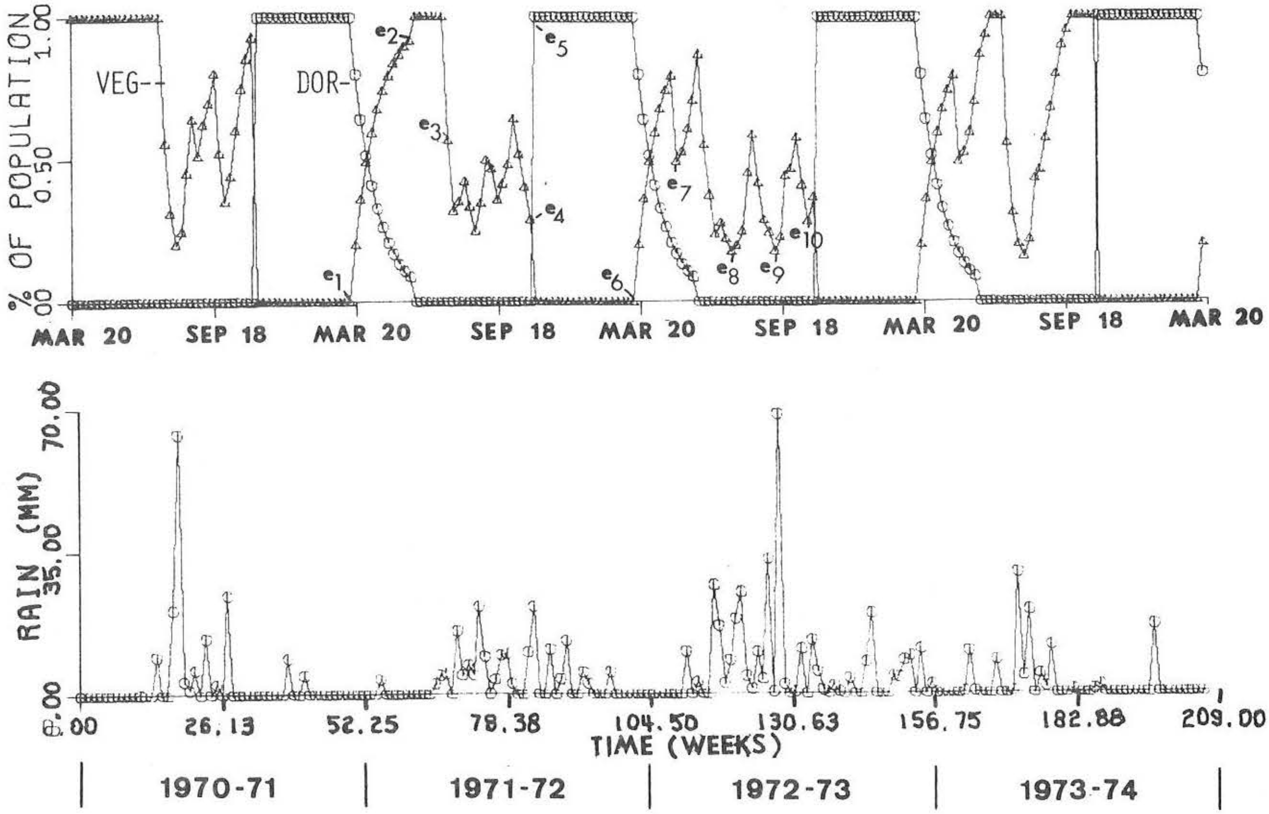

Figure 9. Four-year simulation of phenology for *Hilaria*. See text for explanation.

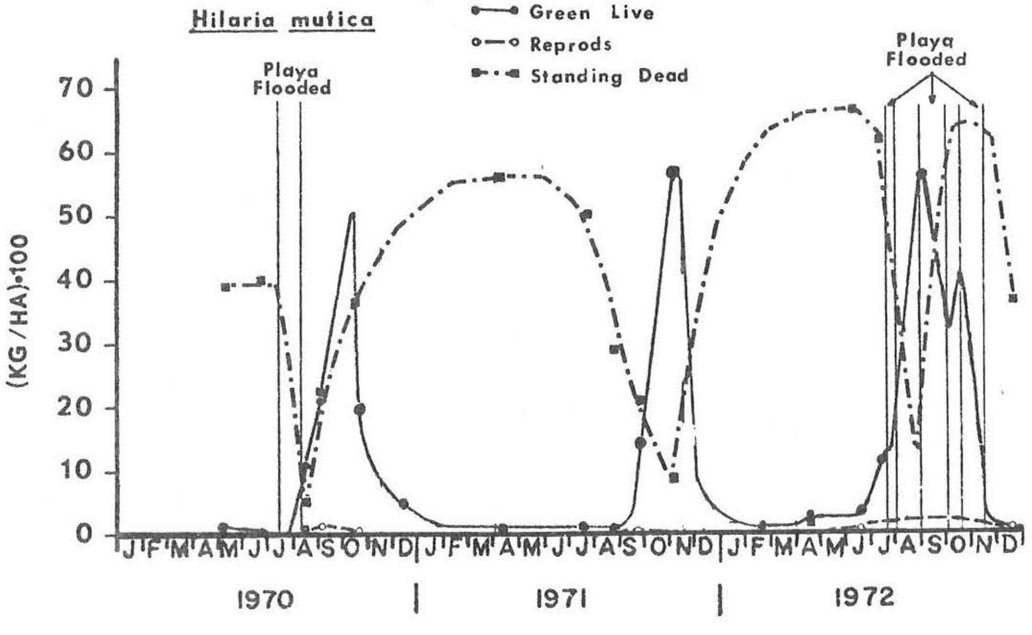

Figure 10. Biomass dynamics for *Hilaria* at the Jornada site from 1970 through 1972.

Illustrated in Figure 11 are the outputs from a 190-day model simulation for two hypothetical plant species, an annual and a perennial. The results of this simulation show the phenological progression of these plants as determined by the specific input coefficients for each plant. As illustrated by this output, a wide range of phenological situations can be simulated by the submodel.

Although actual data may not be available for some species, the user may experiment with different coefficients which govern the rates of phenological progression: these may then be compared to field observations to obtain realistic simulations.

The phenology submodel presented here was developed to accomodate any set of phenological data available; any environmental or endogenous variable can be used to determine a flow rate. New functional relationships can be easily introduced in the submodel to supplement or replace current ones with a minimal amount of effort.

Restrictions within the present format include the annual-perennial distinction, the defined phenophases and the direction of flows (e.g., *Fouquieria*) wherein flowering cannot occur directly from a dormant state. However, these restrictions can be further diminished with a moderate amount of restructuring of the program.

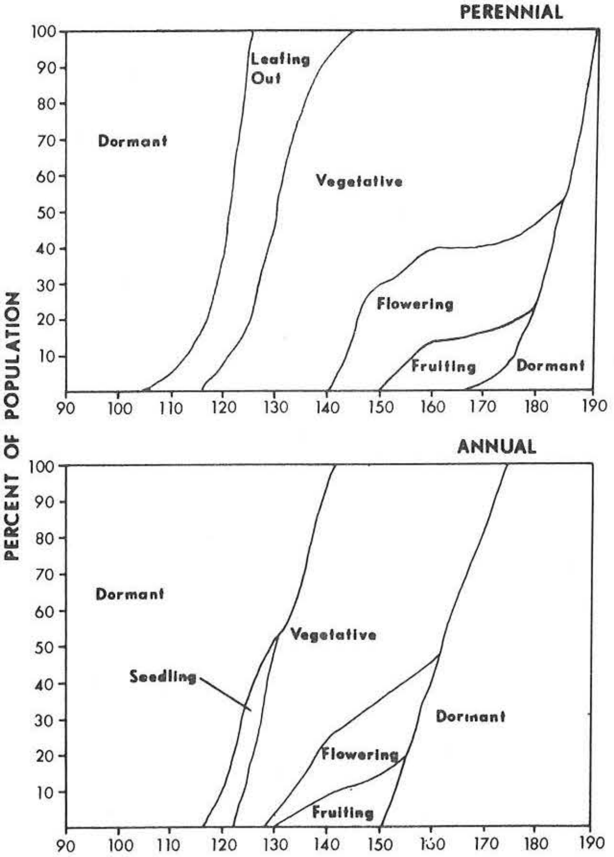

**Figure 11.** Ninety-day simulation for a hypothetical perennial and a hypothetical annual to illustrate model flexibility.

In conclusion, it appears this approach can be used to obtain satisfactory simulations of phenological changes in plants. The use of such coefficients as "RATMX" gives the submodel the flexibility necessary to simulate such situations as a rapid response to an environmental change. Further development must come in the area of incorporating detailed field data into the submodel. A submodel such as this can be a useful tool to synthesize various concepts of phenology into an organized format for use in a large systems model.

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# APPENDIX 1

## PROGRAM LISTING

### *Subroutine* PHENOL

```
      SUBROUTINE PHENOL
C
C  AM1,AM2   PARAMETERS USED IN THE MITCHERLICH EQUATION
C  BM1,ETC
C  AE1,AE2   PARAMETERS USED IN THE EXPOTENTAL FUNCTION
C  BE1,ETC
C  AIRTTH    THRESHOLD AIR TEMPERATURE USED TO DETERMINE DEGREE DAYS
C  COLDT     MINIMUM SOIL TEMP NEC FOR COLD HARDENING REQUIREMENT
C  COLDTH    NO. DAYS NEC. THAT SOIL TEMP BE LESS THAT COLDT TO MEET COLD
C            HARDENING REQUIREMENT
C  FREEZE    VALUE OF MIN AIR TEMP THAT TRIGGERS DORMANCY/DEATH
C  GERMRX    MAX RATE OF PERENNIAL GERMINATION PHENOLOGICAL PROGRESSION
C  GERM      PERCENT OF SHED SEED RESERVE THAT WILL GERMINATE
C  ICOLDS    COUNTER FOR NO. DAYS SOIL TEMP BELOW COLDT
C  ICLDMA    VECTOR CONTAINING PREVIOUS 90-DAY RECORD OF RESULTS OF
C  ICHARD    0-WHEN COLDHARD. REQ. NOT MET, 1 WHEN MET
C            TESTS TO MEET COLDHARDENING REQ (0-NO, 1-YES)
C  IGTEMP    0 IF SOIL TEMP NOT ADEQ FOR GERMINATION, 1 IF ADEQUATE
C  IPHENO    1=DORMANCY  2=SEEDLING OR LEAFING OUT  3=VEGETATIVE GROWTH
C            4=FLOWERING 5=FRUITING  6=SENSCENCE/DEATH
C  IPHOT1    0 IF DAYLENGTH NOT ADEQ FOR BREAKING DORMANCY OF PERENNIALS
C  IPHOT2    0 IF DAYLENGTH NOT ADEQ FOR FLOWERING IN ALL PLANTS
C  PJUVEN    PERENNIAL SURVIVING PAST THE SEEDLING STAGE AFTER GERM
C  PHASE     PHENOPHASES (COMPARTMENTS) CONTAINING PERCENT OF BIOMASS
C            IN THAT PARTICULAR PHENOLOGICAL STATE
C  PHOTOF    DAYLENGTH NEC FOR FLOWERING
C  PHOTDR    DAYLENGTH NEC FOR BREAKING DORMANCY
C  PREDGM    VARIABLE (0 TO 1) DETERMING AMOUNT OF SEED RESERVE GERM-
C            INATING AS A FUNCTION OF SOIL WATER POTENTIAL
C  RATMX     MAX RATE OF PHENOLOGICAL PROGRESSION FROM PHENOPHASE
C            I TO J
C  SEED      REPRESENTS TOTAL SEED CARBON IN SOIL FOR PERENNIALS - IS
C            EQUILIVANT TO PHASE 1 OF ANNUALS
C  SEEDLN    PERENNIAL SEEDLINGS - EQUIL. TO PHASE 2 OF ANNUALS
C  SMORT     PERENNIAL SEEDLINGS THAT FAIL TO BECOME ESTABLISHED -
C            A PERCENT (EQUIV. TO PHASE 6 IN ANNUALS WHEN FLOW FROM PHASE
C            2, I.E., ANNUALS FAILING TO ESTABLISH
C  SOILTH    SOIL TEMP NEC FOR GERMINATION
C  SMHEAT    COUNTER FOR ACCUMULATION OF DEGREE DAYS
C  THHEAT    THRESHOLD DEGREE DAYS NEC. FOR BREAKING PERENNIAL DORMANCY
C
C-----------------------------------------------------------------------
      DIMENSION RCHECK(20)
      DIMENSION PHASE%15,6<,GERM%15<,SEED%15<,SEEDLN%15<,SMORT%15<,
     -          PJUVEN%15<
      COMMON /INCOMV/ I,II,IPHENO%15<,IPHENN%15<,PSRATE%15<,RSRATE%15<,
     - TROOT,ORGTEM%10<,ORGSWP%10<,WST,WSWP,TIME%15<
      COMMON /IPARAM/ IN,IA,IP,IR,IS,ILF,IST,IFR,IRT,LIFORM%10<,IANUAL,
     - IPHERB,ISHRB,LSOIL,NCOV,ICOV%5<,LTD%15,10<,IDUMP%16<,KDUMP,
     - ISTL
      COMMON /PARAM/
     .           SMHEAT(15),THHEAT(15),RATMX(15,6),SOILTH(15),ICOLDS(15)
     -,          COLDT(15),COLDTH(15),ICLDMA(90,15),PHOTOF(15),PHOTDR(15
     -),          AIRTTH(15),HEATMA(60,15),GERMRX(15,3),Y6(9930),FREEZE(1
     -5),          AM1(15),AM2(15),AE1(15),AE2(15),AE3(15
     -,          BM1(15),BM2(15),BE1(15),BE2(15),BE3(15),BE4(15),BE5(15)
     -,          CE1%15<,CE2%15<,CE3%15<,CE4%15<,CE5%15<
      COMMON /SPEC/ Q1%21<,NSPECV,Q2,NORGAN,NFRACT,Q3%2<,NOLIT,NCHECK,
     -   IDAY,IYRDAY,Z35%20<,NDEBUG,Z36%121<,NVECOH,Y7%52<
      COMMON/OTHER/ATOT,ATOTO,SNODEP,SOILTE%5<,PRECMM, WATER%5<
      COMMON/METFOR/EVAP,TDAY,TNIGHT,DAYWVP,DWINAV,DWINMX,DAPHOT,
     -DAYRAD,DUST,DUSCOM%6<,RAINCC%6<,ERODE,DAYRUN,DRUNMI%16<,DRUNOR%6<,
     - DRUNL%5,6<,DASNOW,DARAIN
      COMMON /TOTALS/ Z3%60<,CVEGO%15,6<,Z4%16<,AVEGO%15<,Z5%56<,
       AVEG%15,10<,Z6%952<,ASEEDH%10<,Y8%110<
      COMMON /STAT/ CVEG%15,10,6<,Y10%1040<
C
      FUNEXP(AE,BE,CE,XE)=AE+BE*EXP(CE*XE)
      FUNMIT(AM,BM,XM)=AM*(1.0-EXP(BM*XM))
C-----------------------------------------------------------------------
      IF(IDAY.EQ.IDUMP(KDUMP))WRITE(6,7654)
      IF(NDEBUG.NE.0)WRITE(6,7654)
 7654 FORMAT(' EXECUTING SUBROUTINE PHENOL')
C
      IFORM  = LIFORM(I)
C
      IRAIN1=IRAIN2
      IRAIN2=IRAIN3
      IRAIN3=0
      KEY=DARAIN
      IF(KEY.EQ.0) GOTO 804
      IRAIN3=1
C
C-----------------------------------------------------------------------
C     SECTION FOR CALCULATING HEATSUM AND COLDHARDENING REQUIREMENTS
C-----------------------------------------------------------------------
C.....HEAT SUM (SMHEAT) CALCULATION FOR PERENNIALS (60 DAY SUM)
  804 DO 800 INUM=1,59
 800  HEATMA(INUM,I) = HEATMA(INUM+1,I)
      HEATMA(60,I) = TDAY-AIRTTH(I)
      SMHEAT(I) = 0.
      DO 801 INUM=1,60
 801  SMHEAT(I) = SMHEAT(I) + HEATMA(INUM,I)
C
C.....COLDHARDENING CALCULATION BASED ON PREVIOUS 90-DAY EVENTS
C       THAT IS, COLD HARD. REQ. HAS TO BE MET IN LAST 90-DAY PERIOD
      DO 802 INUM=1,89
 802  ICLDMA(INUM,I) = ICLDMA(INUM+1,I)
      ICLDMA(90,I) = 0
      IF (SOILTE(LSOIL).LE.COLDT(I)) ICLDMA(90,I) = 1
      ICOLDS(I) = 0
      DO 803 INUM=1,90
 803  ICOLDS(I) = ICOLDS(I) + ICLDMA(INUM,I)
C
C-- --------------------------------------------------------------------
C     SECTION FOR ANNUAL AND PERENNIAL SEED GERMINATION
C-----------------------------------------------------------------------
C
      IGTEMP=0
      ICHARD=0
C
C.....GERMINATION OF ANNUALS AND PERENNIALS
C     CALCULATE INITIAL PERCENT OF SEED CARBON THAT WILL GERMINATE
C     FOR PURPOSES OF INITIALIZING GERM(I) .   THIS CAN OCCUR
C     ANY TIME CONDITIONS ARE SUITABLE FOR GERMINATION
C
      IF(SOILTE(LSOIL).GE.SOILTH(I)) IGTEMP=1
      IF(ICOLDS(I).GE.COLDTH(I)) ICHARD=1
C
      GOTO (66,67,67),IFORM
   66 KEY=PHASE(I,1)
      IF(KEY.EQ.100) GOTO 65
      GOTO 69
   67 KEY=SEED(I)
      IF(KEY.EQ.100) GOTO 65
      GOTO 69
C
   65 IF(IGTEMP.EQ.0.OR.ICHARD.EQ.0) GOTO 73
   69 PREDGM=FUNEXP(AE1(I),BE1(I),CE1(I),WATER(LSOIL))
C
      GOTO (30,31,31),IFORM
   30 KEY=PHASE(I,1)
      GOTO 32
   31 KEY=SEED(I)
   32 IF(KEY.EQ.100) GOTO 72
C
      IF(IRAIN1.EQ.1.OR.IRAIN2.EQ.1) GOTO 72
      GOTO  73
C
   72 GOTO (70,71,71),IFORM
C
   70 GERM(I)=PREDGM*PHASE(I,1)+GERM(I)
      GOTO 73
   71 GERM(I)=PREDGM*SEED(I)+GERM(I)
C
C.....ESTABLISHMENT AS A FUNCTION OF SOIL WATER POTENTIAL
   73 SM23E=FUNEXP(AE2(I),BE2(I),CE2(I),WATER(LSOIL))
      SM26E=1.-SM23E
      SM24E=SM26E
C
C-----------------------------------------------------------------------
C     CHECK FOR FREEZING AIR TEMPERATURES :IF POSITIVE TEST EMPTY
C       CONTENTS OF ALL COMPARTMENTS TO DORMANT (PERENNIALS) OR
C       SENSCENSE (ANNUALS)
C-----------------------------------------------------------------------
   75  IF(TDAY.GT.FREEZE(I)) GOTO 76
       KEY=PHASE(I,1)
       IF(KEY.EQ.100) GOTO 99
C
      F12=0.0
      F23=0.0
      F34=0.0
      F45=0.0
      F54=0.0
C
      GOTO (50,51,51),IFORM
C
C.....PERENNIALS
   51 F21=PHASE(I,2)
      F31=PHASE(I,3)
      F41=PHASE(I,4)
      F51=PHASE(I,5)
      G12=0.
      G23=0.
      G24=0.
      G21=SEEDLN(I)
      G31=PJUVEN(I)
      G41=SMORT(I)
      GERM(I)=0.
      GOTO 79
C
C.....ANNUALS
   50 F26=PHASE(I,2)
      F36=PHASE(I,3)
      F46=PHASE(I,4)
      F56=PHASE(I,5)
      F61=PHASE(I,6)*RATMX(I,6)
      GERM(I) = 0.
      IF(PHASE(I,6).LT.1.0) F61=PHASE(I,6)
      GOTO 79
C
C-----------------------------------------------------------------------
C     CALCULATE RATE   COEFFICIENTS
C-----------------------------------------------------------------------
C
   76 IDTEMP=0
      IPHOT1=0
      IPHOT2=0
C
C.....COEFF FOR BREAKING DORMANCY IN PERENNIALS
      IF(LIFORM(I).EQ.IANUAL) GOTO 755
      IF(SMHEAT(I).GE.THHEAT(I)) IDTEMP=1
      IF(DAPHOT.GE.PHOTDR(I))  IPHOT1=1
      SM12=FUNEXP(AE2(I),BE2(I),CE2(I),WATER(LSOIL))
C
C.....COEFF FOR LEAFING-OUT TO VEGETATIVE GROWTH
      SM23=FUNEXP(AE2(I),BE2(I),CE2(I),WATER(LSOIL))
      IF(PSRATE(I).LE.0.0) PSRATE(I)=0.0001
      CR23=FUNEXP(AE3(I),BE3(I),CE3(I),RSRATE(I)/PSRATE(I))
C
C.....COEFF FOR VEGETATIVE TO FLOWERING
  755 IF(DAPHOT.GE.PHOTOF(I)) IPHOT2=1
      SM34=FUNEXP(AE2(I),BE2(I),CE2(I),WATER(LSOIL))
      IF(AVEGO(I).LE.0.000) AVEGO(I)=0.0001
      CR34=FUNMIT(AM1(I),BM1(I),CVEGO(I,IR)/AVEGO(I))
C
C... .COEFF FOR FLOWER TO FRUIT
      SM45=FUNMIT(AM2(I),BM2(I),WATER(LSOIL))
C
C.....COEFF FOR FRUIT TO FLOWER
      SM54=1.-SM45
C
C.....SENSCENCE   ANNUALS:F56  PERENNIALS:F51
      CR56=FUNEXP(AE4(I),BE4(I),CE4(I),AVEG(I,IFR)/AVEGO(I))
```

```
      CR51=FUNLXP(AE5(I),BE5(I),CE5(I),CVEG(I,ILF,IR)/AVEGO(I))
C
C-----------------------------------------------------------------------
C     COMPUTATION OF FLOWS
C-----------------------------------------------------------------------
C
      GOTO (81,82,82),IFORM
C
C.....ANNUAL
   81 F12=GERM(I)*RATMX(I,1)
      F23=PHASE(I,2)*SM23E*RATMX(I,2)
      F26=PHASE(I,2)*SM26E*RATMX(I,6)
      F56=PHASE(I,5)*CR56*RATMX(I,5)
      F61=PHASE(I,6)*RATMX(I,6)
      GOTO 83
C
C.....PERENNIAL GERMINATION
   82 G12=GERM(I)*GERMRX(I,1)
      G23=SEEDLN(I)*SM23E*GERMRX(I,2)
      G24=SEEDLN(I)*SM24E*GERMRX(I,3)
C.....PERENNIAL
      F12=PHASE(I,1)*IDTEMP*IPHOT1*SM12*RATMX(I,1)
      F23=PHASE(I,2)*CR23*SM23*RATMX(I,2)
      F51=PHASE(I,5)*CR51*RATMX(I,5)
C.....ALL PLANTS
   83 F34=PHASE(I,3)*IPHOT2*CR34*SM34*RATMX(I,3)
      F45=PHASE(I,4)*SM45*RATMX(I,4)
      F54=PHASE(I,5)*SM54*RATMX(I,4)
      F21=0.0
      F31=0.0
      F41=0.0
      F51=0.0
      F61=0.0
      F36=0.0
      F46=0.0
C-----------------------------------------------------------------------
C     UPDATE ALL COMPARTMENTS
C-----------------------------------------------------------------------
C
   79 CONTINUE
C
      GOTO (87,88,88),IFORM
C
   87 PHASE(I,1)=PHASE(I,1)+F61-F12
      GERM(I)=GERM(I)-F12
      PHASE(I,2)=PHASE(I,2)+F12-F26-F23
      PHASE(I,3)=PHASE(I,3)+F23-F34-F36
      PHASE(I,4)=PHASE(I,4)+F34+F54-F45-F46
      PHASE(I,5)=PHASE(I,5)+F45-F54-F56
      PHASE(I,6)=PHASE(I,6)+F26+F36+F46+F56-F61
      GOTO 99
   88 SEED(I)=SEED(I)+G21+G31+G41-G12
      GERM(I)=GERM(I)-G12
      SEEDLN(I)=SEEDLN(I)+G12-G24-G23-G21
      PJUVEN(I)=PJUVEN(I)+G23-G31
      SMORT(I)=SMORT(I)+G24-G41
C
      PHASE(I,1)=PHASE(I,1)+F21+F31+F41+F51-F12
      PHASE(I,2)=PHASE(I,2)+F12-F23-F21
      PHASE(I,3)=PHASE(I,3)+F23-F34-F31
      PHASE(I,4)=PHASE(I,4)+F34+F54-F45-F41
      PHASE(I,5)=PHASE(I,5)+F45-F54-F51
C
C***************************** TEMPORARY SECTION ************************
```

```
C
   99 CONTINUE
C
      SUM=0.
C
      GOTO (97,98,98), IFORM
C
   97 DUMMY= 100.1-PHASE(I,1)
      DO 90 J=2,6
   90 SUM=SUM + J * (PHASE(I,J)/DUMMY)
      IF(SUM.LT.0.05) SUM=1.
      GOTO 93
C
C.....PERENNIALS
   98 DO 91 J=1,5
   91 SUM=SUM + J*PHASE(I,J)
C
   93 IPHENO(I) = SUM
      PHENXX   = SUM
C
C
C
  100 CONTINUE
C
C***********************************************************************
      IF(IDAY.EQ.IDUMP(KDUMP))WRITE(6,2000)I,IPHENO(I)
      IF(NDEBUG.NE.0)WRITE(6,2000)I,IPHENO(I)
 2000 FORMAT('  I=',I2,5X,'IPHENO(I) =',I2)
      WRITE(6,2006) IYRDAY,
     -                PHASE(I,1),PHASE(I,2),PHASE(I,3),PHASE(I,4),
     -                PHASE(I,5),PHASE(I,6),
     -GERM(I),PREDGM,IGTEMP,ICHARD,IDTEMP,IPHOT1,IPHOT2,IPHENO(I),
     -                PHENXX,SM23E,                  SM34,SM45,SM54,
     -      CR34,CR56
 2006 FORMAT(2X,I3,3X,6(F5.1,1X),3X,2(F5.1,1X),3X,6(1X,I1),
             2X,F4.2,2X, 6(1X,F4.2))
      RETURN
C
C-----------------------------------------------------------------------
      ENTRY INPHEN
      READ(5,5) RCHECK
      WRITE(6,4) RCHECK
    4 FORMAT(' ',20A4)
    5 FORMAT(20A4)
      DO 1000 I=1,NVECOH
      READ(5,6)
     -ICOLDS(I),AM1(I),AM2(I),AE1(I),AE2(I),AE3(I),AE4(I),AE5(I),BM1(I),
     1BM2(I),BE1(I),BE2(I),BE3(I),BE4(I),BE5(I),CE1(I),CE2(I),CE3(I),
     2CE4(I),CE5(I),THHEAT(I),SOILTH(I),COLDT(I),COLDTH(I),FREEZE(I),
     3PHOTOR(I),PHOTOF(I),AIRTTH(I),SEED(I),SEEDLN(I),PJUVEN(I),SMORT(I)
     4,GERM(I)
    6 FORMAT(I5,13F5.0/14F5.0/14F5.0)
      READ(5,8) (PHASE(I,J), J=1,6)
      READ(5,8) (RATMX(I,J), J=1,6)
      READ(5,10)(GERMRX(I,J),J=1,3)
    8 FORMAT(6F10.0)
   10 FORMAT(3F10.0)
      DO 9 J=1,60
    9 HEATMA(J,I) = 0.
      DO 11 J=1,90
   11  ICLDMA(J,I) = 0
C
1000  CONTINUE
      RETURN
      END
```

**1972/73 PROGRESS REPORT**

# MODEL FOR ESTIMATING WATER, SALT AND TEMPERATURE DISTRIBUTION IN THE SOIL PROFILE

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# INTRODUCTION

In a desert ecosystem, the distributions of water, salt and heat in the soil profile are basic properties needed to evaluate most biological and physical processes. They are therefore of primary concern to an ecosystem model. The submodel which predicts these fundamental parameters is one of the most important to the overall modeling effort of the Desert Biome program.

This report describes a computer model which was developed to predict the distribution of water, total salt and temperature in a soil profile from a minimum of measurements.

The program listing and a sample output are given in Appendices 1 and 2, respectively.

The results of a 28-day validation run using 1971 field data from Curlew Valley, Utah, showed excellent agreement between predicted and actually measured soil parameters, leading to the tentative conclusion the the model would adequately serve the needs of the Desert Biome ecosystem analysis program where heat and water flow were mostly vertical (one dimensional). The use of the computer program and results of limited field testing under desert conditions are reported.

# MODEL DESCRIPTION

The soil water, temperature and salt models were developed originally by Nimah and Hanks (1973); Hanks et al. (1971); Bresler and Hanks (1969); and Bresler (1973), respectively. The theory of the models is described in detail in these publications.

Briefly, the theoretical aspects of the model can be described by the following relationships. The soil water model involves the numeric solution to the one-dimensional general flow equation with a plant root extraction term, A(z) as given by Nimah and Hanks (1973):

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} [K(\theta)\frac{\partial H}{\partial z}] + A(z) \qquad (1)$$

A(z) is defined as:

$$A(z) = \frac{[\text{Hroot} + (\text{RRES} * z) - h(z) - S(z)] * \text{RDF}(z) * K(\theta)}{\Delta z} \qquad (2)$$

Where $\theta$ is the volumetric water content, t is time, z is depth, K is hydraulic conductivity, H is hydraulic head, and Hroot is an effective water potential in the root at the soil surface where z is considered zero and RRES = 1 + Rc. Rc is the flow coefficient, h(z) is the soil pressure head at depth z, S(z) is the salt (osmotic) potential at depth z (in equivalent head units), and RDF(z) is the proportion of total active roots in depth increment $\Delta z$.

The partial differential equation describing soil temperature, T, as a function of depth, z, and time, t, in one dimension as given by Hanks et al. (1971) is:

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left[\sigma \frac{\partial T}{\partial t}\right] \qquad (3)$$

where $\sigma$ is the thermal diffusivity (which in general may be a function of time and depth). The thermal diffusivity is equal to the ratio of thermal conductivity to heat capacity.

The mathematical expression for one-dimensional transient salt conditions was derived from continuity considerations by Bresler (1973) and led to:

$$\frac{\partial}{\partial t}[ Q + \theta c) = \frac{\partial}{\partial z}[D(V,\theta)\frac{\partial c}{\partial z}] - \frac{\partial (qc)}{\partial z} + S \qquad (4)$$

Where Q is the local concentration (positive or negative) of solute in the "adsorbed" phase (meq/cm$^3$ soil); c is the concentration in the solution phase (meq/cm$^3$ soil solution); S is any sink or source term due to salt uptake, precipitation or dissolution; z is the vertical space coordinate (considered to be positive downward); D is the combined diffusion-dispersion coefficient (cm$^2$·sec$^{-1}$); q is the volumetric flux of solution (cm$^3$·cm$^{-2}$·sec$^{-1}$); and V is the average interstitial flow velocity (cm·sec$^{-1}$).

### ASSUMPTIONS

As presently used the model does not consider hysteresis or layered soil although both of these have been considered earlier by Hanks et al. (1969) and Bresler and Hanks (1969). It is assumed that air escapes freely and that the soil properties, primarily the hydraulic conductivity and the pressure head-water content relation, do not change with time, i.e., there is no change in soil structure. Other assumptions are that the flow is isothermal, vertical and one dimensional. Since the soil temperature is computed, future improvements in the model could remove the assumption of isothermal flow which would then allow vapor movement and condensation in the soil profile to be predicted.

Further assumptions are that roots are considered to be distributed in a continuous (but not necessarily uniform) manner, and that no water is stored or consumed by the plant itself.

The temperature prediction assumes soil organic matter is negligible and the specific heat (mass) of the solid soil material is taken as $0.2\ cal\cdot g^{-1}\cdot C^{-1}$. The present case assumes the average surface soil temperature is the average daily air temperature.

As a first approximation, the present salt model is restricted to solutes that do not interact with the soil and therefore the effect of salt fluctuations on water flow is neglected. Thus, for an inert solute and porous medium, the Q and S terms of equation (4) are assumed zero.

### INPUT DATA REQUIREMENTS

The basic data needed for the solution of the model are:

1. Latitude of the site.
2. Amount and intensity of rainfall.
3. Average daily air temperature.
4. Salt concentration of input water.
5. Distribution of roots in the profile.
6. Hydraulic conductivity-water content and pressure head-water content data covering the range of water content to be encountered.
7. Thermal conductivity and heat capacity of the soil. If these data are not available a good approximation for $\sigma$, the ratio K/Cv, is 12 $cm^2/hr$.
8. Water content-depth, temperature-depth and salt content (E.C.)— depth data at the beginning (initial conditions).
9. Air dry and saturated soil water contents (may be estimated from the pressure head-water content data).
10. Root water potential below which the root will not go (presumably the plant wilts). This may be estimated to be between 15 and 40 atm with little difference in the computed soil-water contents.
11. Presence or absence of a water table at the bottom of the soil profile.

### COMPUTATIONAL PROCEDURE

The general computational procedure involved the following steps:

1. Read input data.
2. The subroutine EVAPO is called. EVAPO is a service subroutine which computes the evapotranspiration, evaporation, salt content of the input water, and soil surface temperature arrays and passes them to the appropriate program.
3. The diffusivity as a function of water content is computed.
4. From the initial water content as a function of depth, values of hydraulic conductivity as a function of depth are computed. Values of specific water capacity $(C = \frac{\Delta\theta}{\Delta h})$ as a function of depth are computed.
5. The surface pressure head is determined to correspond to the surface flux conditions provided the pressure head is above air dry.
6. A value of Hroot is hunted for that satisfies the potential transpiration conditions. Root extraction is assumed zero during the period water or rain is added.
7. The tridiagonal matrix made up of the series of linear equations for each depth is solved for the pressure head at the end of the time interval at each depth increment.
8. The program tests the total absolute change in water content. If it is greater than a given value the time is reduced by half and the program goes back to step 6. Otherwise it will continue.
9. The distribution and dispersion of salt in the profile are computed.
10. The subroutine DEGREE is called. DEGREE computes the temperature of the soil profile and returns the array to the main program.
11. The desired output information is printed.
12. A new $\Delta t$ is chosen, and the values for water content, salt content and temperature are taken as the new initial conditions. The cumulative time is checked and adjustments to the potential boundary conditions at the surface are made if necessary.

## COMPUTER IMPLEMENTATION

### DEFINITION OF INPUT/OUTPUT PARAMETERS

| | |
|---|---|
| A | negative values show the soil depth increment from which roots are extracting water |
| ALAMBA | constant used in salt concentrations |
| BEGTEM | initial soil temperatures in °C |
| C | water capacity of the soil increment in cm |
| CB | constant to multiply D array by, usually 1.0 |
| CONDUC | soil thermal conductivity in cal/cm-hr-deg |
| CONQ | largest water content change allowed each computation; the smaller the number the more accurate the computation but the longer the run time, usually .03 to .05 |
| COVER | fraction of ground covered by plants |
| CUMS | cumulative water flow at the surface in cm |
| CV | soil heat capacity in cal/gm |
| CWF | cumulative water flow in cm |
| D | cm/hr hydraulic conductivity-water content array in DELW increments |
| DD | soil depth increments in cm |
| DEG | average daily temperature-time array |
| DELW | water content difference of the P, D arrays, usually .01 |
| DELX | constant equal to 7.6 |
| DETT | smallest time increment allowed, usually .0024 hr |

| | |
|---|---|
| DIFA | constant used in salt calculations |
| DIFB | constant used in salt calculations |
| DIFO | constant used in salt calculations |
| DTIME | size of the time interval for soil temperature calculations in hours |
| FACTOR | Blaney-Criddle crop factor |
| GRAVY | gravity constant equal to DELX |
| H | water potential in the soil in cm |
| HDRY | cm pressure of air dry soil water content |
| HHI | maximum root potential allowed, usually zero |
| HLOW | minimum root potential allowed, usually —15,000 to —40,000 cm |
| HROOT | root water potential in cm |
| HWET | cm pressure of saturation soil water content |
| IDAY | number of days of the simulation run |
| IER | size of the TET, V, SF, DEG arrays, equal to twice IDAY |
| JDAY | Julian day the simulation starts |
| JULDAY | Julian day of the simulation |
| K | number of depth increments |
| KK | is K + 1 |
| LAT | latitude of the site |
| LDAY | day of the simulation run |
| MDAY | day increment of the simulation run |
| ML | number of data sets being processed |
| MM | prints every MM iterations if desired |
| NB | equal to K or less, used when computation over only a portion of the profile is desired |
| ND | size of the potential-water content table |
| P | cm of pressure head-water content array in DELW increments |
| PLACE | name of the site |
| RAIN | inches of rainfall each day |
| RDF | fraction of roots in each depth increment |
| RRES | root resistance, 1.05 |
| RUNOF | cumulative cm of runoff water |
| SALTFX | concentration of salt in rainfall, irrigation or runon water (meq/1) |
| SD | amount of salt in each soil depth increment in meq |
| SE | concentration of salt in each soil depth increment, E.C. readings in mmhos/cm |
| SF | concentration of salt in rainfall, irrigation or runon water-time array in meq/1 |
| SOCON | constant used in salt calculations |
| SOURCE | constant used in salt calculations |
| STEMP | temperature of each soil depth increment, °C |
| SUMA | cumulative cm of water transpired |
| T | water content table, has even increments DELW in size |
| TAA | zero if the bottom boundary is a water table, otherwise equal to 1.0 |
| TEMP | average daily temperature, °F |
| TET | evapotranspiration-time array; cm of water lost per hour, evapotranspiration appears as zero during periods of rain or irrigation |
| TIME | time the computation starts, usually 0; and the cumulative hours of the simulation run |
| TRAIN | hours that rain fell each day |
| TT | 1.0 for Laasonen or 0.5 for Crank Nicholson computational procedure |
| V | evaporation-time array; cm of water evaporating per hr, rain or irrigation appears as positive evaporation per hour |
| W | initial volumetric fractional water content of each soil depth increment |
| WATH | saturation soil water content |
| WATL | volumetric fractional air dry soil water content |

## INPUT EXAMPLES

Example input data and the order of data cards are as follows:

1. The name of the site starting in column 1, i.e., Curlew Valley, Utah.
2. The latitude of the site (42.00) is in columns 1-6, IDAY (28) in columns 7-9, JDAY (228) in columns 10-12, FACTOR (0.80) in columns 13-17, and COVER (0.25) in columns 18-22.
3. Rainfall data has IDAY entries in a F5.2 field with 14 entries per card maximum.
4. Average daily temperature is entered IDAY times in an F5.2 field with 14 entries per card maximum.
5. TRAIN, rainfall intensity is entered IDAY times in an F5.2 field with 14 entries per card maximum.
6. SALTFX is entered IDAY times in an F5.2 field with 14 entries per card maximum. If chemical analysis of rainfall is unavailable, the data can be assumed zero.
7. ML (01) is entered in columns 1-3.
8. K (09) is entered in columns 1-3, MM (099) is entered in columns 3-6, IER (056) is entered in 7-9, NB (009) is entered in 10-12, ND (054) is entered in 13-15, and DTIME (24.) is a real number entered in columns 16-22.
9. RDF (+.0000E+00, +.3640E+.00, etc.) is entered KK times in an E10.4 field with seven entries per card maximum. Note that the surface RDF value must be zero.
10. P data (—.1800E+00, —.2000E—01, etc.) is entered ND times in an E10.4 field with seven entries per card maximum. Data starts with conductivities corresponding to the driest moisture contents.
11. D data (+.8800E—05, +.10000E—04, etc.) is entered ND times in an E10.4 field with seven entries per card maximum. Data starts with conductivities corresponding to the driest moisture contents.
12. W data (+.0100E+00, +.3200E+00, etc.) is entered KK times in an E10.4 field with seven entries per card maximum.
13. DELX (+.7600E+01) is in columns 1-10, DETT (+.0024E+00) is in columns 11-20, GRAVY (+.7600E+01) is in columns 21-30, CONQ (+.0500E+00) is in columns 31-40, DELW (+.0100E+00) is in columns 41-50, TIME (+.0000E+00) is in columns 51-60.

14. TT (+.1000E+01) is in columns 1-10, TAA (+.1000E+01) is in columns 11-20, HLOW (—.2000E+05) is in columns 21-30, HHI (+.0000E+00) is in columns 31-40, RRES (+.1050E+01) is in columns 41-50.
15. HDRY (—.5000E+06) is in columns 1-10, HWET (+.0000E+00) is in columns 11-20, WATL (+.1000E—01) is in columns 21-30, WATH (+.5200E+00) is in columns 31-40, CB (+.1000E+01) is in columns 41-50.
16. SE data (+.9900E+00, +.5100E+00, etc.) is entered KK times in an E10.4 field with a maximum of seven entries per card.
17. DD data (+.0000E+00, +.3000E+01, +.3000E+01, etc.) is entered KK times in an E10.4 field with a maximum of seven entries per card.
18. ALAMBA (+.1000E+00) is in columns 1-10, SOURCE (+.0000E+00) is in columns 11-20, DIFO (+.1000E—01) is in columns 21-30, DIFA (+.1000E—02) is in columns 31-40, DIFB (+.1000E+01) is in columns 41-50, and SOCON (+.1000E+00) is in columns 51-60.
19. BEGTEM data (20.8, 24.0, etc.) are entered KK times in an F8.2 field with 10 entries maximum per card.
20. CV data (.30, .30, etc.) are entered KK times in an F8.2 field with 10 entries maximum per card.
21. CONDUC data (3.6, 3.6, etc.) are entered KK times in an F8.2 field with 10 entries maximum per card.

The dimensions of arrays are as follows:

IER in size are TET, V, SF, and DEG; IDAY in size are ATIME, SALTFX, ET, EVAP, TEMP, RAIN, TRAIN, DAYMIN, DALITE, and CTEMP; KK in size are H, G, Y, W, RDF, A, SE, SS, SD, C, B, E, F, STEMP, DD, CV, CONDUC, and BEGTEM; ND in size are P, D, and T; PLACE is dimensioned 80.

### SAMPLE OUTPUT

The sample output consists of the results of an actual 28-day validation run at Curlew Valley, Utah, beginning with a report of the input data or the results of computed input parameters (Appendix 2).

Water, Potential, Conductivity, and Diffusivity table columns give the values of these parameters for each water content from zero to 53%. The C(I), Depth, W-Depth, H-Depth, RDF-Depth, and SE-Depth table gives their respective values at each soil depth.

The second major table presents the evapotranspiration results obtained from the EVAPO subroutine for each day of the run.

The soil temperature data table has input parameters needed by the DEGREE subroutine in the computation of soil temperatures.

The DELX, etc., table contains the input constants and single point data needed in the calculations.

The input information is followed by a daily report of the desired output computations performed by the model.

## FIELD TEST OF THE MODEL

The sample output (Appendix 2) is an actual example using data from the southern sagebrush site at Curlew Valley, Utah. The validation run is for the 28 days from August 18, 1971 to September 15, 1971.

There were four rainfall events that occurred on the 11th, 12th, 16th, and 21st days of the run. Figure 1 shows the water distribution in the soil profile at the start of the run. In Figure 1 the model's predicted and the experimental field values are matched to initialize the validation run. Figure 2 illustrates the response of the model to a light rainfall which saturated the soil surface. Figure 3 gives the results of validation after 25 days. The initial and validation data are taken from Jurinak and Griffin (1972). The results of the validation run show that the model started from an initial condition of dry soil, responded to rainfall additions, and then successfully dried out to predict the field-measured soil moisture content on September 12, 1971, within the experimental error of the measurement.

Figure 4 illustrates the initialization of the total salt distribution in the soil profile for the same time period as the soil water run. Figure 5 shows the results of the 25-day validation run. Comparison of Figures 4 and 5 indicates that the model was able to predict (within the experimental error of the E.C. measurement) the upward redistribution of salt in the profile due to evaporation of water from the soil surface.

Validation data for soil temperatures were not available; however, the soil temperature model has been tested by Hanks et al. (1971). Figure 6 shows the soil temperatures at two depths predicted by the model during the 28-day run. The figure illustrates that the temperature near the surface fluctuates widely in response to the air temperature variation. The temperature changes deep in the profile are very slow and gradual. These results indicate that the model is responding in an expected manner and that the values reported are reasonable for conditions at Curlew Valley.

This successful validation run leads to the conclusion that the soil water, salt and temperature model will predict these parameters within experimental error under arid conditions where one-dimensional flow predominates. It is further concluded that the model will adequately serve most of the needs of the Desert Biome ecosystem analysis program. However, these conclusions must be considered as tentative until further validation is carried out using data from other sites and at different seasons of the year.

## ACKNOWLEDGEMENT

Thanks is given to Curtis Wilcott for contributing the loop which computes the fraction of daylight hours in the subroutine EVAPO.

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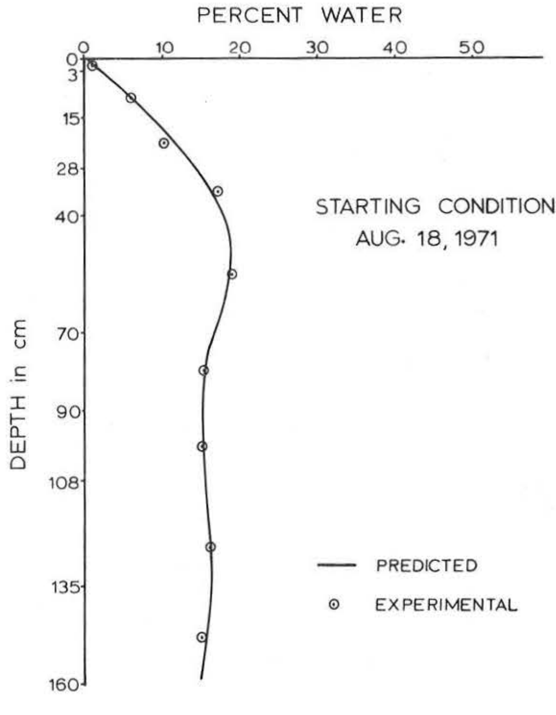

**Figure 1.** Moisture content as a function of depth in the soil profile.

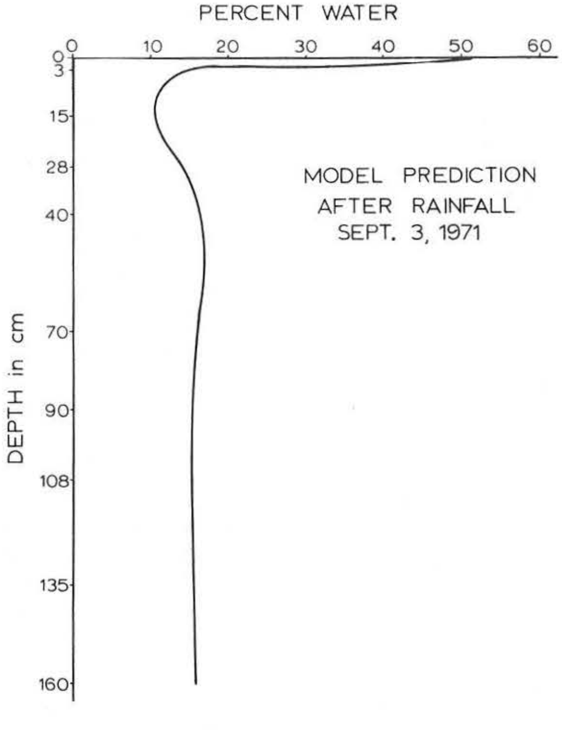

**Figure 2.** Moisture content as a function of depth in the soil profile.

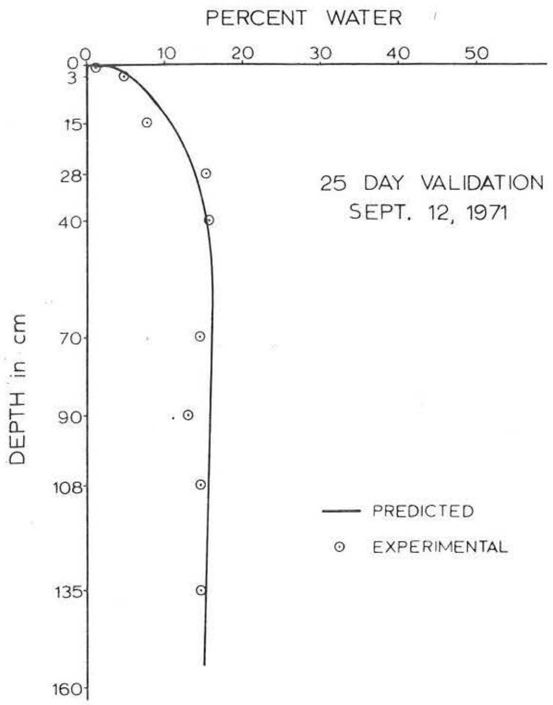

**Figure 3.** Moisture content as a function of depth in the soil profile.

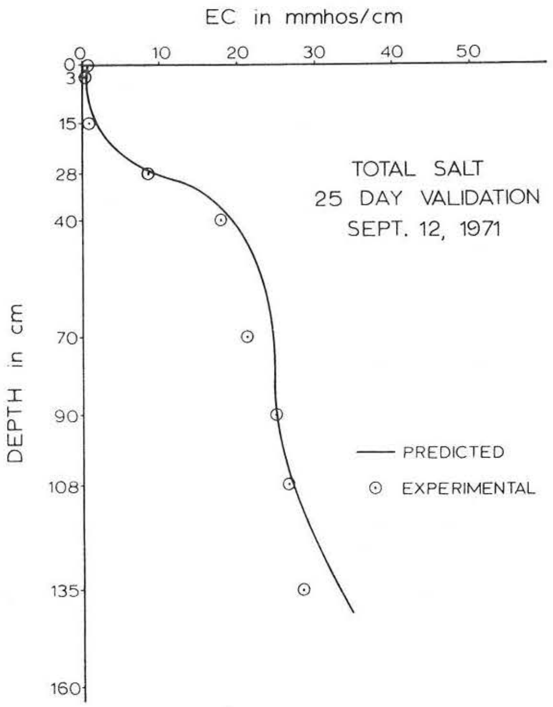

**Figure 5.** Total salt content as a function of depth in the soil profile.

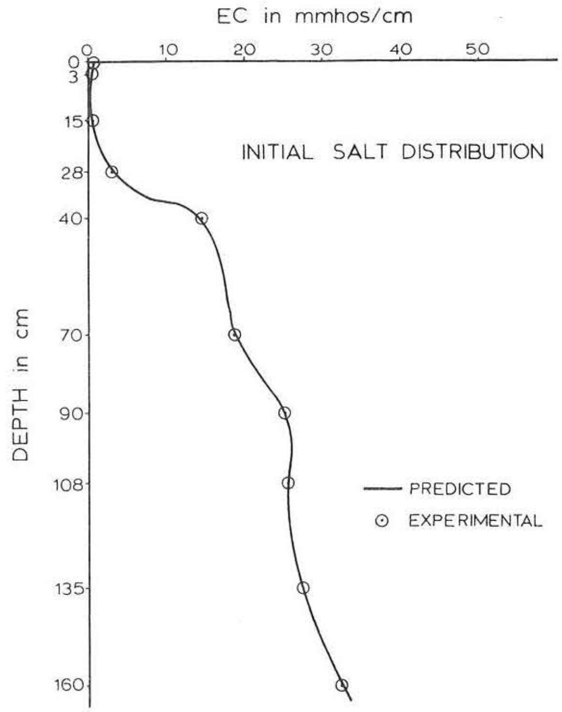

**Figure 4.** Total salt content as a function of depth in the soil profile.

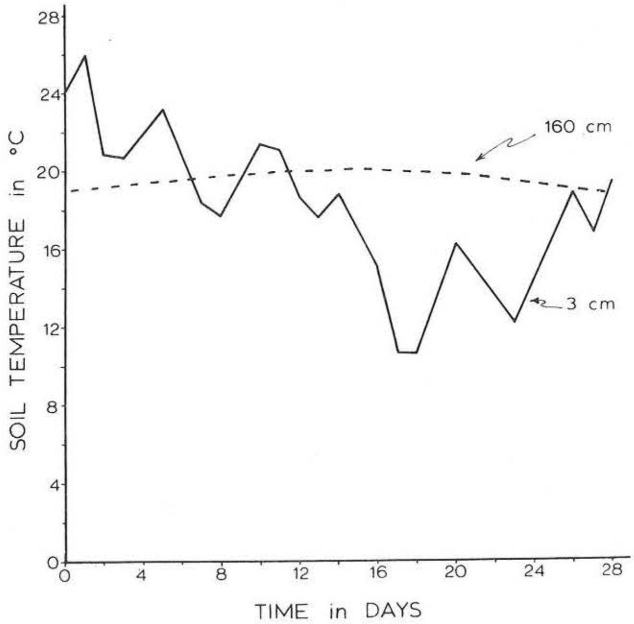

**Figure 6.** Predicted temperature at two depths in the soil profile as a function of time.

# APPENDIX 1

## Program Listing

```
C*****************************************************************
C         PROGRAM TO COMPUTE WATER, TOTAL SALT, AND TEMPERATURE DISTRIBUTION
C                              IN THE SOIL PROFILE
C*****************************************************************
      DIMENSION H(25),G(25),Y(25),W(25),RDF(25),A(25),SE(25)
      DIMENSION SS(25),SD(25),C(25),B(25),E(25),F(25)
      COMMON/TRANS/TET(732),V(732),SP(732),JDAY
      COMMON/TTEMP/K,KK,IER,STEMP(25),DD(25),CV(25),
     1CONDUC(25),BEGTEM(25),JJJ
      COMMON/EVDEG/DEG(732)
      COMMON DTIME
      DIMENSION P(60),D(60),T(60)
C*************************************************************
      CALL EVAPO
C*****************************************************************
      READ 163, ML                                            A   9
      LDAY=0
      LMM=0                                                   A  11
1     LMM=LMM+1                                               A  10
      JJJ=1
C*****************************************************************
C          READ ARRAYS
C*****************************************************************
      READ (5,163) K,MM,IER,NB,ND,DTIME
      KK=K+1                                                  A  18
      READ(5,165) (RDF(I),I=1,KK)
      KC=1
      WFDD=-.009
      ET=TET(1)
      LL=MM                                                   A  19
      READ(5,165)(P(I),I=1,ND)
      READ(5,165)(D(I),I=1,ND)
      READ 165, (W(I),I=1,KK)                                 A  25
      READ 165, DELX,DETT,GRAVY,CONQ,DELW,TIME
      READ 165, TT,TAA,HLOW,HHI,RRES
      READ 165, HDRY,HWET,WATL,WATH,CB
      READ 165, (SE(I),I=1,KK)
      READ 165,(DD(I),I=1,KK)
      READ (5,165) ALAMBA,SOURCE,DIFO,DIFA,DIFB,SOCON
      READ (5,101) (BEGTEM(I),I=1,KK)
      READ (5,101) (CV(I),I=1,KK)
      READ (5,101) (CONDUC(I),I=1,K)
      CUMT=V(IER)
      WRITE (6,169)
      WRITE (6,163) K,MM,IER,NB,ND,DTIME
      DO 4 I=1,KK
    4 SE(I)=(SE(I)*10.)/(W(I)/WATH)
C*****************************************************************
C                THE DIFFUSIVITY AS A FUNCTION OF WATER CONTENT IS COMPUTED
C*****************************************************************
      P(1)=P(1)*1.0E+03
      T(1)=0.0                                                A  38
      DO 900 I=2,ND
      T(I)=DELW+T(I-1)
 900  P(I)=P(I)*1.0E+03
      SE(1)=SF(1)
      SMAX=350.
      CWFLX=0.0
      EOR=V(1)                                                A  74
      DELT=DETT
      TM=1.0-TT                                               A  76
      TBB=1.0-TAA                                             A  77
      YMAX=WATH                                               A  82
      DO 14 I=1,KK
      SS(I)=SE(I)
      SD(I)=SE(I)*W(I)
14    Y(I)=W(I)                                               A  87
      PIT=0.0                                                 A  89
      DO 15 I=2,K
   15 PIT=W(I)*(DD(I+1)-DD(I-1))/2.+PIT
      WRITE (6,170)
      TW=D(1)
      D(1)=(D(1)*(P(2)-P(1)))*CB                              A  39
      J=(W(1)-T(1))/DELW+1.0
      H(1)=(P(J+1)-P(J))*(W(1)-T(J))/DELW+P(J)
      G(1)=H(1)
      C(1)=DELW/(P(J+1)-P(J))
      WRITE (6,274) T(1),P(1),TW,D(1),C(1),DD(1),W(1),H(1),RDF(1),SE(1)
      DO 3 I=2,KK
      TW=D(I)
      D(I)=D(I)*(P(I)-P(I-1))*CB+D(I-1)                       A  41
      J=(W(I)-T(1))/DELW+1.0
      H(I)=(P(J+1)-P(J))*(W(I)-T(J))/DELW+P(J)
      C(I)=DELW/(P(J+1)-P(J))
      G(I)=H(I)                                               A  86
      WRITE (6,274) T(I),P(I),TW,D(I),C(I),DD(I),W(I),H(I),RDF(I),SE(I)
3     CONTINUE
      N=KK+1
      DO 2 I=N,ND
      TW=D(I)
      D(I)=D(I)*(P(I)-P(I-1))*CB+D(I-1)
    2 WRITE (6,274) T(I),P(I),TW,D(I)
C*************************************************************
C     D IS NOW DIFFUSIVITY TIMES DELW NOT CONDUCTIVITY
C*****************************************************************
      WRITE (6,179)
      MDAY=0
      JULDAY=JDAY-1
      DO 5 I=2,IER,2
      MDAY=MDAY+1
      JULDAY=JULDAY+1
      WRITE (6,164) MDAY,JULDAY,V(I),V(I-1),TET(I-1),SF(I-1),DEG(I-1)
    5 CONTINUE
      WRITE (6,201)
      WRITE (6,202)
      DO 10 I=1,KK
      WRITE (6,203) DD(I),BEGTEM(I),CONDUC(I),CV(I)
   10 CONTINUE
      WRITE (6,180)
      WRITE (6,166) DELX,DETT,GRAVY,CONQ,DELW,TIME
      WRITE (6,181)
      WRITE (6,166) TT,CUMT,TAA,HLOW,HHI,RRES
      WRITE (6,172)
      WRITE (6,166) HDRY,HWET,WATL,WATH,CB
      WRITE (6,284)
      WRITE (6,274) ALAMBA,SOURCE,DIFO,DIFA,DIFB,SOCON
      KCK=1                                                   A  93
      HROOT=G(2)
      RUNOF=0.0                                               A  95
      CUMS=0.0                                                A  96
      CUMM=0.0                                                A  98
      SUMA=0.0
C*************************************************************
C----COMPUTATION OF CONDUCTIVITY (B) AND WATER CAPACITY (C)    A  99
C*****************************************************************
16    TOP=WATH                                                A 100
      BOT=WATL                                                A 101
      HKP=H(1)
      WKP=W(1)
      IF (EOR-0.0) 17,19,18                                   A 102
17    W(1)=WATL                                               A 103
      H(1)=HDRY                                               A 104
      GO TO 19                                                A 105
18    W(1)=WATH                                               A 106
      H(1)=HWET                                               A 107
19    TWW=(W(1)+Y(1))*0.5                                     A 108
      J=(TWW-T(1))/DELW+1.0
      BB=(TWW-T(J))/DELW                                      A 110
      DIFFA=(D(J+1)-D(J))*BB+D(J)                             A 111
      HI=(P(J+1)-P(J))*BB+P(J)                                A 112
      DO 37 I=1,K                                             A 113
      TW=(W(I+1)+Y(I+1))*0.5                                  A 114
      J=(TW -T(1))/DELW+1.0
      BB=(TW-T(J))/DELW                                       A 116
      DIFFB=(D(J+1)-D(J))*BB+D(J)                             A 117
      GI=(P(J+1)-P(J))*BB+P(J)
  219 IF(HI-GI)20,32,20
20    B(I)=(DIFFA-DIFFB)/(HI-GI)                              A 120
      IF (I-1) 21,21,33                                       A 121
21    IF (EOR-0.0) 22,33,22
  22  ER=(B(1)*(H(1)*TT-H(2)*TT-G(2)*TM+G(1)*TM+DD(2)))/DD(2)
      IF (ABS(1.1*EOR-ER)-ABS(0.1*EOR)) 236,236,23
23    IF(KCK.EQ.1) GO TO 220
      IF (KCK-20)305,236,236
C*****************************************************************
C          THE SURFACE PRESSURE HEAD IS DETERMINED
C*****************************************************************
  236 H(1)=(1.1*EOR*DD(2)/D(1)+H(2)*TT-G(1)*TM+G(2)*TM-DD(2))/TT
      IF(H(1).LT.HDRY) H(1)=HDRY
      IF (H(1).GT.HWET) H(1)=HWET
      GO TO 33
220   H(1)=HKP
      W(1)=WKP
      KCK=KCK+1
      GO TO 19
305   KCK=KCK+1
      IF (ER-EOR) 24,33,26
24    IF (W(1)-WATH) 25,33,33                                 A 126
25    BOT=W(1)                                                A 127
      W(1)=(W(1)+TOP)*0.5                                     A 128
      GO TO 28                                                A 129
26    IF (W(1)-WATL) 33,33,27                                 A 130
27    TOP=W(1)                                                A 131
      W(1)=(W(1)+BOT)*0.5                                     A 132
   28 J=(W(1)-T(1))/DELW+1.0
      BB=(W(1)-T(J))/DELW                                     A 134
      IF(EOR-0.0)30,33,30
30    H(1)=(P(J+1)-P(J))*BB+P(J)                              A 138
  218 TWW=(W(1)+Y(1))*0.5
      J=(TWW-T(1))/DELW+1.0
      BB=(TWW-T(J))/DELW                                      A 110
      DIFFA=(D(J+1)-D(J))*BB+D(J)                             A 111
      HI=(P(J+1)-P(J))*BB+P(J)                                A 112
      GO TO 219
32    B(I)=(D(J+1)-D(J))/(P(J+1)-P(J))                        A 142
      IF (I-1) 33,21,33                                       A 143
33    TWW=TW                                                  A 144
      HI=GI                                                   A 145
      DIFFA=DIFFB                                             A 146
      TW=(W(I+1)+Y(I+1))*0.5                                  A 147
      J=(TW -T(1))/DELW+1.0
35    C(I+1)=DELW/(P(J+1)-P(J))                               A 151
37    CONTINUE                                                A 154
      KCK=1
      IF(EOR.GT.0.0.AND.ET.GE.0.0) GO TO 6666
      IF(EOR.GT.0.0.AND.ET.LT.0.0) GO TO 5555
 6666 ETPL=ET-EOR
      IF(ET.GE.0.0) GO TO 39
      IF(ETPL-0.0) 365,39,39
 5555 ETPL=ET
C*************************************************************
C     SEARCHING FOR THE PROPER HROOT VALUE
C*****************************************************************
365   HHOLD=HROOT                                             BB
      HROOT=HLOW
      SINK=0.0
      DO 250 I=2,K
  250 E(I)=G(I)-36.*SE(I)-DD(I)*RRES
      DO 420 I=2,K
      IF(HROOT-E(I).GT.0.0) GO TO 420
      SINK=B(I)*RDF(I)*(HROOT-E(I))+SINK
 420  CONTINUE
      IF(SINK-ETPL.GT.0.0) GO TO 402
      HROOT=HHOLD
410   HROOT=1.2*HROOT
      SINK=0.0
      DO 421 I=2,K
      IF(HROOT-E(I).GT.0.0) GO TO 421
      SINK=B(I)*RDF(I)*(HROOT-E(I))+SINK
 421  CONTINUE
      IF(SINK-ETPL)411,402,410
 411  HRLO=HROOT
      HROOT=HHOLD
      LCOUNT=0
412   HROOT=0.8*HROOT
      LCOUNT=LCOUNT+1
      IF(LCOUNT.EQ.5) GO TO 490
      SINK=0.0
      DO 422 I=2,K
      IF(HROOT-E(I).GT.0.0) GO TO 422
      SINK=B(I)*RDF(I)*(HROOT-E(I))+SINK
 422  CONTINUE
      IF(SINK-ETPL)412,402,413
 413  HRHI=HROOT
      GO TO 491
  490 HRHI=HHI
491   LCOUNT=0
      HROOT=HHOLD
405   SINK=0.0                                                BB
      DO 400 I=2,K                                            BB
      IF(HROOT-E(I).GT.0.0) GO TO 400
      SINK=B(I)*RDF(I)*(HROOT-E(I))+SINK
400   CONTINUE                                                BB
      LCOUNT=LCOUNT+1                                         BB
      IF(LCOUNT.EQ.20) GO TO 402
      IF(ABS(SINK-ETPL)-0.002)402,402,401
401   IF(SINK-ETPL)403,402,404                                BB
403   HRLO=HROOT                                              BB
      HROOT=0.5*(HROOT+HRHI)                                  BB
      GO TO 405                                               BB
 404  HRHI=HROOT
      HROOT=0.5*(HROOT+HRLO)                                  BB
      GO TO 405                                               BB
   39 DO 251 I=2,K
      SINK=0.0
  251 A(I)=0.0
```

```
      GO TO 38
C***********************************************************************
C     A IS THE DEL WATER/DELT CAUSED BY PLANT EXTRACTION
C***********************************************************************
  402 DO 406 I=2,K
      IF(HROOT-E(I).GT.0.0) GO TO 407
      A(I)=B(I)*(HROOT-E(I))*2.0*RDF(I)/(DD(I+1)-DD(I-1))
      GO TO 406
 407  A(I)=0.0
406   CONTINUE
C*****************************************************************
C----COMPUTATION OF TRIDIAGONAL MATRIX MAIN BODY                      A 158
C***********************************************************************
38    DO 42 I=2,K                                                      B 159
      POT=(DD(I+1)-DD(I-1))/(2.0*DELT)                                 B 160
      DLXA=(DD(I)-DD(I-1))                                             B 161
      DLXB=(DD(I+1)-DD(I))                                             B 162
      BB=C(I)*POT/TT+B(I)/DLXB+B(I-1)/DLXA                             B 1621
      DA=(C(I)*POT*G(I)+(B(I)/DLXB)*(TM*(G(I+1)-G(I))-DLXB)+(B(I-1)/DLXA  B 1622
     1)*(TM*(G(I-1)-G(I))+DLXA)+A(I)*(DD(I+1)-DD(I-1))*0.5)/TT
      IF(I-2)390,390,40
  390 IF(H(1).GE.HWET.OR.H(1).LE.HDRY) GO TO 394
      DA=DA-((B(I-1)/DLXA)*(TM*(G(I-1)-G(I))+DLXA))/TT+EOR/TT
      BB=BB-B(I-1)/DLXA
      GO TO 393
  394 DA=DA+H(I-1)*B(I-1)/DLXA
  393 F(I)=DA/BB
      E(I)=(B(I)/DLXB)/BB                                              B 1661
      GO TO 42                                                         A 167
40    TF (I-K) 41,43,43                                                A 168
41    E(I)=(B(I)/DLXB)/(BB-(B(I-1)/DLXA)*E(I-1))                       B 169
      F(I)=(DA+(B(I-1)/DLXA)*F(I-1))/(BB-(B(I-1)/DLXA)*E(I-1))         B 170
 42   CONTINUE
43    BB=BB-TAA*B(I)/DLXB                                              B 172
      DA=DA+TAA*(B(I)/DLXB)*((G(I)-G(I+1))*TM+DLXB)/TT+TBB*B(I)/DLXB*H(  B 173
     1KK)                                                              B 174
      H(I)=(DA+(B(I-1)/DLXA)*F(I-1))/(BB-(B(I-1)/DLXA)*E(I-1))         B 1741
44    I=I-1                                                            A 175
      H(I)=E(I)*H(I+1)+F(I)                                            A 176
      TF (I-2) 45,45,44                                                A 177
45    IF(TAA-1.0)47,46,46
46    H(KK)=H(K)+DD(KK)-DD(K)                                          B 178
47    DO 60 I=2,KK
300   TF (H(I)-HWET-DD(I)) 60,60,55
55    H(I)=HWET+DD(I)
60    CONTINUE                                                         A 197
C*****************************************************************
C----COMPUTATION OF WATER CONTENTS AS A FUNCTION OF PRESSURES JUST COMP  A 199
C***********************************************************************
      IF(H(1).GE.HWET.OR.H(1).LE.HDRY) GO TO 1005
      WFDD=EOR
      H(1)=(EOR*DD(2)/B(1)+H(2)*TT-G(1)*TM+G(2)*TM-DD(2))/TT
      IF(H(1).LT.HDRY) H(1)=HDRY
      TF (H(1).GT.HWET) H(1)=HWET
      GO TO 134
 1005 WFDD=B(1)*((H(1)-H(2))*TT+(G(1)-G(2))*TM+DD(2))/DD(2)            B 189
 134  I=1
 62   TF (H(I)-G(I)) 65,116,65
65    NHI=54                                                           A 206
      NLO=1                                                            A 207
      J=25                                                             A 208
66    TF (H(I)-P(J)) 67,72,68                                          A 209
67    NHI=J                                                            A 210
      GO TO 69                                                         A 211
68    NLO=J                                                            A 212
69    JT=J                                                             A 213
      J=(NHI-NLO)/2+NLO                                                A 214
      IF (J-JT) 66,70,66                                               A 215
70    TF (H(I)-P(J)) 71,72,72                                          A 216
71    J=J-1                                                            A 217
72    WAT=(H(I)-P(J))*DELW/(P(J+1)-P(J))+T(J)                          A 218
      W(I)=WAT
      GO TO 117
116   W(I)=Y(I)                                                        A 300
  117 DO 268 I=2,KK
      W(I)=C(I)*(H(I)-G(I))+Y(I)
      TF (W(I).GT.WATH) W(I)=WATH
  268 TF (W(I).LT.WATL) W(I)=WATL
269   SUM3=0.0
      SUM2=0.0                                                         A 326
      SUM1=0.0
      DO 131 I=2,K                                                     A 327
      SUM1=W(I)+SUM1                                                   A 328
      SUM2=Y(I)+SUM2                                                   A 329
      IF (ABS(SUM1-SUM2)-ABS(SUM3)) 131,131,130                        A 330
130   SUM3=SUM1-SUM2                                                   A 331
131   CONTINUE                                                         A 332
      TF(ABS(SUM3)-ABS(CONQ))63,63,132
 132  IF(DELT-DETT*0.1)63,63,133
  133 DELT=0.5*DELT
      GO TO 38                                                        A336
   63 SUM1=0.0
      SUM2=0.0
      DO 800 I=2,K
      SUM1=W(I)*(DD(I+1)-DD(I-1))/2.+SUM1
  800 SUM2=Y(I)*(DD(I+1)-DD(I-1))/2.+SUM2
      CWF=SUM1-PIT
      CUMS=WFDD*DELT+CUMS                                              A 341
      SUMA=SUMA+SINK*DELT
      CWFLX=(SUM1-SUM2)                                               A343A
C*****************************************************************
C           SALT LOOP
C***********************************************************************
      KB=K-1
      WFRU=B(1)*((H(1)-H(2))*TT+(G(1)-G(2))*TM+DD(2))/DD(2)
      DO 214 I=2,K
      DLXA=(DD(I)-DD(I-1))
      DLXB=(DD(I+1)-DD(I))
      DLXC=(DD(I+1)-DD(I-1))*0.5
      WFRD=B(I)*((H(I)-H(I+1))*TT+(G(I)-G(I+1))*TM+DLXB)/DLXB
  176 WATD=(Y(I)*TM+W(I)*TT+Y(I+1)*TM+W(I+1)*TT)/2.0
      DTSD=DLXC*0.5*WFRD-(W(I)-Y(I))*(WFRD+WFRU)*WFRD*DELT/(8.0*WATD*
     1(W(I)+Y(I)))
      BETA=DIFO*DIFA*EXP(DIFB*WATD)+ALAMBA*ABS(WFRD/WATD)-DISD
      TF (I .GT. 2) GO TO 680
      ALFA=0.0
      TF (WFRU .GT. 0.) GO TO 182
      WFRU=0.0
      GO TO 182
  680 WATU =(Y(I)*TM+W(I)*TT+Y(I-1)*TM+W(I-1)*TT)/2.0
      DTSU=DLXC*0.5*WFRU-(W(I)-Y(I))*(WFRD+WFRU)*WFRU*DELT/
     1(8.0*WATU*(W(I)+Y(I)))
      ALFA=DIFO*DIFA*EXP(DIFB*WATU)+ALAMBA*ABS(WFRU/WATU)-DISU
      TF (WFRU .GE. 0.0) GO TO 182
      UP=0.0
      GO TO 183
  182 UP=1.0
  183 DN=1.0-UP
      TF (WFRD .GE. 0.0) GO TO 185
      UPP=0.0
      GO TO 186
  185 UPP=1.0
  186 DNN=1.0-UPP
      SE(I)=(DLXC*Y(I)*SS(I)/DELT+ALFA*(SS(I-1)-SS(I))/DLXA-BETA*(SS(I)-
     1SS(I+1))/DLXB-WFRD*(SS(I)*UPP+SS(I+1)*DNN)+WFRU*(SS(I-1)*UP+SS(I)
     2*DN)+SOURCE*DLXC)*DELT/(W(I)*DLXC)
      SE(I)=SS(I)+(SE(I)-SS(I))*SOCON
  214 WFRU=WFRD
      SE(KK)=SS(KK)
      SD(1)=SE(1)*W(1)
      DO 217 I=2,KK
  217 SD(I)=SE(I)*W(I)
706   IF(EOR-0.0)136,136,135
135   RUNOF=(EOR-WFDD)*DELT+RUNOF                                      A 345
136   TIME=TIME+DELT                                                   A 346
      TF (SUM3-0.0) 139,301,139
  301 DELT=2.0*DELT
      GO TO 145
139   TW=ABS(CONQ*DELT/SUM3)                                           A 357
140   TF (TW-0.1*DETT) 141,142,142                                     A 359
  141 TW=0.1*DETT
      GO TO 144
  142 IF(TW-1000.0*DETT)144,144,143
 143  TW=1000.0*DETT
  144 IF(TW.GT.2.0*DELT) GO TO 301
      DELT=TW
C*****************************************************************
C----TEST TO SEE IF EVAP OR RAIN INTENSITY (EOR) HAS CHANGED          A 365
C***********************************************************************
145   IF(TIME-V(KC+1))148,147,148
  147 CONTINUE
C***********************************************************************
      CALL DEGREE
C***********************************************************************
      LDAY=LDAY+1
      WRITE (6,666)
      WRITE (6,168)(DD(I),W(I),H(I),A(I),SE(I),SD(I),STEMP(I),I=1,KK)
      WRITE (6,184)
      WRITE (6,167) LDAY,TIME,SUMA,RUNOF,HROOT,CWF,CUMS
C**********************************************************************
C          COMPUTED VALUES ARE TAKEN AS NEW INITIAL CONDITIONS
C**********************************************************************
      DELT=DETT                                                        A 375
      EOR=V(KC+2)
      SE(1)=SF(KC+2)
      ET=TET(KC+2)
      KC=KC+2
      GO TO 151                                                        A 379
148   IF(TIME+DELT-V(KC+1))151,151,149
149   DELT=V(KC+1)-TIME
151   LL=LL+1                                                          A 384
      TF (TIME-CUMT) 153,152,152                                       A 385
152   TF (ML-LMM) 162,162,1                                            A 386
153   Y(1)=(W(1)+Y(1))*0.5                                             A 387
      J=(Y(1)-T(1))/DELW+1.0
      BB=(Y(1)-T(J))/DELW                                              A 389
      TF (EOR-0.0) 155,156,155                                         A 390
155   G(1)=(P(J+1)-P(J))*BB+P(J)                                       A 393
156   DO 161 I=2,KK                                                    A 394
      J=(W(I)-T(1))/DELW+1.0
      BB=(W(I)-T(J))/DELW
      C(I)=(P(J+1)-P(J))*BB+P(J)
      TW=(W(I)-Y(I))+W(I)                                              A 395
      TF (TW-WATH) 157,157,159                                         A 396
157   TF (TW-WATL) 158,160,160                                         A 397
158   TW=WATL                                                          A 398
      GO TO 160                                                        A 399
159   TW=WATH                                                          A 400
160   Y(I)=W(I)                                                        A 401
      W(I)=TW                                                          A 402
      SS(I)=SE(I)
161   CONTINUE                                                         A 404
      SS(1)=SE(1)
      GO TO 16                                                         A 407
162   STOP                                                             A 408
C*****************************************************************
  101 FORMAT (10F8.2)
  163 FORMAT (5I3,F7.1)
  164 FORMAT (4X,I3,5X,I3,4X,4(E12.4),6X,F6.1)
165   FORMAT (7E10.4)                                                  A 413
166   FORMAT (11E11.4)
  666 FORMAT (4X,'DEPTH',7X,'WATER',6X,'POTENTIAL',3X,'ROOT EXT.'
     1,4X,'SALT CONC',4X,'AMT SALT',4X,'TEMP.')
  167 FORMAT (4X,I3,6(E12.4),//)
  168 FORMAT(3X,F7.1,3X,F7.4,3X,E12.4,1X,E12.4,6X,F7.2,3X,F7.2,3X,F6.1)
  169 FORMAT (1X,'K',1X,'MM',1X,'IER',1X,'NB',1X,'ND',1X,'DTIME')
170   FORMAT (119H   WATER    POTENTIAL   CONDUCTIVITY DIFFUSIVITY
     1C(I)      DEPTH        W-DEPTH      H-DEPTH      RDF-DEPTH   SE-DEPTH)
172   FORMAT (53H   HDRY           HWET          WATL          WATH          CB)
  179 FORMAT (1H0,4X,'DAY',3X,'JULDAY',5X,'TIME END',4X,'SOIL FLUX',4X,
     1'ET FLUX',4X,'SALT CONC.',2X,'AVE DAILY TEMP')
180   FORMAT (66H  DELX          DETT          GRAVY          CONQ          DELW
     1          TIME)
181   FORMAT (66H   TT            CUMT          TAA            HLOW          HHI
     1          RRES)
  184 FORMAT (4X,'DAY',1X,'CUM. HOURS',2X,'CUM. TRANS.',3X,'CUM RUNOFF',
     13X,'HROOT',7X,'CWF',8X,'CUMS')
  201 FORMAT (1H0,3X,'DEPTH',5X,'TEMP AT START',10X,
     1'SOIL HEAT CONDUCTIVITIES',7X,'SOIL HEAT CAPACITY')
  202 FORMAT (40X,'(CAL/CM-HR-DEG C)',15X,'(CAL/GM)')
  203 FORMAT (3X,F6.1,5X,F7.2,18X,F9.4,20X,F9.4)
  274 FORMAT (11E12.4)
  284 FORMAT(68H    ALAMBA       SOURCE        DIFO          DIFA          DIFB
     1          SOCON)
      END                                                              A 417-
C*****************************************************************
```

## *Subroutine* DEGREE

```
      SUBROUTINE DEGREE
C***********************************************************************
C         DEGREE COMPUTES SOIL TEMPERATURES
C*********************************************************************
      COMMON/TTEMP/K,KK,IER,STEMP(25),DD(25),CV(25),
     1CONDUC(25),BEGTEM(25),JJJ
      COMMON/EVDEG/DEG(732)
      COMMON DTIME
      DIMENSION F(25),E(25)
      STEMP(KK)=BEGTEM(KK)
      STEMP(1)=DEG(JJJ)
      JJJ=JJJ+2
C***********************************************************************
C          SOLUTION TO TRI-DIAGONAL MATRIX
C***********************************************************************
      DO 46 I=2,K
      POT=(DD(I+1)-DD(I-1))/(2.*DTIME)
      DLXA=(DD(I)-DD(I-1))
      DLXB=(DD(I+1)-DD(I))
      BB=CV(I)*POT+CONDUC(I)/DLXB+CONDUC(I-1)/DLXA
      DA=CV(I)*POT*BEGTEM(I)
      IF (I .GT. 2) GO TO 44
      DA=DA+CONDUC(I-1)*STEMP(I-1)/DLXA
      F(I)=DA/BB
      E(I)=(CONDUC(I)/DLXB)/BB
```

```
      GO TO 46
   44 IF (I .GE. K) GO TO 47
   45 E(I)=(CONDUC(I)/DLXB)/(BB-(CONDUC(I-1)/DLXA)*E(I-1))
      F(I)=(DA+(CONDUC(I-1)/DLXA)*F(I-1))/(BB-(CONDUC(I-1)/DLXA)*E(I-1))
   46 CONTINUE
   47 BB=BB-CONDUC(I)/DLXB
      STEMP(I)=(DA+(CONDUC(I-1)/DLXA)*F(I-1))/(BB-(CONDUC(I-1)/DLXA)*
     1E(I-1))
   48 I=I-1
      STEMP(I)=E(I)*STEMP(I+1)+F(I)
      IF (I .GT. 2) GO TO 48
      STEMP(KK)=(BEGTEM(KK)+STEMP(K))/2.
C***********************************************************************
C         COMPUTED TEMPERATURE TAKEN AS NEW INITIAL CONDITIONS
C*********************************************************************
      DO 50 I=1,KK
      BEGTEM(I)=STEMP(I)
   50 CONTINUE
      RETURN
      END
```

## *Subroutine* EVAPO

```
      SUBROUTINE EVAPO
C***********************************************************************
C             EVAPO COMPUTES THE TET, V, SF, AND DEG ARRAYS
C**********************************************************************
      COMMON/TRANS/TET(732),V(732),SF(732),JDAY
      COMMON/EVDEG/DEG(732)
      COMMON DTIME
      DIMENSION ATIME(366),SALTFX(366)
      DIMENSION ET(366), EVAP(366)
      DIMENSION TEMP(366), RAIN(366), TRAIN(366)
      DIMENSION PLACE (80)
      DIMENSION DAYMIN(366), DALITE(366)
      DIMENSION CTEMP(366)
      READ (5,12) PLACE
      WRITE (6,13) PLACE
      REAL LAT
      READ (5,6) LAT,IDAY,JDAY,FACTOR,COVER
      WRITE (6,6) LAT,IDAY,JDAY,FACTOR,COVER
C***********************************************************************
C           COMPUT DAYLIGHT HOURS
C***********************************************************************
      DO 1 I=1,365
      C=I
      A=730.-.274*LAT+.00793*(LAT**2)
      B=34.2-.78*LAT+.1*(LAT**2)
      Z=2.*3.1416*((C+285.)/365.)
      DAYMIN(I)=A+B*SIN(Z)
      TOTMIN=DAYMIN(I)+TOTMIN
    1 CONTINUE
      DO 7 I=1,365
      DALITE(I)=DAYMIN(I)/TOTMIN
    7 CONTINUE
C***********************************************************************
C          COMPUTE ET BY BLANEY-CRIDDLE ESTIMATE
C                 INPUT DATA IS IN INCHES AND DEG F
C                OUTPUT DATA CONVERTED TO CM AND DEG C
C*********************************************************************
      READ(5,200)(RAIN(I),I=1,IDAY)
      READ(5,200)(TEMP(I),I=1,IDAY)
      READ(5,200)(TRAIN(I),I=1,IDAY)
      READ (5,200) (SALTFX(I),I=1,IDAY)
      DO 20 I=1,IDAY
      CTEMP(I)=(5./9.)*(TEMP(I)-32.)
      J=JDAY+(I-1)
      IF (RAIN(I).GT.0.)  GO TO 10
      IF (TEMP(I).LT.32.) GO TO 5
      IF (TEMP(I) .LT. 40.) GO TO 8
      IF (TEMP(I) .LT. 50.) GO TO 9
      ET(I)=-(DALITE(J)*TEMP(I)*FACTOR)
      EVAP(I)=ET(I)*(1.0-COVER)
      ET(I)=(ET(I)*2.54)/24.
      EVAP(I)=(EVAP(I)*2.54)/24.
      GO TO 20
    5 ET(I)=0.
      EVAP(I)=0.
      GO TO 20
    8 ET(I)=(-(DALITE(J)*TEMP(I))*.10)*2.54/24.
      EVAP(I)=ET(I)*(1.0-COVER)*2.54/24.
      GO TO 20
    9 ET(I)=(-(DALITE(J)*TEMP(I))*.20)*2.54/24.
      EVAP(I)=ET(I)*(1.0-COVER)*2.54/24.
      GO TO 20
   10 ET(I)=0.
      EVAP(I)=RAIN(I)*2.54/TRAIN(I)
   20 CONTINUE
      SUM=24.
      IF (TRAIN(1) .GT.0.) GO TO 4
      ATIME(1)=SUM
      GO TO 2
    4 ATIME(1)=TRAIN(1)
    2 SUM=SUM+24.
      DO 3 I=2,IDAY
      J=I-1
      IF (TRAIN(I) .GT. 0.) GO TO 11
      ATIME(I)= SUM
      GO TO 3
   11 ATIME(I)=ATIME(J)+TRAIN(I)
    3 SUM=SUM+24.
C***********************************************************************
C        FORMING TET, V, SF, AND DEG ARRAYS
C***********************************************************************
      JX=IDAY*2
      BTIME=DTIME
      DO 14 K=1,JX,2
      D=K
      L=(D/2.)+.501
      M=(K+1)/2
      TET(K)=ET(L)
      TET(K+1)=ATIME(M)
      V(K)=EVAP(L)
      V(K+1)=ATIME(M)
      SF(K)=SALTFX(L)
      SF(K+1)=ATIME(M)
      DEG(K)=CTEMP(L)
      DEG(K+1)=BTIME
      BTIME=BTIME+DTIME
   14 CONTINUE
    6 FORMAT (F6.2,2I3,2F5.2)
   12 FORMAT (80A1)
   13 FORMAT (1H0,80A1)
  200 FORMAT(14F5.2)
      RETURN
      END
```

# APPENDIX 2

## SAMPLE OUTPUT

### Computed and Given Inputs

```
WATER     POTENTIAL   CONDUCTIVITY DIFFUSIVITY
.0000     -.9000+06    .9000-08    .2560-02
.1000-01  -.5000+06    .1000-07    .5760-02
.2000-01  -.2500+06    .1500-07    .1026-01
.3000-01  -.1200+06    .2000-07    .1226-01
.4000-01  -.9000+05    .2600-07    .1282-01
.5000-01  -.4000+05    .3800-07    .1434-01
.6000-01  -.3500+05    .5200-07    .1438-01
.7000-01  -.2800+05    .7000-07    .1510-01
.8000-01  -.2450+05    .9000-07    .1524-01
.9000-01  -.2150+05    .1200-06    .1567-01
.1000+00  -.2100+05    .1700-06    .1577-01
.1100+00  -.1900+05    .2300-06    .1621-01
.1200+00  -.1700+05    .3200-06    .1659-01
.1300+00  -.1500+05    .4400-06    .1725-01
.1400+00  -.1300+05    .5000-06    .1795-01
.1500+00  -.1100+05    .8100-06    .2119-01
.1600+00  -.9000+04    .1100-05    .2449-01
.1700+00  -.6000+04    .1500-05    .2839-01
.1800+00  -.4000+04    .2100-05    .3100-01
.1900+00  -.3000+04    .2900-05    .3428-01
.2000+00  -.2000+04    .3800-05    .3694-01
.2100+00  -.1700+04    .5400-05    .3964-01
.2200+00  -.1400+04    .7200-05    .4185-01
.2300+00  -.1100+04    .9900-05    .4493-01
.2400+00  -.1000+04    .1400-04    .4528-01
.2500+00  -.9000+03    .1900-04    .4820-01
.2600+00  -.8000+03    .2700-04    .5028-01
.2700+00  -.7500+03    .3500-04    .5273-01
.2800+00  -.7000+03    .4200-04    .5513-01
.2900+00  -.6100+03    .6500-04    .6034-01
.3000+00  -.5500+03    .9000-04    .6303-01
.3100+00  -.5000+03    .1200-03    .7328-01
.3200+00  -.4700+03    .1700-03    .7838-01
.3300+00  -.4100+03    .2300-03    .9218-01
.3400+00  -.3800+03    .3200-03    .1018+00
.3500+00  -.3700+03    .4400-03    .1238+00
.3600+00  -.3000+03    .5900-03    .1412+00
.3700+00  -.2900+03    .7000-03    .1482+00
.3800+00  -.2500+03    .9000-03    .1826+00
.3900+00  -.2300+03    .1000-02    .2126+00
.4000+00  -.2100+03    .1200-02    .2246+00
.4100+00  -.1900+03    .1500-02    .2546+00
.4200+00  -.1900+03    .1800-02    .2726+00
.4300+00  -.1700+03    .2200-02    .3026+00
.4400+00  -.1100+03    .2600-02    .4346+00
.4500+00  -.9000+02    .3200-02    .4986+00
.4600+00  -.8000+02    .3800-02    .5366+00
.4700+00  -.6000+02    .4600-02    .6286+00
.4800+00  -.4000+02    .5600-02    .7406+00
.4900+00  -.2000+02    .6600-02    .8726+00
.5000+00  -.1000+02    .8000-02    .9526+00
.5100+00  -.1000+01    .9800-02    .1041+01
.5200+00   .0000       .1200-01    .1053+01
.5300+00   .1000+10    .1200-01    .1200+08

   C(I)      DEPTH      W-DEPTH     H-DEPTH     ROF-DEPTH   SE-DEPTH
.2273-07    .0000      .1200-01   -.4400+00    .0000       .9000+00
.2857-05    .7000+01   .6000-01   -.7000+05    .3340+00    .5027+02
.5000-05    .1500+02   .1030+00   -.2040+05    .3000+00    .3029+02
.1000-04    .2000+02   .1730+00   -.4700+04    .2720+00    .7304+02
.9091-05    .4000+02   .1900+00   -.2900+04    .3400-01    .4064+03
.3333-05    .7000+02   .1530+00   -.1010+05    .0000       .6308+03
.3333-05    .9000+02   .1510+00   -.1070+05    .0000       .9788+03
.3333-05    .1080+03   .1630+00   -.7100+04    .0000       .8109+03
.3333-05    .1350+03   .1500+00   -.1100+05    .0000       .9565+03
.2500-05    .1600+03   .1400+00   -.1500+05    .0000       .1189+04
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### 28-Day Output

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DAY   JULDAY     TIME END    SOIL FLUX   ET FLUX    SALT CONC.  AVE DAILY TEMP
 1     228       .2400+02   -.1956-01   -.2608-01   .9000+00        26.7
 2     229       .4800+02   -.1659-01   -.2210-01   .0000           20.0
 3     230       .7200+02   -.1677-01   -.2236-01   .0000           20.6
 4     231       .9600+02   -.1744-01   -.2326-01   .0000           22.2
 5     232       .1200+03   -.1797-01   -.2396-01   .0000           23.6
 6     233       .1440+03   -.1637-01   -.2182-01   .0000           20.0
 7     234       .1680+03   -.1535-01   -.2047-01   .0000           17.8
 8     235       .1920+03   -.1514-01   -.2018-01   .0000           17.4
 9     236       .2160+03   -.1621-01   -.2161-01   .0000           20.0
10     237       .2400+03   -.1686-01   -.2248-01   .0000           21.7
11     238       .2412+03    .2642+00    .0000      .0000           21.1
12     239       .2457+03    .5644-01    .0000      .0000           18.7
13     240       .3120+03   -.1481-01   -.1974-01   .0000           17.2
14     241       .3360+03   -.1546-01   -.2061-01   .0000           18.9
15     242       .3600+03   -.1470-01   -.1960-01   .0000           17.2
16     243       .3625+03    .3556+00    .0000      .0000           14.4
17     244       .4080+03   -.2427-03   -.3058-02   .0000            9.4
18     245       .4320+03   -.1154-01   -.1539-01   .0000           10.0
19     246       .4560+03   -.1265-01   -.1686-01   .0000           12.8
20     247       .4800+03   -.1420-01   -.1894-01   .0000           16.7
21     248       .4825+03    .9144-01    .0000      .0000           12.8
22     249       .5280+03   -.1205-01   -.1606-01   .0000           11.7
23     250       .5520+03   -.1313-01   -.1751-01   .0000           14.4
24     251       .5760+03   -.1421-01   -.1895-01   .0000           17.7
25     252       .6000+03   -.1505-01   -.2007-01   .0000           19.4
26     253       .6240+03   -.1388-01   -.1850-01   .0000           16.7
27     254       .6480+03   -.1516-01   -.2021-01   .0000           20.0
28     255       .6720+03   -.1310-01   -.1747-01   .0000           15.0

DEPTH     TEMP AT START        SOIL HEAT CONDUCTIVITIES      SOIL HEAT CAPACITY
                                 (CAL/CM-HR-DEG C)               (CAL/GM)
   .0       20.00                    3.6000                       .3000
  3.0       24.00                    3.6000                       .3000
 15.0       24.20                    3.6000                       .3000
 28.0       23.00                    3.6000                       .3000
 40.0       21.70                    3.6000                       .3000
 70.0       19.90                    3.6000                       .3000
 90.0       19.40                    3.6000                       .3000
108.0       19.30                    3.6000                       .3000
135.0       19.20                    3.6000                       .3000
160.0       19.00                     .0000                       .3000
DFLX       DETT        GRAVY       CONQ        DFLW        TIME
 .7600+01  .2400-02   .7600+01   .5000-01    .1000-01   .0000
 TT         CUMT        TAA         HLOW        HHT         PRES
 .1000+01  .6720+03   .1000+01  -.2000+05    .0000       .1050+01
 HDRY       HWET        WATL        WATH        CB
-.5000+06  .0000      .1000-01   .5200+00    .1000+01
 ALAMBA     SOURCE       DIFO        DIFA        DIFB        FOCON
 .1000+00   .0000        .1000-01    .1000-02    .1000+01    .1000+00

DEPTH        WATER       POTENTIAL   ROOT EXT.     SALT CONC    AMT SALT    TEMP.
   .0        .0100      -.5000+06    .0000             .90         .01      26.7
  3.0        .0509      -.3908+05    .0000           51.12        2.60      26.1
 15.0        .1044      -.2012+05    .0000           30.40        3.17      24.6
 28.0        .1603      -.7895+04   -.4027-03        73.92       11.95      23.3
 40.0        .1985      -.3060+04   -.1702-04       406.36       76.52      22.1
 70.0        .1533      -.9996+04    .0000          630.76       96.73      20.2
 90.0        .1517      -.1060+05    .0000          878.81      133.99      19.6
108.0        .1620      -.7227+04    .0000          810.95      131.84      19.4
135.0        .1507      -.1095+05    .0000          956.45      143.62      19.3
160.0        .1502      -.1093+05    .0000         1188.57      178.57      19.1
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT         CWF         CUMS
 1    .2400+02   -.1599+00    .0000        -.2000+05   -.2797+00   -.7093-01

DEPTH        WATER       POTENTIAL   ROOT EXT.     SALT CONC    AMT SALT    TEMP.
   .0        .0100      -.5000+06    .0000             .00         .00      20.0
  3.0        .0429      -.6836+05    .0000           57.04        2.43      20.9
 15.0        .1051      -.1997+05    .0000           30.47        3.20      22.2
 28.0        .1577      -.1001+05   -.2641-03        74.90       11.47      22.3
 40.0        .1867      -.3259+04   -.1631-04       406.27       75.87      21.9
 70.0        .1537      -.9899+04    .0000          630.73       95.93      20.4
 90.0        .1516      -.1051+05    .0000          878.79      133.90      19.8
108.0        .1627      -.7347+04    .0000          810.95      131.52      19.5
135.0        .1503      -.1091+05    .0000          956.44      143.76      19.3
160.0        .1504      -.1099+05    .0000         1188.57      178.74      19.2
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT         CWF         CUMS
 2    .4800+02   -.2620+00    .0000        -.2000+05   -.3977+00   -.1352+00

DEPTH        WATER       POTENTIAL   ROOT EXT.     SALT CONC    AMT SALT    TEMP.
   .0        .0100      -.5000+06    .0000             .00         .00      20.6
  3.0        .0302      -.8757+05    .0000           57.98        1.92      20.7
 15.0        .1054      -.1991+05    .0000           30.52        3.22      21.4
 28.0        .1490      -.1141+05   -.1938-03        75.71       11.28      21.5
 40.0        .1849      -.3460+04   -.1759-04       406.14       75.10      21.5
 70.0        .1540      -.9807+04    .0000          630.69       97.11      20.5
 90.0        .1519      -.1042+05    .0000          878.77      133.52      20.0
108.0        .1619      -.7459+04    .0000          810.95      131.21      19.6
135.0        .1504      -.1087+05    .0000          956.47      143.90      19.4
160.0        .1505      -.1084+05    .0000         1188.57      178.91      19.3
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT         CWF         CUMS
 3    .7200+02   -.3365+00    .0000        -.2000+05   -.5284+00   -.1919+00

DEPTH        WATER       POTENTIAL   ROOT EXT.     SALT CONC    AMT SALT    TEMP.
   .0        .0100      -.5000+06    .0000             .00         .00      22.2
  3.0        .0301      -.9087+05    .0000           54.04        1.62      22.0
 15.0        .1055      -.1990+05    .0000           30.58        3.23      21.7
 28.0        .1463      -.1247+05   -.1443-03        76.59       11.20      21.6
 40.0        .1831      -.3661+04   -.1191-04       406.01       74.33      21.4
 70.0        .1543      -.9723+04    .0000          630.65       97.29      20.6
 90.0        .1522      -.1033+05    .0000          878.75      133.76      20.1
108.0        .1615      -.7564+04    .0000          810.95      130.93      19.8
135.0        .1506      -.1083+05    .0000          956.42      144.01      19.5
160.0        .1507      -.1080+05    .0000         1188.57      179.07      19.4
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT         CWF         CUMS
 4    .9600+02   -.3921+00    .0000        -.2000+05   -.6773+00   -.2457+00

DEPTH        WATER       POTENTIAL   ROOT EXT.     SALT CONC    AMT SALT    TEMP.
   .0        .0100      -.5000+06    .0000             .00         .00      23.6
  3.0        .0249      -.1510+06    .0000           55.17        1.37      23.2
 15.0        .1053      -.1993+05    .0000           30.67        3.23      22.4
 28.0        .1446      -.1314+05   -.1160-03        77.40       11.20      21.8
 40.0        .1813      -.3955+04   -.1032-04       405.86       77.59      21.4
 70.0        .1545      -.9645+04    .0000          630.63       97.44      20.6
 90.0        .1525      -.1026+05    .0000          878.73      133.99      20.2
108.0        .1611      -.7662+04    .0000          810.95      130.66      19.9
135.0        .1507      -.1079+05    .0000          956.42      144.13      19.6
160.0        .1508      -.1076+05    .0000         1188.57      179.22      19.5
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT         CWF         CUMS
 5    .1200+03   -.4359+00    .0000        -.2000+05   -.7286+00   -.2927+00

DEPTH        WATER       POTENTIAL   ROOT EXT.     SALT CONC    AMT SALT    TEMP.
   .0        .0100      -.5000+06    .0000             .00         .00      20.0
  3.0        .0209      -.1908+06    .0000           56.26        1.18      20.4
 15.0        .1050      -.2000+05    .0000           30.68        3.22      21.2
 28.0        .1435      -.1358+05   -.9819-04        78.23       11.23      21.3
 40.0        .1796      -.4038+04   -.8882-05       405.70       77.87      21.3
 70.0        .1548      -.9573+04    .0000          630.61       97.59      20.6
 90.0        .1527      -.1019+05    .0000          878.71      134.20      20.2
108.0        .1609      -.7755+04    .0000          810.95      130.41      19.9
135.0        .1509      -.1075+05    .0000          956.41      144.25      19.7
160.0        .1509      -.1073+05    .0000         1188.57      179.36      19.6
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT         CWF         CUMS
 6    .1440+03   -.4723+00    .0000        -.2000+05   -.8054+00   -.3330+00

DEPTH        WATER       POTENTIAL   ROOT EXT.     SALT CONC    AMT SALT    TEMP.
   .0        .0100      -.5000+06    .0000             .00         .00      17.8
  3.0        .0181      -.2563+06    .0000           57.24        1.04      18.7
 15.0        .1045      -.2011+05    .0000           30.72        3.21      19.8
 28.0        .1428      -.1388+05   -.8700-04        79.03       11.29      20.5
 40.0        .1780      -.4201+04   -.7753-05       405.54       72.18      20.8
 70.0        .1550      -.9505+04    .0000          630.58       97.73      20.6
 90.0        .1529      -.1012+05    .0000          878.69      134.40      20.3
108.0        .1605      -.7841+04    .0000          810.95      130.19      20.0
135.0        .1509      -.1072+05    .0000          956.40      144.36      19.8
160.0        .1510      -.1069+05    .0000         1188.57      179.50      19.7
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT         CWF         CUMS
 7    .1680+03   -.5040+00    .0000        -.2000+05   -.8762+00   -.3667+00

DEPTH        WATER       POTENTIAL   ROOT EXT.     SALT CONC    AMT SALT    TEMP.
   .0        .0100      -.5000+06    .0000             .00         .00      17.4
  3.0        .0165      -.3039+06    .0000           57.98         .96      17.7
 15.0        .1038      -.2025+05    .0000           30.77        3.19      19.0
 28.0        .1423      -.1409+05   -.7901-04        79.81       11.36      19.9
 40.0        .1764      -.4359+04   -.6677-05       405.38       71.51      20.3
 70.0        .1552      -.9442+04    .0000          630.56       97.86      20.4
 90.0        .1532      -.1005+05    .0000          878.68      134.58      20.2
108.0        .1603      -.7922+04    .0000          810.94      129.96      20.1
135.0        .1510      -.1069+05    .0000          956.40      144.47      19.9
160.0        .1511      -.1066+05    .0000         1188.57      179.67      19.9
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT         CWF         CUMS
 8    .1920+03   -.5323+00    .0000        -.2000+05   -.9244+00   -.3921+00

DEPTH        WATER       POTENTIAL   ROOT EXT.     SALT CONC    AMT SALT    TEMP.
   .0        .0100      -.5000+06    .0000             .00         .00      20.0
  3.0        .0156      -.3307+06    .0000           58.53         .92      19.8
 15.0        .1030      -.2041+05    .0000           30.82        3.17      19.7
 28.0        .1419      -.1424+05   -.7306-04        80.57       11.43      19.9
 40.0        .1749      -.4511+04   -.5655-05       405.21       70.87      20.1
 70.0        .1554      -.9382+04    .0000          630.53       97.98      20.3
 90.0        .1534      -.9990+04    .0000          878.66      134.76      20.2
108.0        .1600      -.7998+04    .0000          810.94      129.76      20.1
135.0        .1511      -.1065+05    .0000          956.39      144.56      19.9
160.0        .1512      -.1063+05    .0000         1188.57      179.75      19.9
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT         CWF         CUMS
 9    .2160+03   -.5581+00    .0000        -.2000+05   -.9718+00   -.4137+00
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DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .0100    -.5000+06    .0000          .00        .00     21.7
  3.0     .0151    -.3450+05    .0000        53.07        .99     21.4
 15.0     .1021    -.2059+05    .0000        30.88       3.15     20.6
 28.0     .1410    -.1434+05   -.6845-04     81.31      11.52     20.3
 40.0     .1774    -.4659+04   -.4629-05    405.05      70.24     20.2
 70.0     .1555    -.9326+04    .0000       630.51      98.10     20.2
 90.0     .1535    -.9933+04    .0000       878.65     134.92     20.2
108.0     .1599    -.8069+04    .0000       810.94     129.55     20.1
135.0     .1517    -.1063+05    .0000       956.39     144.65     20.0
160.0     .1517    -.1060+05    .0000      1188.57     179.87     19.9
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 10   .2400+03   -.5813+00     .0000      -.2000+05   -.1015+01   -.4370+00

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .5200     .0000       .0000          .00        .00     21.1
  3.0     .0498    -.4415+05    .0000        53.01       2.64     21.1
 15.0     .1021    -.2057+05    .0000        30.89       3.15     20.7
 28.0     .1417    -.1431+05    .0000        81.34      11.53     20.5
 40.0     .1734    -.4665+04    .0000       405.04      70.21     20.3
 70.0     .1550    -.9323+04    .0000       630.51      98.10     20.2
 90.0     .1530    -.9930+04    .0000       878.65     134.93     20.2
108.0     .1598    -.8073+04    .0000       810.94     129.55     20.1
135.0     .1517    -.1062+05    .0000       956.39     144.66     20.0
160.0     .1513    -.1060+05    .0000      1188.57     179.87     20.0
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 11   .2412+03   -.5819+00    .7047-01    -.2000+05   -.7550+00   -.1732+00

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .5200     .0000       .0000          .00        .00     19.3
  3.0     .0974    -.2335+05    .0000        50.51       4.71     18.7
 15.0     .1022    -.2056+05    .0000        30.88       3.16     19.7
 28.0     .1420    -.1471+05    .0000        81.46      11.56     20.1
 40.0     .1731    -.4689+04    .0000       405.00      70.11     20.2
 70.0     .1556    -.9313+04    .0000       630.51      98.12     20.2
 90.0     .1536    -.9920+04    .0000       878.64     134.96     20.2
108.0     .1597    -.8086+04    .0000       810.94     129.52     20.1
135.0     .1517    -.1062+05    .0000       956.39     144.67     20.0
160.0     .1514    -.1059+05    .0000      1188.57     179.93     20.0
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 12   .2457+03 —-.5818+00     .7263-01    -.2000+05   -.5037+00    .7862-01

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .0100    -.5000+06    .0000          .00        .00     17.2
  3.0     .0555    -.3355+05    .0000        52.55       2.97     17.6
 15.0     .1029    -.2042+05    .0000        30.97       3.19     18.8
 28.0     .1413    -.1447+05   -.6061-04     83.39      11.79     19.5
 40.0     .1694    -.5173+04   -.1506-05    404.53      68.54     19.9
 70.0     .1561    -.9177+04    .0000       630.45      98.40     20.1
 90.0     .1541    -.9778+04    .0000       878.61     135.37     20.1
108.0     .1591    -.8262+04    .0000       810.94     129.04     20.1
135.0     .1515    -.1054+05    .0000       956.37     144.91     20.1
160.0     .1516    -.1052+05    .0000      1188.57     180.19     20.0
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 13   .3120+03   -.6405+00    .7263-01    -.2000+05   -.7685+00   -.1280+00

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .0100    -.5000+06    .0000          .00        .00     18.9
  3.0     .0477    -.4938+05    .0000        53.47       2.55     18.8
 15.0     .1030    -.2040+05    .0000        31.00       3.19     19.0
 28.0     .1412    -.1454+05   -.5764-04     84.05      11.86     19.4
 40.0     .1693    -.5525+04    .0000       404.35      68.03     19.7
 70.0     .1562    -.9137+04    .0000       630.43      98.48     20.0
 90.0     .1542    -.9732+04    .0000       878.60     135.50     20.1
108.0     .1589    -.8320+04    .0000       810.94     128.99     20.1
135.0     .1516    -.1052+05    .0000       956.37     144.99     20.1
160.0     .1517    -.1049+05    .0000      1188.57     180.29     20.1
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 14   .3360+03   -.6585+00    .7263-01    -.2000+05   -.8555+00   -.1970+00

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .0100    -.5000+06    .0000          .00        .00     17.2
  3.0     .0402    -.7913+05    .0000        54.47       2.19     17.5
 15.0     .1029    -.2041+05    .0000        31.04       3.19     18.4
 28.0     .1410    -.1460+05   -.5471-04     84.67      11.94     19.1
 40.0     .1672    -.5854+04    .0000       404.18      67.56     19.4
 70.0     .1563    -.9101+04    .0000       630.42      98.55     19.9
 90.0     .1544    -.9688+04    .0000       878.58     135.63     20.0
108.0     .1588    -.8374+04    .0000       810.94     128.74     20.1
135.0     .1517    -.1049+05    .0000       956.37     145.07     20.1
160.0     .1519    -.1047+05    .0000      1188.57     180.39     20.1
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 15   .3600+03   -.6753+00    .7263-01    -.2000+05   -.9332+00   -.2580+00

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .5200     .0000       .0000          .00        .00     14.4
  3.0     .1352    -.1522+05    .0000        48.76       6.59     15.1
 15.0     .1030    -.2040+05    .0000        31.04       3.20     17.0
 28.0     .1411    -.1455+05    .0000        84.77      11.96     18.2
 40.0     .1670    -.5887+04    .0000       404.16      67.51     19.0
 70.0     .1563    -.9098+04    .0000       630.41      98.56     19.7
 90.0     .1544    -.9684+04    .0000       878.58     135.64     19.9
108.0     .1587    -.8380+04    .0000       810.94     128.72     20.0
135.0     .1517    -.1049+05    .0000       956.37     145.08     20.1
160.0     .1518    -.1047+05    .0000      1188.57     180.40     20.1
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 16   .3625+03   -.6753+00    .2491+00    -.2000+05   -.2207+00    .4545+00

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .1200    -.1751+05    .0000          .00        .00      9.4
  3.0     .1311    -.1589+05   -.3633-04     48.89       6.41     10.7
 15.0     .1041    -.2017+05    .0000        31.10       3.24     14.3
 28.0     .1408    -.1469+05   -.5006-04     85.83      12.08     16.7
 40.0     .1651    -.6457+04    .0000       403.86      66.70     18.0
 70.0     .1565    -.9044+04    .0000       630.39      98.67     19.4
 90.0     .1546    -.9608+04    .0000       878.56     135.86     19.8
108.0     .1584    -.8475+04    .0000       810.94     128.47     19.9
135.0     .1518    -.1045+05    .0000       956.36     145.22     20.0
160.0     .1519    -.1042+05    .0000      1188.57     180.58     20.0
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 17   .4080+03   -.7190+00    .2491+00    -.2000+05   -.2755+00    .4435+00

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .0100    -.5000+06    .0000          .00        .00     10.0
  3.0     .1183    -.1776+05   -.7982-05     49.38       5.84     10.7
 15.0     .1046    -.2008+05    .0000        31.13       3.26     13.3
 28.0     .1406    -.1475+05   -.4743-04     86.77      12.15     15.5
 40.0     .1642    -.6734+04    .0000       403.71      66.30     17.1
 70.0     .1566    -.9022+04    .0000       630.38      98.71     19.0
 90.0     .1549    -.9571+04    .0000       878.55     135.97     19.5
108.0     .1583    -.8522+04    .0000       810.94     128.34     19.9
135.0     .1519    -.1042+05    .0000       956.35     145.29     20.0
160.0     .1520    -.1040+05    .0000      1188.57     180.65     20.0
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 18   .4320+03   -.7374+00    .2491+00    -.2000+05   -.3840+00    .3574+00

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .0100    -.5000+06    .0000          .00        .00     12.8
  3.0     .1069    -.1962+05    .0000        49.98       5.33     12.9
 15.0     .1050    -.2000+05    .0000        31.15       3.27     13.9
 28.0     .1405    -.1480+05   -.4500-04     86.89      12.21     15.4
 40.0     .1633    -.6996+04    .0000       403.57      65.97     16.5
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 70.0     .1567    -.9001+04    .0000       630.37      98.75     18.8
 90.0     .1549    -.9527+04    .0000       878.55     136.07     19.3
108.0     .1581    -.8566+04    .0000       810.94     128.22     19.7
135.0     .1520    -.1040+05    .0000       956.35     145.36     19.9
160.0     .1521    -.1039+05    .0000      1188.57     180.75     19.9
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 19   .4560+03   -.7514+00    .2491+00    -.2000+05   -.4805+00    .2688+00

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .0100    -.5000+06    .0000          .00        .00     15.7
  3.0     .0962    -.2119+05    .0000        50.47       4.85     16.3
 15.0     .1057    -.1395+05    .0000        31.19       3.28     15.7
 28.0     .1404    -.1486+05   -.4273-04     87.78      12.27     16.0
 40.0     .1625    -.7244+04    .0000       403.47      65.57     16.7
 70.0     .1567    -.8989+04    .0000       630.36      98.76     18.4
 90.0     .1550    -.9504+04    .0000       878.54     136.10     19.1
108.0     .1580    -.8607+04    .0000       810.94     128.11     19.5
135.0     .1521    -.1039+05    .0000       956.35     145.42     19.9
160.0     .1521    -.1036+05    .0000      1188.57     180.83     19.9
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 20   .4800+03   -.7645+00    .2491+00    -.2000+05   -.5764+00    .1881+00

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .5200     .0000       .0000          .00        .00     12.9
  3.0     .1230    -.1691+05    .0000        49.19       5.10     13.4
 15.0     .1053    -.1994+05    .0000        31.18       3.28     14.7
 28.0     .1405    -.1482+05    .0000        87.47      12.28     15.7
 40.0     .1624    -.7269+04    .0000       403.42      65.53     16.5
 70.0     .1567    -.8987+04    .0000       630.36      98.78     18.2
 90.0     .1550    -.9501+04    .0000       878.54     136.17     18.9
108.0     .1590    -.8612+04    .0000       810.94     128.10     19.4
135.0     .1521    -.1038+05    .0000       956.75     145.43     19.7
160.0     .1521    -.1036+05    .0000      1188.57     180.94     19.8
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 21   .4825+03   -.7645+00    .2694+00    -.2000+05   -.3682+00    .3057+00

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .0100    -.5000+06    .0000          .00        .00     11.7
  3.0     .1021    -.2059+05    .0000        50.16       5.12     12.2
 15.0     .1050    -.1380+05    .0000        31.27       3.31     13.9
 28.0     .1402    -.1492+05   -.3917-04     88.70      12.38     15.2
 40.0     .1610    -.7698+04    .0000       403.19      64.91     16.2
 70.0     .1568    -.8969+04    .0000       630.34      98.82     18.0
 90.0     .1552    -.9445+04    .0000       878.52     136.73     18.7
108.0     .1577    -.8684+04    .0000       810.93     127.90     19.2
135.0     .1522    -.1034+05    .0000       956.34     145.54     19.5
160.0     .1523    -.1032+05    .0000      1188.57     180.99     19.6
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 22   .5280+03   -.7891+00    .2694+00    -.2000+05   -.5545+00    .2346+00

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .0100    -.5000+06    .0000          .00        .00     14.4
  3.0     .0915    -.2143+05    .0000        50.71       4.64     14.2
 15.0     .1062    -.1976+05    .0000        31.25       3.32     14.6
 28.0     .1401    -.1497+05   -.3717-04     89.74      12.43     15.4
 40.0     .1603    -.7908+04    .0000       403.06      64.61     16.1
 70.0     .1569    -.8963+04    .0000       630.33      98.83     17.8
 90.0     .1553    -.9419+04    .0000       878.52     136.41     18.5
108.0     .1576    -.8725+04    .0000       810.93     127.80     19.0
135.0     .1523    -.1032+05    .0000       956.34     145.60     19.4
160.0     .1523    -.1030+05    .0000      1188.57     181.05     19.5
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 23   .5520+03   -.8006+00    .2694+00    -.2000+05   -.6457+00    .1548+00

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .0100    -.5000+06    .0000          .00        .00     17.2
  3.0     .0812    -.2370+05    .0000        51.33       4.17     16.8
 15.0     .1064    -.1972+05    .0000        31.28       3.33     16.1
 28.0     .1400    -.1500+05   -.3568-04     89.16      12.48     16.0
 40.0     .1596    -.8106+04    .0000       402.94      64.33     16.4
 70.0     .1568    -.8960+04    .0000       630.33      98.84     17.7
 90.0     .1554    -.9394+04    .0000       878.51     136.48     18.4
108.0     .1575    -.8753+04    .0000       810.93     127.71     18.9
135.0     .1523    -.1031+05    .0000       956.33     145.66     19.2
160.0     .1524    -.1028+05    .0000      1188.57     181.13     19.4
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 24   .5760+03   -.8114+00    .2694+00    -.2000+05   -.7749+00    .7652-01

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .0100    -.5000+06    .0000          .00        .00     19.4
  3.0     .0713    -.2618+05    .0000        52.01       3.71     18.9
 15.0     .1066    -.1969+05    .0000        31.30       3.34     17.6
 28.0     .1398    -.1502+05   -.3495-04     89.56      12.53     17.0
 40.0     .1590    -.8296+04    .0000       402.87      64.06     16.9
 70.0     .1568    -.8959+04    .0000       630.32      98.84     17.7
 90.0     .1554    -.9371+04    .0000       878.50     136.55     18.3
108.0     .1574    -.8785+04    .0000       810.93     127.63     18.7
135.0     .1524    -.1029+05    .0000       956.37     145.72     19.1
160.0     .1525    -.1026+05    .0000      1188.57     181.20     19.2
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 25   .6000+03   -.8220+00    .2694+00    -.2000+05   -.8214+00    .5713-01

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .0100    -.5000+06    .0000          .00        .00     16.7
  3.0     .0617    -.2941+05    .0000        52.78       3.26     16.9
 15.0     .1067    -.1967+05    .0000        31.33       3.34     17.1
 28.0     .1397    -.1503+05   -.3421-04     89.95      12.57     17.1
 40.0     .1584    -.8478+04    .0000       402.72      63.79     17.1
 70.0     .1568    -.8959+04    .0000       630.32      98.84     17.7
 90.0     .1555    -.9350+04    .0000       878.50     136.61     18.2
108.0     .1573    -.8815+04    .0000       810.93     127.54     18.6
135.0     .1524    -.1027+05    .0000       956.33     145.77     18.9
160.0     .1525    -.1025+05    .0000      1188.57     181.27     19.1
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 26   .6240+03   -.8324+00    .2694+00    -.2000+05   -.9058+00   -.7348-01

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .0100    -.5000+06    .0000          .00        .00     20.0
  3.0     .0525    -.3746+05    .0000        53.66       2.82     19.5
 15.0     .1067    -.1966+05    .0000        31.36       3.35     18.3
 28.0     .1396    -.1504+05   -.3345-04     90.33      12.61     17.7
 40.0     .1578    -.8652+04    .0000       402.62      63.54     17.5
 70.0     .1568    -.8961+04    .0000       630.32      98.83     17.8
 90.0     .1556    -.9330+04    .0000       878.49     136.66     18.2
108.0     .1572    -.8844+04    .0000       810.93     127.47     18.5
135.0     .1525    -.1026+05    .0000       956.33     145.82     18.8
160.0     .1526    -.1023+05    .0000      1188.57     181.33     19.0
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 27   .6480+03   -.8425+00    .2694+00    -.2000+05   -.9875+00   -.1450+00

DEPTH     WATER    POTENTIAL   ROOT EXT.   SALT CONC   AMT SALT   TEMP.
   .0     .0100    -.5000+06    .0000          .00        .00     15.0
  3.0     .0443    -.6285+05    .0000        54.62       2.42     15.6
 15.0     .1067    -.1967+05    .0000        31.38       3.35     16.8
 28.0     .1394    -.1506+05   -.3269-04     90.70      12.65     17.3
 40.0     .1573    -.8820+04    .0000       402.52      63.30     17.5
 70.0     .1568    -.8965+04    .0000       630.32      98.82     17.9
 90.0     .1556    -.9312+04    .0000       878.49     136.72     18.2
108.0     .1571    -.8871+04    .0000       810.93     127.39     18.5
135.0     .1525    -.1024+05    .0000       956.32     145.87     18.7
160.0     .1526    -.1021+05    .0000      1188.57     181.40     18.8
DAY CUM. HOURS  CUM. TRANS.   CUM RUNOFF    HROOT        CWF         CUMS
 28   .6720+03   -.8524+00    .2694+00    -.2000+05   -.1063+01   -.2111+00
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**1973 PROGRESS REPORT**

# A NITROGEN SUBMODEL

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# INTRODUCTION

The nitrogen submodel deals with the nitrogen transformation in soil caused by microorganisms. In addition to those biological processes, it includes an option for ammonium volatilization because of its importance in desert conditions. As in the decomposition submodel (Parnas and Radford, 1974), all the biological transformations are proportional to the growth rate of the particular microbial population which is responsible for that process. The model includes most of the possible nitrogen transformations, even those which are very small in magnitude in desert conditions. The purpose is to keep the submodel as general as possible.

# PROCESSES INCLUDED IN THE NITROGEN SUBMODEL

In order to understand the way in which some of the processes are handled in this subroutine it is important to mention here that one of the assumptions in the nitrogen and the decomposition submodels is that all the constituents of a living microorganism are not available to plants or to any other source. Only through death does the microbial biomass become available.

## SYMBIOTIC FIXATION OF $N_2$

Symbiotic fixation causes enrichment of the symbiotic roots with some of the fixed nitrogen, and that of the symbiotic microflora with some of the root carbon. In the submodel the only way in which the soil organic matter will be enriched with the fixed nitrogen is by the death of the symbiotic microflora, which in this case is the same as death of the symbiotic roots. Thus, symbiotic microbes are considered part of the root tissue. Plants know how much carbon to allow roots in order to account for microbial growth because the microbial biomass value is continually calculated and communicated to the plant submodel (or at least back to the SOILS calling program).

## HETEROTROPHIC FIXATION OF $N_2$

Some heterotrophic types of bacteria fix $N_2$. Soil organic matter will be enriched by that fixed nitrogen only after the death of the fixers.

## AUTOTROPHIC FIXATION OF $N_2$

Autotrophic fixation of $N_2$ is accomplished mainly by the blue-green algae on the soil surface. The same rule as in symbiotic and heterotrophic fixations holds here also. Growth of autotrophs is actually calculated elsewhere (e.g., by a plant submodel), as is death. Nitrogen fixation itself depends on growth but is calculated here.

## $NH_4^+$ OXIDATION TO $NO_2^-$

The basic equations of this process are those of McLaren (1971). The process includes use of $NH_4^+$as a source of energy for maintenance and growth. In addition, some external oxidation of $NH_4^+$to $NO_2^-$occurs. This last process is not agreed upon by other authors. $NH_4^+$ oxidation to $NO_2^-$ is accomplished mainly by the *Nitrosomonas* population.

## $NO_2^-$ OXIDATION TO $NO_3^-$

The basic process is the same as above (only the source for energy is $NO_2^-$) and is based on the same work (McLaren, 1971). This process is accomplished mainly by the *Nitrobacter* population.

## DENITRIFICATION

In the submodel this process is accomplished by the same basic population which is responsible for decomposition (Parnas and Radford, 1974). Denitrification can happen in anaerobic conditions. It requires very high moisture or even flood in the upper horizons, which of course is not typical to arid conditions. Nevertheless, denitrification is included for purposes of generality of the submodel.

## $NH_3$ VOLATILIZATION

$NH_3$ volatilization occurs under warm and alkaline conditions. This may optionally be handled outside the nitrogen submodel.

# STRUCTURE OF THE SUBROUTINE

The processes mentioned are calculated by soil horizons only. For each process, the growth rate of the corresponding population in a given horizon is calculated. In addition to the growth rate, the death rate for each type of population is calculated. The substrate which limits growth is different for each type of population; so is the cause of death. Usually, if the source of energy for that specific population drops to zero, a higher rate of death will occur. When the source of energy is available, a smaller rate of death takes place. $NH_4^+$, $NO_2^-$and $NO_3^-$concentrations are calculated separately and used in a combined pool which is the total mineral nitrogen. This last pool is the source of mineral nitrogen for immobilization and for the $N_2$ fixers. Preference coefficients are given to the different constituents of the mineral nitrogen in order to determine the immobilization of a specific type of nitrogen.

The input to this subroutine requires initial concentrations of the various pools, the various microbial biomass concentrations, and maximal growth rate for each type of population. Again as in the decomposition submodel (Parnas and Radford, 1974), the product microbial biomass times maximal growth rate can be replaced by "potential activity" if biomass cannot be measured meaningfully.

### APPLICABILITY

The model can be applied to many ecosystems at various environmental conditions. The reason is its generality, as has been discussed in the decomposition submodel (Parnas and Radford, 1974).

## VERBAL AND GRAPHICAL DESCRIPTION OF PROCESSES

### SYSTEM DIAGRAM

The system modelled and some of the necessary connecting flows to related submodels are shown in Figure 1.

### VERBAL DESCRIPTION OF PROCESSES

#### Growth Rate of the Various Microbial Populations

The growth rate is a function of maximal growth rate of the specific population, environmental coefficients in the different horizons and of the growth-limiting nutrient. In most cases the growth-limiting nutrient will be the source of energy. In this way the growth-limiting factor for the *Nitrosomonas* will be the $NH_4^+$ concentration, and for *Nitrobacter* the $NO_2^-$ concentration. For the $N_2$ fixers, the growth-limiting factor will be the carbon source (in roots, in dead material) or the light intensity (for the autotrophic fixers). The function which describes the growth rate as a function of the limiting nutrient is that of Michaelis-Menton.

The environmental coefficients are calculated by use of trapezoidal functions as described in Figure 3 of the decomposition submodel (Parnas and Radford, 1974).

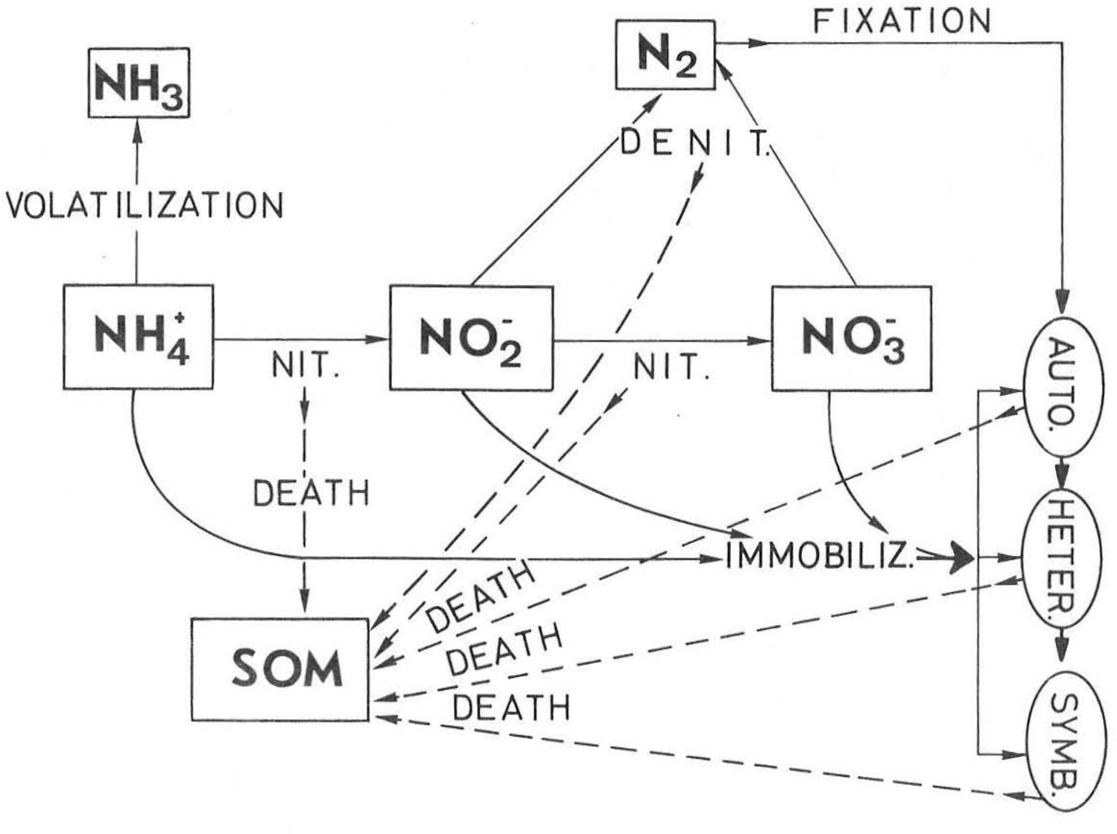

Figure 1. Decomposition submodel with connecting flows to related submodels.

### Death Rate of the Various Microbial Populations

Calculation of the death rate is, in principle, the same for all the populations, but the cause for death is different. For each population at each horizon, two values for death rate are given. One (the normal one) is the death rate when the specific energy source is available. This death happens along with growth at a constant rate. When a starvation conditions exists (the energy source is not available), growth stops and death proceeds at a higher rate than at normal conditions. Since the energy source is different for different types of populations, the cause for death will vary from population to population and it is calculated separately for each of them. For the autotrophic $N_2$ fixers where the source of energy is light, the death rate (calculated outside the nitrogen submodel) usually depends on the size of the fixer's biomass. The idea is that when the microbial biomass reaches a certain maximal value the light intensity **per cell** decreases because of the shadow effect. When the population is very dense the lower levels of the population will not accept any light at all; conditions which are similar to starvation.

### Symbiotic $N_2$ Fixation

The symbiotic $N_2$ fixation is dependent on the microbial biomass of the fixers, and on the host plant root carbon. This fixation is inhibited in a regular competitive way by inorganic nitrogen. The $N_2$ that is being fixed serves the microbial population and the symbiotic roots. The biomass of the symbiotic fixers and the symbiotic roots is considered essentially as one biomass for purposes of death. The two types of biomass are calculated separately for fixation rate calculations. By the death of the combined biomass (root death), they are attacked by the decomposers and so become part of the soil organic matter. Carbon dioxide evolution accompanies the growth of the symbiotic fixers. Symbiotic fixation can happen in all horizons. The amount of plant carbon allocated to symbiotic roots (calculated elsewhere, as is $CO_2$ evolution) depends upon symbiotic microbe biomass (calculated here). In the general process of symbiotic $N_2$ fixation, the following processes are included: (1) $N_2$ fixation, an increasing function of microbial biomass and of root carbon -- decreasing function of inorganic nitrogen concentration; (2) increase in fixers' biomass; (3) death of the fixers and root biomass -- this last process is responsible for the enrichment of soil organic matter by organic nitrogen.

### Heterotrophic $N_2$ Fixation

The growth-limiting substrate for the heterotrophic fixers is the soil organic carbon by horizon. The heterotrophic $N_2$ fixation is also inhibited by the available inorganic nitrogen. The growth rate of this population is determined by the usual components, that is, maximal growth rate, environmental coefficients by horizon, organic carbon concentration by horizon, and the microbial biomass by horizon. The death constant by horizon will be dependent on presence of soil organic carbon. By their death they are subject to decomposition and the soil organic matter is enriched in organic nitrogen (among other constituents). The enrichment of soil organic matter by organic nitrogen is proportional to the fraction of nitrogen in the microbial cells which is around 5-12% of the cell biomass.

### Autotrophic $N_2$ Fixation

It is assumed that the main autotrophic fixation is done by the blue-green algae on the soil surface. The growth rate of the autotrophic fixers depends on light intensity and the length of the day. In addition, their growth rate is dependent, as in the other cases, on environmental conditions and the concentration of their biomass. The actual growth of these surface autotrophs is calculated by a plant submodel or elsewhere. This nitrogen submodel receives the information about the amount of carbon fixation and autotroph growth and proceeds to calculate how much nitrogen assimilation occurs and, of this nitrogen, how much is inorganic soil nitrogen (as is determined for the nitrogen fixers in general). As in symbiotic and heterotrophic $N_2$ fixations, the enrichment of soil organic matter by the organic nitrogen of the free fixers occurs only by the death of the autotrophic population. Their fixation is also inhibited by the presence of inorganic nitrogen.

### Oxidation of $NH_4^+$ to $NO_2^-$

Oxidation of $NH_4^+$ to $NO_2^-$ can happen in all horizons. The source of energy for growth and maintenance of the corresponding population is $NH_4^+$; $NO_2^-$ is the oxidation product. The disappearance of $NH_4^+$ is proportional to three subprocesses: (1) Growth rate of the oxidizers, multiplied by (1/efficiency). The growth rate, as always, is proportional to the maximal growth rate, microbial biomass concentration and $NH_4^+$ concentration. The efficiency describes the amount of $NH_4^+$ assimilated divided by the amount of $NH_4^+$ used for growth. (2) Maintenance requirement--the specific maintenance energy is a constant independent of growth rate, per unit biomass. It has to be multiplied by the microbial biomass. Its units are time$^{-1}$. (3) In addition to the processes (1 and 2 above) which are connected with microbial growth, some external oxidation happens. This process is proportional to the external enzymes present which are due to that waste metabolism. The rate of the waste metabolism has also the general form of a Michaelis-Menton equation. It means it also has some maximal value and is dependent on $NH_4^+$ concentration. According to McLaren (1971), this is the major process in $NH_4^+$ oxidation, but not all the authors agree on this. In some cases a very good agreement to laboratory conditions could be shown without considering at all the waste metabolism.

The formation of $NO_2^-$ is of course proportional to the loss in $NH_4^+$. For keeping the right balance, the free $NO_2^-$ which is evolved should be calculated by taking into consideration the efficiency of this reaction. The efficiency, which is very low in this case ( ~6% ), gives the amount of $NH_4^+$ which is attached to the microbial cell. In this case, and not as in the fixation process, the $NO_2^-$ formation is a direct product of this transformation. In addition, the death of this population contributes to the soil organic matter.

### OXIDATION OF $NO_2^-$ TO $NO_3^-$

This process is completely analogous to oxidation of $NH_4^+$ to $NO_2^-$. The only difference is that the source of energy is $NO_2^-$ and the oxidation product is $NO_3^-$. This process is faster than the first oxidation; therefore, we don't expect any accumulation of $NO_2^-$, which is really the case in field conditions. The two processes have slightly different sensitivity to pH and temperature. Nitrification as a whole requires higher moisture level than does ammonification. It means that in dry conditions $NH_4^+$ could be accumulated. It is not accumulated because of volatilization.

### DENITRIFICATION

Denitrification can happen in more than one way. In any case the rate of denitrification will be a function of growth rate of the denitrifiers, which in turn will be an increasing function of nitrate, nitrite and organic carbon concentrations and a decreasing function of oxygen. pH and temperature will affect the denitrification in the usual way. The biomass which is responsible for denitrification is part of the decomposers' population. At anaerobic conditions they will use $NO_3^-$ as a competitive electron acceptor. The rate equation for denitrification includes competitive inhibition of $NO_3^-$ use by the presence of $O_2$. Oxygen amount is indicated by soil water potential here. In later models, actual $O_2$ concentration may be calculated and used. The death of denitrifiers, as that of the decomposers, is caused by carbon starvation in that horizon. In normal conditions the death rate will be lower than the starvation rate, and death and growth will happen simultaneously.

### $NH_3$ VOLATILIZATION

The rate of volatilization is an increasing function of $NH_4^+$ concentration, pH and temperature, and a decreasing function of soil plant cover. The dependency of the rate of volatilization upon pH and temperature is shown in Figure 2.

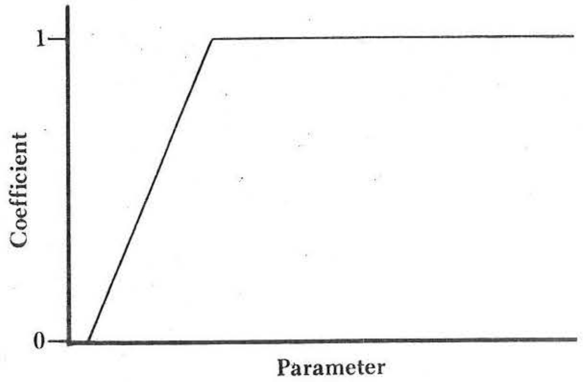

**Figure 2.** Coefficient of $NH_3$ volatilization as a function of environmental conditions.

## ASSUMPTIONS

1. The rate of any biological transformation is proportional to the growth rate of the population responsible for that transformation.
2. The growth rate is described by a Michaelis-Menton equation. It includes maximal growth rate, and is proportional to the concentration of the substrate which is growth-limiting.
3. The environmental coefficients affect the maximal growth rate.
4. The living microbial biomass is not available to the plants. It becomes available only after death and mineralization.
5. Death constants for each type of population can have one out of two values. The lower one is the normal rate constant which takes place while growth is happening. The second and higher one takes place when no source of energy is available.

# MATHEMATICAL DESCRIPTION

See the section on MAIN Calling Program in the 1973 Desert Biome Progress Report, Volume 1, for explanation of symbolism conventions.

## NITROGEN EXCHANGES WITH THE ATMOSPHERE ($\dot{X}_{01_{11}}$)

$$\dot{X}_{01_{11}} = \sum_h \Big[ \sum_{i \in F} (Z_{1ih} \cdot Z_{2ih}) \cdot P_{21} - \sum_{j \in N} Z_{3jh} - Z_{4h} \Big] - Z_S \tag{1}$$

where:

$\sum_h, \sum_{i \in f}, \sum_{j \in N}$ = Summations over all horizons $h$, over the set of nitrogen fixing biomasses or activities $i$, over the set of types of mineral $N_j$, respectively

$Z_{1ih}$ = Instantaneous growth rate of biomass/activity type $i$ in horizon $h$ as in (2)

$Z_{2ih}$ = Quantity of biomass or activity as in (4)

$Z_{3jh}$ = Uptake of mineral N type $j$ by N-fixing organisms as in (10)

$Z_{4h}$ = Denitrification as in (13)

$Z_5$ = Volatilization of $NH_3$ as in (8)

$P_{21}$ = Normal units of N of fixers per unit biomass

## INSTANTANEOUS GROWTH RATE OF NITROGEN TRANSFORMING ACTIVITY *i* ($Z_{1ih}$)

$$Z_{1ih} = Z_{6ih} \cdot (Z_{7ih}/(P_{1i} + Z_{7ih})) \qquad (2)$$

where:

$Z_{6ih}$ = Maximal growth rate adjusted to the physical environment in horizon $h$, as in (5)

$Z_{7ih}$ = Total host root carbon for symbionts, total soil dead material carbon for heterotrophs and denitrifiers, ammonium for ammonium oxidizers, nitrite for nitrite oxidizers

$P_{1i}$ = A Michaelis constant

## INSTANTANEOUS DEATH RATE OF NITROGEN TRANSFORMATION ACTIVITIES ($Z_{8ih}$)

$$\begin{aligned} Z_{8ih} &= P_{2i}, \text{ if } Z_{7ih} \leqslant 0 \\ &= P_{3i}, \text{ if } Z_{7ih} > 0 \end{aligned} \qquad (3)$$

where:

$Z_{7ih}$ = As in (2)

$P_{2i}, P_{3i}$ = Different death rates for the conditions imposed (concerning $Z_{7ih}$), for biomass/activity $i$

## BIOMASS/ACTIVITY ($Z_{2ih}$)

$$Z_{2ih,t} = Z_{2ih,t-1} \cdot \exp(Z_{1ih} - Z_{8ih}) \qquad (4)$$

where:

$t, t\text{-}1$ = The value of $Z_{2ih}$ is for the present ($t$) or preceding ($t$-1) simulation time unit

$Z_{1ih}$ = Growth rate for biomass/activity $i$ of horizon $h$ as in (2)

$Z_{8ih}$ = Death rate for biomass/activity $i$ of horizon $h$ as in (3)

## MAXIMAL GROWTH RATE ADJUSTED TO PHYSICAL ENVIRONMENT ($Z_{6ih}$)

$$Z_{6ih} = (P_{4i} \cdot Z_{9ih} \cdot Z_{10ih} \cdot Z_{11ih} \cdot Z_{12ih}) \cdot Z_{13ih} \qquad (5)$$

where:

$P_{4i}$ = Maximum instantaneous growth rate for biomass/activity type $i$, under ideal conditions

$Z_{9ih}$ = A temperature coefficient specific to horizon $h$ temperature and biomass/activity type $i$ -- calculated in OPT

$Z_{10ih}$ = A pH coefficient -- calculated in the OPT subroutine

$Z_{11ih}$ = A salinity coefficient -- see OPT

$Z_{12ih}$ = A moisture coefficient -- see OPT

$Z_{13ih}$ = As in (6)

## MULTIPLICATION FACTOR ($Z_{13ih}$)

$$\begin{aligned} Z_{13ih} &= 1, \text{ for } i \leqslant 4 \\ &= (X_{24h3} + X_{24h4}) \cdot P_5/((X_{24h3} + X_{24h4} + P_{1_5}) \\ &\qquad \cdot (P_5 + Z_{14h})), \text{ for } i=5 \end{aligned} \qquad (6)$$

where:

$X_{24h3}, X_{24h4}$ = Nitrite and nitrate, respectively

$P_5$ = An inhibition constant for the inhibition of the use of ($NO_2^- + NO_3^-$) as oxygen source, by oxygen present

$Z_{14h}$ = Soil water potential (negative bars), as calculated elsewhere and passed from SOILS

$P_{1_5}$ = A Michaelis constant

## CHANGES IN AMMONIUM ($\dot{X}_{24h2}$)

$$\begin{aligned} \dot{X}_{24h2} &= -Z_5 - Z_{15h} - Z_{31h}, \text{ for } h = 1 \\ &= -Z_{15h} - Z_{31h}, \text{ for } h > 1 \end{aligned} \qquad (7)$$

where:

$Z_5$ = Volatilization as in (8)

$Z_{15h}$ = Oxidation to $NO_2^-$ as in (9)

$Z_{31h}$ = Uptake by fixers as in (10)

### VOLATILIZATION OF AMMONIUM FROM HORIZON 1 ($Z_5$)

$$Z_5 = [Z_{16} \cdot Z_{17} \cdot Z_{18} \cdot P_6] \cdot X_{24_{12}} \qquad (8)$$

where:

$Z_{16}$ = A temperature coefficient as calculated by RAMP subroutine

$Z_{17}$ = A pH coefficient as calculated by RAMP

$Z_{18}$ = A soil cover coefficient as calculated by DCLIN subroutine

$P_6$ = Maximal rate of volatilization under optimal conditions, units per unit present per time

$X_{24_{12}}$ = Quantity of ammonium in horizon 1

### OXIDATION OF $NH_4^+$ TO $NO_2^-$ ($Z_{15_h}$)

$$Z_{15_h} = (P_7 \cdot Z_{1_{3h}} + P_8 + P_9 \cdot P_{10} \cdot X_{24_{h2}} / (X_{24_{h2}} + P_{11})) \cdot Z_{2_{3h}} \qquad (9)$$

where:

$P_7$ = 1/efficiency or $NH_4^+$ transformed to $NO_2^-$ divided by amount of that transformed that is assimilated by transformers

$Z_{1_{3h}}$ = The growth rate of biomass/activity type 3 in horizon $h$ as in (2)

$P_8$ = Units $NH_4^+$ required for transformer maintenance per unit transformer biomass per unit time

$P_9$ = A rate constant for waste metabolism connected to $NH_4^+$ oxidizers

$P_{10}$ = External enzyme concentration per unit $NH_4^+$ oxidizer biomass

$X_{24_{h2}}$ = Ammonium as in (7)

$P_{11}$ = A Michaelis constant for waste product metabolism

$Z_{2_{3h}}$ = Biomass/activity quantity for type 3, horizon $h$ as in (4)

### UPTAKE OF MINERAL NITROGEN TYPE *i* BY FIXERS ($Z_{3_{ih}}$)

$$Z_{3_{ih}} = Z_{19_h} \cdot P_{12_i} \cdot X_{24_{hi}} \qquad (10)$$

where:

$Z_{19_h}$ = Mineral N demand of all fixers in horizon $h$, as in (11)

$P_{12_i}$ = A "preference" factor, units type $i$ taken up per unit mineral N demand

$X_{24_{hi}}$ = Amount of type $i$ nitrogen in horizon $h$

### TOTAL MINERAL N DEMAND BY FIXERS ($Z_{19_h}$)

$$Z_{19_h} = \sum_{i \in F} (Z_{1_{ih}} \cdot Z_{2_{ih}}) / (\sum_{j \in N} X_{24_{hj}} + P_{1_6}) \qquad (11)$$

where:

$\sum_{i \in F}, \sum_{j \in N}$ = Respectively, summation over fixer biomass/activity types $j$, summation over nitrogen types $j$

$Z_{1_{ih}}$ = Growth rate of fixer $i$, horizon $h$ as in (2)

$Z_{2_{ih}}$ = Biomass/activity of fixer type $i$, horizon $h$ as in (4)

$X_{24_{hj}}$ = Nitrogen type $j$ in horizon $h$

$P_{1_6}$ = A Michaelis constant

### CHANGES IN $NO_2^-$ ($\dot{X}_{24_{h3}}$)

$$\dot{X}_{24_{h3}} = Z_{15_h} - (Z_{1_{3h}} \cdot P_{21} \cdot Z_{2_{3h}} / P_7) - Z_{3_{2h}} - Z_{4_h} \cdot (X_{24_{h3}} / (X_{24_{h3}} + X_{24_{h4}})) - Z_{20_h} \qquad (12)$$

where:

$P_7$ = Efficiency of conversion of $NH_4^+$ to $NO_2^-$ as in (9)

$Z_{1_{3h}}$ = Oxidizer growth rate as in (2)

$Z_{15_h}$ = $NH_4^+$ oxidation as in (9)

$Z_{2_{3h}}$ = Oxidizer biomass as in (4)

$Z_{3_{2h}}$ = Uptake of $N_2$ by fixers as in (10)

$Z_{4_h}$ = Denitrification of $NO_2^-$, $NO_3^-$ as in (13)

$X_{24_{h3}}$ and $X_{24_{h4}}$ = $NO_2^-$, $NO_3^-$

$P_{21}$ = As in (16)

$Z_{20_h}$ = $NO_2^-$ oxidation to $NO_3^-$ as in (14)

### DENITRIFICATION ($Z_{4_h}$)

$$Z_{4_h} = P_{14} \cdot Z_{1_{5h}} \cdot Z_{2_{5h}} \qquad (13)$$

where:

$P_{14}$ = Units ($NO_2^- + NO_3^-$) required as oxygen source per unit growth

$Z_{1_{5h}}$ = Growth rate of denitrifiers as in (2)

$Z_{2_{5h}}$ = Biomass/activity type 5 (denitrifiers) in horizon $h$ as in (4)

### OXIDATION OF $NO_2^-$ TO $NO_3^-$ ($Z_{20_h}$)

$$Z_{20_h} = (P_{15} \cdot Z_{1_{4h}} + P_{16} + P_{17} \cdot P_{18} \cdot X_{24_{h3}} / (X_{24_{h3}} + P_{19})) \cdot Z_{2_{h4}} \qquad (14)$$

where:

$P_{15}$ = 1/efficiency or $NO_2^-$ transformed to $NO_3^-$ per unit $NO_2^-$ assimilated by transformers

$Z_{14h}$ = Growth rate of oxidizers as in (2)

$P_{16}$ = $NO_2^-$ required for maintenance per unit biomass of $NO_2^-$ oxidizers

$P_{17}$ = Rate constant for waste metabolism connected to $NO_2^-$ oxidation

$P_{18}$ = External enzyme concentrations per unit microbial biomass of the $NO_2^-$ oxidizers

$X_{24h3}$ = $NO_2^-$ as in (12)

$P_{19}$ = A Michaelis constant

$Z_{24h}$ = Biomass/activity of oxidizers in horizon $h$ as in (4)

### CHANGES IN $NO_3^-$ NITROGEN ($\dot{X}_{24h4}$)

$$\dot{X}_{24h4} = Z_{20h} - (Z_{14h} \cdot P_{21} \cdot Z_{24h}/P_{15}) - Z_{33h} - \\ - Z_{4h} \cdot (X_{24h4}/(X_{24h3} + X_{24h4})) \qquad (15)$$

where:

$P_{15}$ = Efficiency as in (14)

$Z_{20h}$ = $NO_2^-$ oxidized as in (14)

$Z_{33h}$ = Uptake of $NO_3^-$ by fixers in horizon $h$

$Z_{24h}$ = Biomass of $NO_2^-$ oxidizers as in (4)

$Z_{4h}$ = Denitrification of $NO_2^-$, $NO_3^-$ as in (13)

$Z_{14h}$ = Growth rate of $NO_2^-$ oxidizers as in (2)

$X_{24h3}$ and

$X_{24h4}$ = $NO_2^-$, $NO_3^-$ nitrogen

$P_{21}$ = As in (16)

### CHANGES IN SOIL ORGANIC MATTER ($\dot{X}_{22hf}$)

$$\dot{X}_{22hf} = + \left[\sum_{i \in D} Z_{21ih}\right] \cdot P_{21}, \text{ for f} = 1 \qquad (16)$$
$$= - \sum_{i \in D} (P_{20if} \cdot Z_{22ih}), \text{ for f} > 1$$

where:

$\sum_{i \in D}$ = Summation over non-symbiotic types

$Z_{21ih}$ = Death as in (17)

$P_{21}$ = N fraction of biomass

$P_{20if}$ = Requirement of biomass type $i$ for constituent $f$ for growth

$Z_{22ih}$ = Change in biomass $i$ of horizon $h$ as in (18)

### DEATH OF BIOMASS/ACTIVITY $i(Z_{21ih})$

$$Z_{21ih} = Z_{2ih} \cdot (1 - 1/\exp(Z_{8ih})) \qquad (17)$$

where:

$Z_{2ih}$ = Quantity of biomass/acticity as in (4)

$Z_{8ih}$ = Instantaneous death rate as in (3)

### CHANGE IN BIOMASS TYPE $i$ IN HORIZON $h$ ($Z_{22ih}$)

$$Z_{22ih} = Z_{2ih,t} - Z_{2ih,t\text{-}1} \qquad (18)$$

where:

$Z_{2ih}$ = Biomass/activity at present ($t$) or previous time unit ($t$-$1$) as in (4)

### DUMMY BIOMASS EQUIVALENT CHANGES ($\dot{X}_{21Df}$)

$$\dot{X}_{21Df} = + \sum_{h} (Z_{12h} \cdot Z_{22h} - \sum_{i \in D} Z_{21ih} + Z_{13h} \cdot \\ Z_{23h}/P_7 + Z_{14h} \cdot Z_{24h}/P_{15}) \cdot P_{21}, \text{ for } f = 1 \qquad (19)$$
$$= + \sum_{h} \sum_{i \in D} (P_{20if} \cdot Z_{22ih}), \text{ for } f > 1$$

where:

$\sum_{h,} \sum_{i \in D}$ = Summation over all horizons, summation over non-symbiotic types

$Z_{1ih} \cdot Z_{2ih}$ = As in (1)

$Z_{21ih}$ = Death as in (17)

$P_7$, $P_{15}$ = Inverse efficiencies as in (9) and (14)

$P_{20if}$, $P_{21}$ = As in (16)

$Z_{22ih}$ = Change in biomass $i$ as in (18)

### CHANGE IN DENITRIFYING DECOMPOSERS ($\dot{Z}_{25h}$)

$$\dot{Z}_{25h} = (\exp(Z_{15h} - Z_{85h}) - 1) \cdot Z_{25h}/P_{22} \qquad (20)$$

where:

$Z_{15h}$, $Z_{25h}$ = Growth rate (2) and biomass

$Z_{85h}$ = Death rate as in (3)

$P_{22}$ = Units of $Z_{25h}$ biomass not involved in denitrification per unit involved

## TABLE OF SYMBOLS FOR MATHEMATICAL EQUATIONS

| Symbol | FORTRAN | Eq. Where Defined | Units |
|---|---|---|---|
| $X_{01rf}$ | AGAIN(R,F) | 1 | g/ha·time |
| $X_{21Df}$ | CLIT (LDUM,F) | 19 | g/ha |
| $X_{22hf}$ | CORG(H,F) | 16 | g/ha |
| $X_{24hf}$ | SMIN(H,F) | 7, etc. | g/ha |
| $Z_{1ih}$ | GR(I) | 2 | 1/time |
| $Z_{2ih}$ | BIOM(I,N),<br>CBIO(N) | 4 | g/ha |
| $Z_{3ih}$ | V11NH4,<br>V11NO2,<br>V11NO3 | 10 | g/ha·time |
| $Z_{4h}$ | V8 | 13 | g/ha·time |
| $Z_{5}$ | V10 | 8 | g/ha·time |
| $Z_{6ih}$ | G(I),<br>GG | 5 | 1/time |
| $Z_{7ih}$ | CI(N),<br>TOTOC,<br>SMIN(H,*) | 2 | g/ha |
| $Z_{8ih}$ | D(I) | 3 | 1/time |
| $Z_{9ih}$ | TC | 5 | dimensionless |
| $Z_{10ih}$ | PHC | 5 | dimensionless |
| $Z_{11ih}$ | SC | 5 | dimensionless |
| $Z_{12ih}$ | WC | 5 | dimensionless |
| $Z_{13ih}$ | — | 6 | dimensionless |
| $Z_{14h}$ | WATPOT(H) | 6 | -bars |
| $Z_{15h}$ | V6 | 9 | g/ha·time |
| $Z_{16}$ | TC8 | 8 | dimensionless |
| $Z_{17}$ | PHC8 | 8 | dimensionless |
| $Z_{18}$ | SOCOC | 8 | dimensionless |
| $Z_{19h}$ | V11 | 11 | g/ha·time |
| $Z_{20h}$ | V7 | 14 | g/ha·time |
| $Z_{21ih}$ | — | 17 | g/ha·time |
| $Z_{22ih}$ | CHANGE | 18 | g/ha |

| Sym. | FORTRAN | Eq. | Units | Example |
|---|---|---|---|---|
| $P_{1i}$ | CM(I) | 2 | g/ha | 1000. |
| $P_{2i}$ | D1(I) | 3 | 1/time | .02 |
| $P_{3i}$ | D2(I) | 3 | 1/time | .002 |
| $P_{4i}$ | GM(I) | 5 | 1/time | .7 |
| $P_{5}$ | CION | 6 | -bars | -10. |
| $P_{6}$ | FVNH4 | 8 | 1/time | .01 |
| $P_{7}$ | A3 | 9 | dimensionless | 16. |
| $P_{8}$ | MAIN3 | 9 | 1/time | .00005 |
| $P_{9}$ | K3 | 9 | 1/time | 1.0 |
| $P_{10}$ | B3 | 9 | dimensionless | .0005 |
| $P_{11}$ | KM3 | 9 | g/ha | 1.0 |
| $P_{12i}$ | BNH4, | 10 | dimensionless | 1.0 |
|  | BNO2, | 10 |  | .1 |
|  | BNO3 | 10 |  | .3 |
| $P_{14}$ | A5 | 13 | dimensionless | .5 |
| $P_{15}$ | A4 | 14 | dimensionless | 16.0 |
| $P_{16}$ | MAIN4 | 14 | 1/time | .00005 |
| $P_{17}$ | K4 | 14 | 1/time | 1.0 |
| $P_{18}$ | B4 | 14 | dimensionless | .0005 |
| $P_{19}$ | KM4 | 14 | g/ha | 1.0 |
| $P_{20if}$ | CFEPCT(I,F) | 16 | dimensionless | .10, etc. |
| $P_{21}$ | BN | 16 | dimensionless | .10 |
| $P_{22}$ | CBFAC | 20 | dimensionless | 2. |

# COMPUTER IMPLEMENTATION

## DATA REQUIREMENTS AND EXECUTION CHARACTERISTICS

CLIT(LDUM,*) is a dummy storage type which can have an arbitrary value but must be at least as great as actual total equivalent amount of constituent * in all three biomasses (free fixers, two oxidizers) included and over-all horizons. CBFAC must be non-zero. Linkages to other programs are B1(N) (symbionts in plant roots of horizon N); SYMNIT(N) (symbiotic growth requirement for N -- not all fixed necessarily); CI(N) (total host root carbon of horizon N); AUTNIT and AUTGRO (growth requirement for N and input growth of autotrophs as calculated elsewhere). Logical switches must be on or off as desired. TNC(N) is the sum of inorganic types of N and must be summed in some external place. There must always be unique places to store all the different types of N (don't use them summed under something like "total inorganic N"). This is why SMIN is used in place of CMIN. For purposes of a major simulation, plant and animal submodels may not be able to use the different types of N at all and would have to have a "total mineral N" type constituent in CMIN. If they do contribute or take from this category, the distribution of such activity over types of SMIN will have to be determined (happy interfacing!). A flow chart of the submodel is provided in Figure 3.

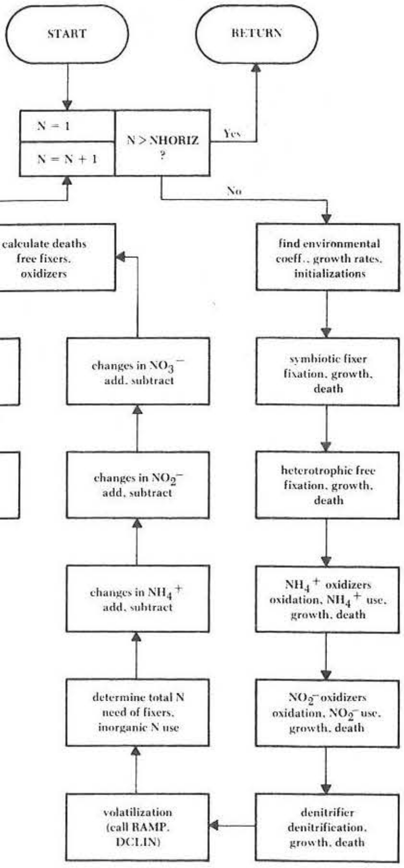

Figure 3. Program flow chart.

## PARAMETER DEFINITIONS

A3

1/Eff. or $NH_4^+$ disappeared/$NH_4^+$ assimilated by the oxidizers ($NH_4^+$ to $NO_2^-$).

A4

1/Eff. or $NO_2^-$ disappeared/$NO_2^-$ assimilated by the oxidizers.

A5

The units of ($NO_2^-$ + $NO_3^-$) required (as oxygen source) per unit growth.

AUTGRO

Growth of autotrophic fixers. Growth rate times biomass, as calculated in plant or other submodel.

BIOM(I,N)

Some measure of total biomass of microbial population I in horizon N. I = 1 for symbionts, I = 2 for heterotrophes, I = 3 for $NH_4^+$ oxidizers, I = 4 for $NO_2^-$ oxidizers.

BN

Nitrogen in biomass populations in general, units N per unit microbial biomass.

BNH4

Preference coefficient for use of $NH_4^+$ as source of nitrogen for microbial growth.

BNO2

Preference coefficient for use of $NO_2^-$ as source of nitrogen for microbial growth.

BNO3

Preference coefficient for use of $NO_3^-$ as source of nitrogen for microbial growth.

B3

External enzyme concentration per unit microbial biomass of the $NH_4^+$ oxidizers.

B4

External enzyme concentration per unit microbial biomass of the $NO_2^-$ oxidizers.

CBFAC

The inverse of CBFAC (1/CBFAC) is the fraction of CBIO(N) which is involved in denitrification.

CBIO(N)

Some measure of decomposer biomass in horizon N as calculated mainly in the DECOMP subroutine.

CFEPCT(I,K)

Units constituent *k* normally found in biomass type *i* per unit total biomass type *i* (dry weight as stored in CLIT(NDUM,*)).

CI(N)
Total symbiotic host root carbon in horizon *n*.

CION
Inhibition constant for the inhibition of the use of ($NO_3^-$ + $NO_2^-$) as source of oxygen, by the oxygen present.

CM
Michaelis constant for the limiting substrate in each reaction.

D1(I)
Death rate under starvation conditions for biomass type *i*. This is used in the EXP exponential function.

D2(I)
Death rate under normal conditions (energy source is available) for biomass type *i*.

FVNH4
Maximal rate of $NH_3$ volatilization independent of $NH_3$ concentration, at optimal conditions for volatilization, units volatilized per unit present.

GM(I)
Maximal growth rate (substrate concentration is high, environmental conditions are optimal) for biomass type *i*.

HETFIX
Logical switch. Set to .TRUE. if free heterotrophic fixation is to be modelled.

IAGN
Nitrogen constituent number in the AGAIN array.

ICO2
Carbon constituent number in the AGAIN array.

INH4
Ammonium constituent number in the SMIN array.

INIT
Organic nitrogen constituent number in the CORG or CLIT or SMIN array.

INO2
Nitrite position in SMIN (usually 3).

INO3
Nitrate position in SMIN (usually 4).

IR
Number of biomasses or of types of transformers involved (usually 5).

KA
Atmospheric route of exchange number in AGAIN.

KM3
Michaelis constant for waste metabolism connected to $NH_4^+$ oxidation.

KM4
Michaelis constant for waste metabolism connected to $NO_2^-$ oxidation.

K3
Rate constant for waste metabolism connected to $NH_4^+$ oxidation.

K4
Rate constant for waste metabolism connected to $NO_2^-$ oxidation.

LDUM
Position in CLIT array reserved for the dummy biomass equivalent to the sum of BIOM in all horizons.

MAIN3
$NH_4^+$ required for maintenance per unit biomass of $NH_4^+$ oxidizers.

MAIN4
$NO_2^-$ required for maintenance per unit biomass of $NO_2^-$ oxidizers.

NNAMLS
Integer switch. If .GT.O, NITRO's namelist (HANNA) if printed out.

PHK(I,J)
pH points for the various types of biomass (I), J = 1 minimum pH below which the pH coefficient is zero, J = 2,3 two maximal pH points between which the pH coefficient is one, J = 4 maximum pH above which the pH coefficient is one.

PHMAX
Maximal pH for $NH_3$ volatilization above which the pH coefficient is one.

PHMIN
Minimal pH for $NH_3$ volatilization below which the pH coeffieicnt is zero.

SA(I,J)
Salinity points for the various types of biomass (I); J = 1 minimum salinity below which the salinity coefficient is zero, J = 2,3 two maximal salinity concentrations between which the salinity coefficient equals 1; J = 4 max salinity above which the salinity coefficient is zero.

SMIN(N,K)
Soil mineral nitrogen pools, including $NO_3^-$, $NO_2^-$ and $NH_4^+$.

SYMFIX
Logical switch. If .TRUE., symbiotic fixation is calculated by NITRO.

T(I,J)
Temperature points for various types of biomass (I); J = 1 minimum temperature below which the temperature coefficient is zero, J = 2,3 two maximal points between which the temperature coefficient is one, J = 4 maximum temperature above which the temperature coefficient is zero.

TMAX
Maximal temperature for $NH_3$ volatization above which the temperature coefficient is one.

TMIN
Minimal temperature for $NH_3$ volatilization below which the temperature coefficient is zero.

VMAX
Maximal plant cover of soil above which the cover coefficient for $NH_3$ volatilization is one.

VOLATL
Logical switch. If .TRUE., volatilization of $NH_3$ is calculated here in NITRO.

W(I,J)
Water potential (in negative bars) points for various

types of biomass (I), includes the requirements for moisture and oxygen; J = 1 minimum water potential below which the water coefficient is zero, J = 2,3 maximal water potential values between which the water coefficient is one, J = 4 maximal water potential above which the water coefficient is zero.

## LITERATURE CITED

McLaren, A. D. 1971. Kinetics of nitrification in soil: growth of the nitrifiers. Soil Sci. Soc. Amer. Proc. 35(1):91-95.

Parnas, H., and J. Radford. 1974. A decomposition submodel. US/IBP Desert Biome Res. Memo. 76-63. 23 pp.

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Listings of the programs which handle both nitrogen and decomposition appear as Appendix 1 to Research Memorandum 74-63 -- *A decomposition submodel.* An example of input/output follows the program listing (Appendix 2).

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**1973 PROGRESS REPORT**

# A DECOMPOSITION SUBMODEL

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and
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Utah State University

**US/IBP DESERT BIOME**
**RESEARCH MEMORANDUM 74-63**

**in**

**REPORTS OF 1973 PROGRESS**
**Volume 1: Central Office, Modelling**
Auxiliary Submodels Section, pp. 105-127

**MAY, 1974**

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Utah State Univ., Logan. 23 pp.

Ecology Center, Utah State University, Logan, Utah 84322

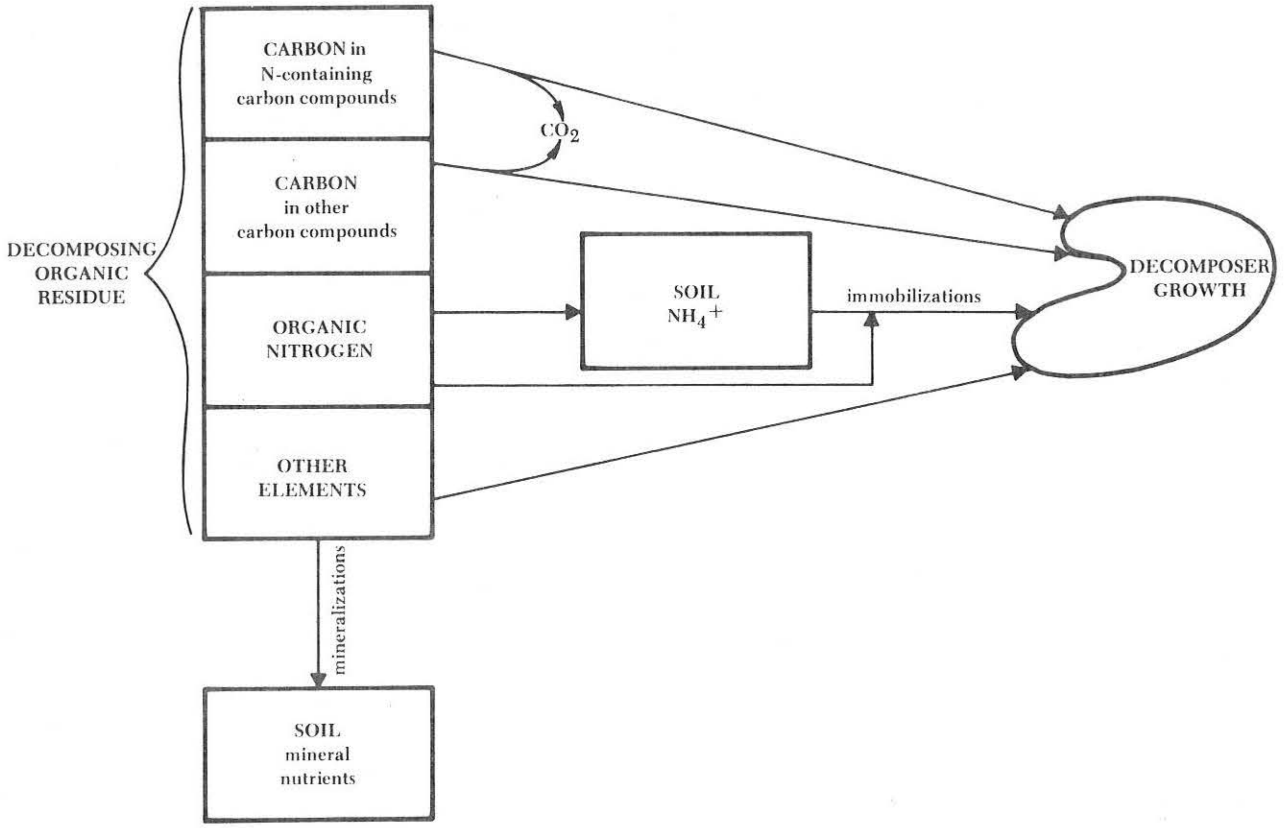

Figure 1. General flows of constituents.

microbial biomass are considered part of soil organic matter, for purposes of simplicity.

*Breakdown of C-N-Compounds*

The only representative of the C-N-compounds is protein. The rate of protein breakdown in any type of organic material depends on the C:N ratio of that organic material. If the ratio is above the critical ratio $a/f_n$ (which represents the ratio between the required carbon to the required nitrogen), then the rate of protein breakdown will be governed by the requirement for nitrogen. If the ratio is below the critical ratio, then the requirement for carbon will determine the rate of protein breakdown. The proportion of protein in the mixture of the organic material can be explicitly calculated from the concentration of the organic material and its C:N ratio.

*Breakdown of C-Compounds ("Other" Carbon)*

The rate of breakdown of the C-compounds is always complementary to that of the protein. When the C:N ratio of the organic material being decomposed is higher than the critical ratio, the C-compounds will serve as the main source for carbon. On the other hand, when the ratio is below $a/f_n$, their contribution decreases and is exactly proportional to their relative concentration. Their relative concentration decreases as the C:N ratio decreases.

*Organic Nitrogen Mineralization*

No mineralization occurs when the C:N ratio of the substrate is greater than $a/f_n$ because, under such conditions, nitrogen is the growth-limiting factor. When the ratio is below $a/f_n$, mineralization occurs together with the decomposition of the substrate. Mineralization occurs because, under such conditions, the breakdown of protein is determined by the requirement for carbon. Along with carbon that is being released, a proportional amount of nitrogen is being released. However, the amount of required carbon is 20-30 times higher than that of nitrogen, meaning that the excess nitrogen will be released to the environment as ammonium. Thus, the rate of mineralization is inversely proportional to the C:N ratio. The addition of extra nitrogen might increase the requirement for carbon but, on the other hand, it always decreases the relative requirement for the organic material nitrogen (because organic nitrogen and the extra nitrogen serve for growth according to their relative concentration). It follows that the rate of mineralization is increased by addition of extra nitrogen.

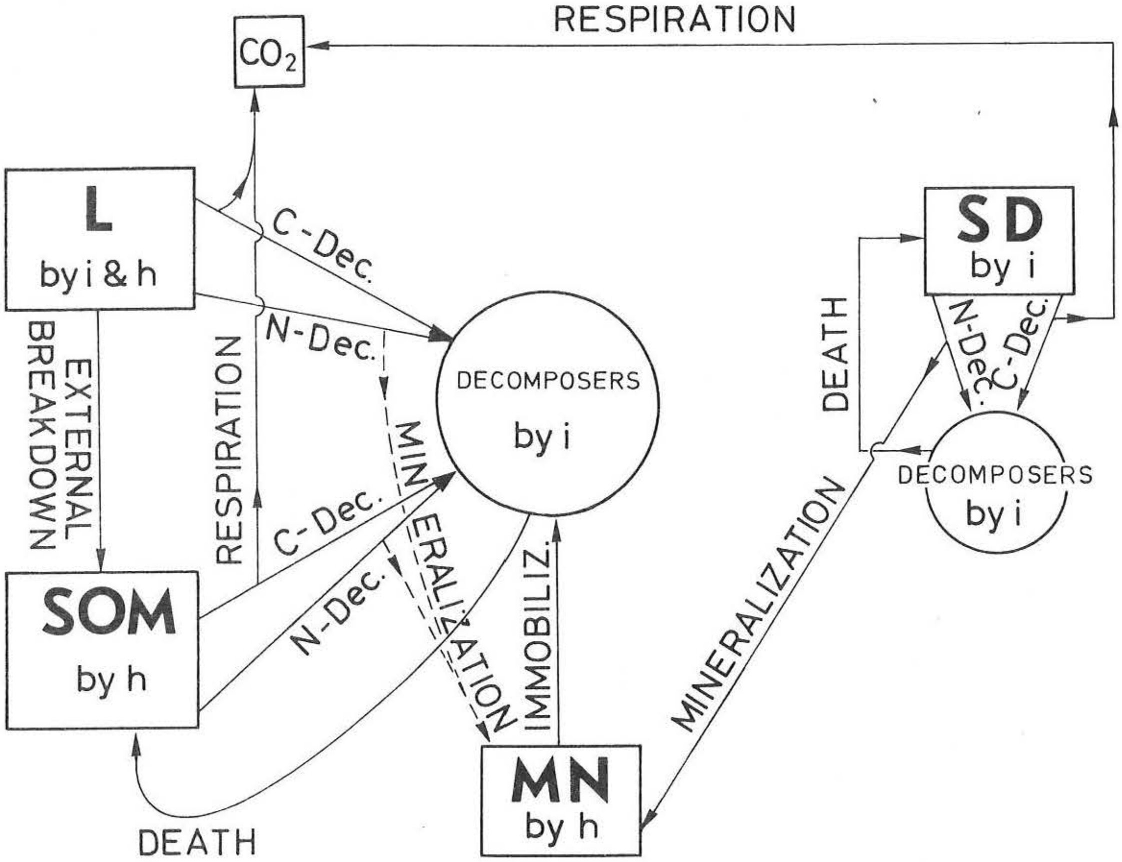

**Figure 2.** System diagram. Note that surface litter and/or standing dead with soil affect only horizon 1. Decomposers of the top horizon normally work on all types of surface litter; each standing dead type has a separate decomposer type *k*. The generally physical-mechanical transfer of standing dead to surface litter (as well as a number of other processes) is handled elsewhere.

*Inorganic Nitrogen Immobilization*

When inorganic nitrogen is available and when the growth rate of the decomposers is still dependent on nitrogen concentration, immobilization of inorganic nitrogen will occur. This will always be the case for organic materials which are poor in nitrogen, such as those whose C:N ratio is below $a/f_n$.

$CO_2$ *Evolution*

The process of microbial decomposition is accompanied by $CO_2$ evolution. The rate of $CO_2$ evolution by organic material being decomposed is proportional to the rate of carbon decomposition multiplied by (1-efficiency). The efficiency is defined as the ratio of carbon assimilated to carbon decomposed.

*External Breakdown*

The major route of organic material decomposition is via microbial breakdown. In addition to this, a relatively unimportant route is added in some artificial way to the subroutine. This last route is breakdown by the external enzymes which are available in the area. The purpose of that process is to have a direct input to soil organic matter from the various litter types, dead roots and the animal

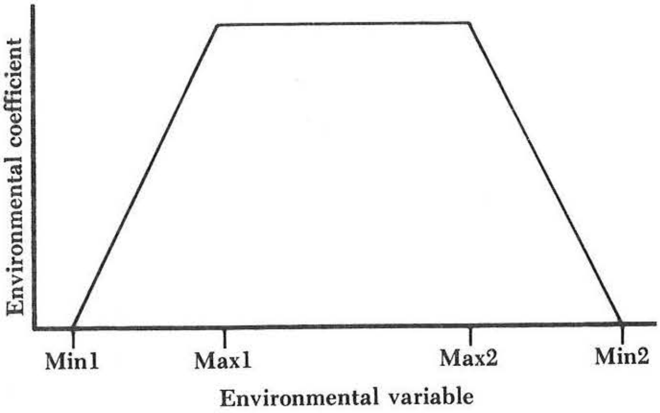

**Figure 3.** Dependency of maximal growth rate on environmental conditions (for explanations see text).

residues. The direct input should normally compensate for the loss from soil organic matter caused by microbial breakdown. More efficient ways of generating this input could and should be introduced.

*Mineralization of Non-Carbon, Non-Nitrogen Elements*

In order for other organic materials to be added eventually to soil mineral nutrients and so to complete decomposition, a constant ratio (amount of constituent mineralized to total carbon decomposed) is multiplied by total carbon decomposed. This ratio is specific to dead materials generally and to soil organic matter. Such an artificial means of calculating net mineralization (mineralization minus immobilization) should be replaced later by explicit calculations as is the case for nitrogen.

### ASSUMPTIONS

1. The rate of decomposition of any type of organic material is proportional to the growth rate of its decomposers.
2. Both the carbon of the C-compounds and that of the C-N-compounds can serve as a carbon source for microbial growth. Their relative contribution depends on optimal considerations which will cause maximal long-term growth rate.
3. Both organic and inorganic nitrogen can serve as a nitrogen source for microbial growth. Their relative contribution is according to their relative concentration.
4. Each of the organic materials is being decomposed at a rate determined by its own concentration and its own C:N ratio.
5. In addition to microbial breakdown of litter, dead roots and animal residues, external breakdown takes place. This process is not accompanied by $CO_2$ evolution. It is more a mechanical breakdown. Its order of magnitude is very small compared to the microbial breakdown.
6. The nutrients in the first soil horizon are available to the decomposers which react on soil surface. The products of decomposition which happen on the soil surface move to the first soil horizon (or to the microbes, or to the atmosphere).
7. The decomposition of each type of organic material by horizon is made by the same mixed population of that horizon. This population can move from one substrate to the other.
8. The nutrients which are included in the living microbial biomass are made available to plants only after death and decomposition/mineralization of the microbes themselves.

## MATHEMATICAL DESCRIPTION

### CHANGES IN DETRITUS DUE TO DECOMPOSITION ($\dot{X}_{21df}$)

$$\dot{X}_{21df} = -{}_{D}Z_{1df} - {}_{D}Z_{2df} - Z_{3df} - {}_{D}Z_{4df} + P_{1kf} \cdot {}_{D}Z_{5kd} \qquad (1)$$

where:

${}_{D}Z_{1df}$ = Decomposition of detritus type *d* carbon type *f* as in (7)

${}_{D}Z_{2df}$ = Decomposition of detritus type *d* non-carbon, non-nitrogen constituent *f* as in (13)

$Z_{3df}$ = External breakdown as in (14)

${}_{D}Z_{4df}$ = Decomposition to mineral form of nitrogen constituent *f* in detritus type *d* as in (16)

$P_{1kf}$ = Units constituent *f* normally found per unit total carbon in biomass *k*

${}_{D}Z_{5kd}$ = Death of biomass type *k* due to subsistence on detritus type *d* as in (10)

$k$ = The biomass type numbers of the decomposers which utilize dead material *d*

### CHANGES IN SOIL ORGANIC MATTER DUE TO DECOMPOSITION ($\dot{X}_{22hf}$)

$$\dot{X}_{22hf} = -{}_{S}Z_{1hf} - {}_{S}Z_{2hf} - {}_{S}Z_{4hf} + \sum_{d\in S_h} Z_{3df} + P_{1kf} \cdot {}_{S}Z_{5kh} \qquad (2)$$

where:

${}_{S}Z_{1hf}$ = Carbon decomposition of SOM in horizon *h* as in (7)

${}_{S}Z_{2hf}$ = Non-C, non-N decomposition of SOM in horizon *h* as in (13)

${}_{S}Z_{4hf}$ = Nitrogen mineralization from SOM in horizon *h* as in (16)

$\sum_{d\in S_h} Z_{3df}$ = The sum of externally broken-down detritus constituents *f* for all detritus types *d* contributing to SOM in horizon *h* as in (14)

$P_{1kf}$ = As in (1)

${}_{S}Z_{5kh}$ = Decomposer death due to subsistence on SOM in horizon *h* as in (10)

$k$ = The decomposer population which utilizes SOM in horizon *h*

### CHANGES IN MINERAL NITROGEN TYPE OR DUE TO DECOMPOSERS ($\dot{X}_{24_{hn}}$)

$$\dot{X}_{24_{hn}} = \sum_{d\in N_h}(-{}_{D}Z_{6_{dn}} + {}_{D}Z_{4_{dn}}) - {}_{S}Z_{6_{hn}} + {}_{S}Z_{4_{hn}} \qquad (3)$$

where:

$\sum_{d\in N_h}$ = Summation over all detritus types in the set of detritus types exchanging nitrogen with the horizon $h$ pool

$Z_{6_{in}}$ = Immobilization of mineral N by decomposers in detritus types ($D/d$) or in SOM ($S/h$) as in (17)

$Z_{4_{in}}$ = Demineralization of organic N to the $X_{24_{hn}}$ pool from detritus ($D/d$) and SOM ($S/h$) as in (16)

$n$ = Mineral N type ($n$ = 1, organic N; $n$ = 2, $NH_4$; $n$ = 3, $NO_2$; $n$ = 4, $NO_3$)

### CHANGES IN ASH ELEMENTS (NON-N, NON-C) DUE TO DECOMPOSITION ($\dot{X}_{23_{hf}}$)

$$\begin{aligned} \dot{X}_{23_{hf}} &= \sum_{n} \dot{X}_{24_{hn}}, \text{ if } f = 1 \\ \text{and } &= \sum_{d\in M_h} {}_{D}Z_{2_{df}} + {}_{S}Z_{2_{hf}}, \text{ if } kf < 3 \\ \text{and } &= 0\ , \text{ if } f > 3 \end{aligned} \qquad (4)$$

where:

$\dot{X}_{24_{hn}}$ = Mineral nitrogen type $n$ increment or decrement as in (3)

$\sum_{d\in M_h}$ = Summation over all detritus types $d$ which are in the set of types $M_h$ contributing to horizon $h$ minerals

${}_{D}Z_{2_{df}}$, ${}_{S}Z_{2_{hf}}$ = Demineralizations due to decomposer growth on detritus ($D/d$) and SOM ($S/h$) as in (13)

### CHANGES IN DECOMPOSER BIOMASSES (STATE VARIABLE EQUIVALENT)($\dot{X}_{25_{kf}}$)

$$\begin{aligned} \dot{X}_{25_{kf}} &= \sum_{d\in D_k}({}_{D}Z_{1_{df}} - {}_{D}Z_{7_{df}}) + \sum_{h\in S_k}({}_{S}Z_{1_{hf}} - {}_{S}Z_{7_{hf}}), \text{ for } f > 1 \\ \text{and } &= \sum_{d\in D_k}(\sum_{n} {}_{D}Z_{6_{dn}} - {}_{D}Z_{4_{d2}}) + \sum_{h\in S_k}(\sum_{n} {}_{S}Z_{6_{hn}} - {}_{S}Z_{4_{h2}}), \text{ for } f = 1 \end{aligned} \qquad (5)$$

where:

$\sum_{d\in D_k}$ = Summation over all detritus types $d$ that are utilized by biomass $k$

$\sum_{h\in S_k}$ = Summation over all SOM that is utilized by biomass $k$

${}_{D}Z_{1_{df}}$, ${}_{S}Z_{1_{hf}}$ = As in (7)

${}_{D}Z_{7_{df}}$, ${}_{D}Z_{7_{hf}}$ = As in (20)

$\sum_{n}$ = Summation over all mineral N types

${}_{D}Z_{6_{dn}}$, ${}_{S}Z_{6_{hn}}$ = N immobilizations as in (17)

${}_{D}Z_{4_{d2}}$, ${}_{S}Z_{4_{h2}}$ = $NH_4^+$ evolutions as in (16)

### $CO_2$ RESPIRATION ($\dot{X}_{01_{13}}$)

$$\dot{X}_{01_{13}} = \sum_{f\in C}(-\sum_{d} {}_{D}Z_{7_{df}} - \sum_{h} {}_{S}Z_{7_{hf}}) \qquad (6)$$

where:

$\sum_{f\in C}$ = Summation over all C types

$\sum_{d}$ & $\sum_{h}$ = Summation over all detritus types and all SOM, respectively

${}_{D}Z_{7_{df}}$ & ${}_{S}Z_{7_{hf}}$ = Respiration from C types $f$ in detritus ($D/d$) and SOM ($S/h$) as in (20)

### NITROGEN AND CARBON DECOMPOSITION IN DETRITUS AND SOM ($Z_{1_{if}}$)

$$\begin{aligned} Z_{1_{if}} &= Z_{8_i}/P_2, \text{ if } f = 1 \\ \text{and } &= Z_{8_i}, \text{ if } f = 3 \\ \text{and } &= Z_{9_i} \cdot (Z_{10_i} - Z_{8_i}), \text{ if } f > 3 \end{aligned} \qquad (7)$$

where:

$Z_{8_i}$ = Protein C decomposition of material type $i$ as in (8)

$P_2$ = The ratio units C to units N normally found in biological N-containing compounds (i.e., protein)

$Z_{9_i}$ = The ratio units carbon type $f$ to units total C in material $i$

$Z_{10_i}$ = Total carbon decomposition from material $i$ as in (9)

### PROTEIN CARBON DECOMPOSITION ($Z_{8i}$)

$$Z_{8i} = P_2 \cdot P_3 \cdot Z_{11kd} \cdot Z_{12k} \cdot (X_{21d1}/Z_{13k}), \text{ for detritus types } d$$

$$\text{and} = P_2 \cdot P_3 \cdot Z_{11kh} \cdot Z_{12k} \cdot (X_{22h1}/Z_{13k}), \text{ for SOM in horizon } h$$

$$\text{and} = Z_{10i} \cdot Z_{14i}/Z_{15i}, \text{ if material } i \text{ C:N ratio is less than } P_4 \qquad (8)$$

where:

$P_2$ = As in (7)

$P_3$ = Normal ratio units N to units total biomass of decomposers

$Z_{11kd}$ & $Z_{11kh}$ = Growth of decomposers *k* on detritus (*d*) or SOM (*h*) in units growth per unit biomass per unit time as in (10)

$Z_{12k}$ = Decomposer biomass *k* which utilizes material type *i* as in (12)

$X_{21df}$ & $X_{22hf}$ = As in (1), (2)

$Z_{10i}$ = Total carbon decomposition of material *i* as in (9)

$Z_{14i}$ = Total protein C in material *i*

$Z_{15i}$ = Total carbon of all types in *i*

$P_4$ = $a/f_n$ (see Verbal Description) or carbon concentration in decomposer cells divided by the product of nitrogen concentration and decomposition assimilation efficiency

$Z_{13k}$ = Total N (organic + inorganic) available to biomass *k*, there being no inorganic N available to above-surface *k*

### TOTAL C DECOMPOSITION ($Z_{10i}$)

$$Z_{10i} = (Z_{11ki}/P_5 + P_6) \cdot Z_{12k} \qquad (9)$$

where:

$Z_{11ki}$ = Growth of biomass *k* on dead material *i* as in (10)

$P_5$ = Efficiency of carbon assimilation, units assimilated per unit decomposed by *k*

$P_6$ = Maintenance requirement for carbon, units required per unit *k*

$Z_{12k}$ = Units biomass *k* as in (12)

### GROWTH OF DECOMPOSERS *k* ON MATERIAL *i* ($Z_{11ki}$)

$$Z_{11ki} = Z_{16j} \cdot Z_{15i} \cdot Z_{13k}/((P_7 + Z_{15i}) \cdot (P_8 + Z_{13k})) \qquad (10)$$

where:

$Z_{16j}$ = The environmentally adjusted growth rate of decomposers *k* in the set $R_j$ of *k* which have the same growth rate on material type *j* as in (11)

$Z_{15i}$ = Total carbon as in (8)

$Z_{13k}$ = Total nitrogen available to *k* as in (8)

$P_7$, $P_8$ = Michaelis constants for carbon, nitrogen utilization

### ENVIRONMENTALLY ADJUSTED GROWTH RATES ($Z_{16j}$)

$$Z_{16j} = P_{9j} \cdot Z_{17z} \cdot Z_{18z} \cdot Z_{19z} \cdot Z_{20z}, \text{ if type } j \text{ material is in environmental zone } z \qquad (11)$$

where:

$P_{9j}$ = Maximal growth rate for dead material class *j*

$Z_{17z}$, $Z_{18z}$, $Z_{19z}$, & $Z_{20z}$ = Environmental coefficients returned from OPT subroutine for environmental zone *z*

### BIOMASS OF DECOMPOSERS ($Z_{12k_t}$)

$$Z_{12k_t} = Z_{12k_{t-1}} \cdot \exp\left(\sum_{i \in G_k} Z_{11ki} - Z_{21ki}\right) \qquad (12)$$

where:

*t*, *t-1* = The present and immediately preceding time step

$\sum_{i \in G_k} Z_{11ki}$ = The sum of growth rate increments that affect biomass *k* in its utilization of the set of dead materials $i \in G_k$ as in (10)

$Z_{21ki}$ = Death rate of *k*; $Z_{21k} = P_{10}$ if all $Z_{15i}$, $i \in G_k$, are $\leqslant 0$ ; $Z_{21k} = P_{11}$ if any $Z_{15i} > 0$.

$P_{10}$, $P_{11}$ = Starvation and non-starvation death rates, respectively

### DEMINERALIZATION OF NON-N, NON-C CONSTITUENTS ($Z_{2if}$)

$$Z_{2if} = P_{12f} \cdot P_{1kf} \cdot Z_{10i}, \text{ for } i \text{ being utilized by } k \qquad (13)$$

where:

$P_{12f}$ = Units *f* mineralized per unit *f* decomposed
$P_{1kf}$ = *f* concentration as in (1)
$Z_{10i}$ = Total carbon decomposed by biomass *k* as in (9)

### EXTERNAL BREAKDOWN OF DETRITUS CONSTITUENTS ($Z_{3df}$)

$$Z_{3df} = (X_{21df}/X_{21d\bar{f}}) \cdot Z_{22d} \qquad (14)$$

where:

$X_{21d\bar{f}}$ = As in (1), $\bar{f}$ signifying summation over all constituents
$Z_{22d}$ = Total external breakdown of detritus type *d* as in (15)

### TOTAL EXTERNAL BREAKDOWN OF DETRITUS TYPE *d* ($Z_{22d}$)

$$\begin{aligned} Z_{22d} &= 0 \text{ , for above-ground } d \\ \text{and } &= (P_{13d} \cdot Z_{23z} \cdot Z_{24z} \cdot Z_{25z}) \cdot P_{14} \cdot Z_{12k} \\ &\cdot Z_{15d}/(P_{15d} + Z_{15d}), \text{ for } d \text{ in environment } z \text{ and } k \\ &\text{utilizing } d \qquad (15) \end{aligned}$$

where:

$P_{13d}$ = A maximal breakdown rate, units broken down per unit external enzyme (= $P_{14} \cdot Z_{12k}$)
$Z_{23z}$, $Z_{24z}$ & $Z_{25z}$ = Temperature, pH and water (oxygen) coefficients derived for environmental zone *z* by OPT and RAMP subroutines
$P_{14}$ = Units enzyme normally present per unit biomass present
$Z_{12k}$ = Biomass as in (12)
$Z_{15d}$ = Material *d* total carbon as in (8)
$P_{15d}$ = A Michaelis constant for detritus type *d*

### NITROGEN DEMINERALIZATION FROM DEAD MATERIAL *i* ($Z_{4if}$)

$$\begin{aligned} Z_{4if} &= 0 \text{ , for } f \neq 1 \\ \text{and } &= Z_{1i1} - P_3 \cdot Z_{11ki} \cdot Z_{12k} \cdot ((Z_{13k} - Z_{26k})/Z_{13k}), \\ &\text{for } f = 1 \text{ and for proper } k \qquad (16) \end{aligned}$$

where:

$Z_{1i1}$ = Organic nitrogen decomposition as in (7)
$P_3$ = The normal N concentration in decomposers, units N per unit biomass
$Z_{11ki}$ = Growth of *k* on *i* as in (10)
$Z_{12k}$ = Biomass *k* as in (12)
$Z_{26k}$ = Total mineral N available to *k*; $Z_{26k} = 0$ for above-surface *k*, $Z_{26k} = \sum_n X_{24hn}$ otherwise, for appropriate *h*
$Z_{13k}$ = Total N available to *k* as in (8)

### NITROGEN IMMOBILIZATION BY BIOMASS *k* IN MATERIAL *i* ($Z_{6in}$)

$$Z_{6in} = Z_{27i} \cdot P_{16n} \cdot X_{24jn}/Z_{26k} \qquad (17)$$

where:

$Z_{27i}$ = Total N immobilized by biomass *k* in its activity on material *i* as in (18)
$P_{16n}$ = A preference factor, units *n* immobilized per unit total immobilization
$X_{24jn}$ = Inorganic nitrogen type *n* that is available to *k*, *j* here corresponds to the location of *i* and *k*, as in (3)
$Z_{26k}$ = Total inorganic N available to biomass *k* as in (16)

### TOTAL N IMMOBILIZATION BY DECOMPOSERS *k* ON MATERIAL *i* ($Z_{27i}$)

$$Z_{27i} = P_3 \cdot Z_{11ki} \cdot Z_{12k} \cdot (Z_{26k}/Z_{13k}) \qquad (18)$$

where:

$P_3$ = N concentration in *k* as in (8)
$Z_{11ki}$ = Decomposer growth as in (10)
$Z_{12k}$ = Decomposer biomass in in (12)
$Z_{26k}$ = Total inorganic N as in (16)
$Z_{13k}$ = Total N as in (8)

### DECOMPOSER BIOMASS *k* DEATH WITH RESPECT TO MATERIAL *i* ($Z_{5ki}$)

$$Z_{5ki} = Z_{12k} \cdot (1 - 1/\exp(Z_{21ki})) \qquad (19)$$

where:

$Z_{12k}$ = Biomass as in (12)
$Z_{21ki}$ = Death rate as in (12)

### RESPIRATION OF CARBON TYPE *f* FROM MATERIAL *i* ($Z_{7if}$)

$$\begin{aligned} Z_{7if} &= (1 - P_5) \cdot Z_{2if}, \text{ if } f \geqslant 3 \\ &= 0 \text{ , if } f < 3 \qquad (20) \end{aligned}$$

where:

$P_5$ = Efficiency as in (9)
$Z_{1if}$ = Decomposition of fraction *f* as in (7)

## TABLE OF VARIABLE NAMES

| SYMBOL | FORTRAN | EQUATION | UNITS | TYPICAL VALUES |
|---|---|---|---|---|
| $X_{01_{rf}}$ | AGAIN | 6 | g/ha | |
| $X_{21_{df}}$ | CLIT(D,F) | 1 | g/ha | |
| $X_{22_{hf}}$ | CORG(H,F) | 2 | g/ha | |
| $X_{23_{hf}}$ | CMIN(H,F) | 4 | g/ha | |
| $X_{24_{hn}}$ | SMIN(H,N) | 3 | g/ha | |
| $X_{25_{kf}}$ | DUMBIO(K,F) | 5 | g/ha | |
| $Z_{1_{if}}$ | DLOS | 1 | g/ha · time | |
| $Z_{2_{if}}$ | DMINRL | 13 | g/ha · time | |
| $Z_{3_{df}}$ | EXTLOS | 14 | g/ha · time | |
| $Z_{4_{if}}$ | DMINR | 16 | g/ha · time | |
| $Z_{5_{ki}}$ | VD | 10 | g/ha · time | |
| $X_{6_{in}}$ | DIM | 17 | g/ha · time | |
| $Z_{7_{if}}$ | R | 20 | g/ha · time | |
| $Z_{8_{i}}$ | DPROTC | 8 | g/ha · time | |
| $Z_{9_{i}}$ | — | 7 | dimensionless | |
| $Z_{10_{i}}$ | DORGC | 9 | g/ha · time | |
| $Z_{11_{ki}}$ | GRDEC | 10 | 1/time | |
| $Z_{12_{k}}$ | CBIO(K) | 12 | g/ha | |
| $Z_{13_{k}}$ | RNITNC | 8 | g/ha | |
| $Z_{14_{i}}$ | PROTC | 8 | g/ha | |
| $Z_{15_{i}}$ | RCARB | 8 | g/ha | |
| $Z_{16}$ | GRC | 11 | 1/time | |
| $Z_{17_{z}}$ | TCC | 11 | dimensionless | |
| $Z_{18_{z}}$ | PHCC | 11 | dimensionless | |
| $Z_{19_{z}}$ | SCC | 11 | dimensionless | |
| $Z_{20_{z}}$ | WCC | 11 | dimensionless | |
| $Z_{21_{ki}}$ | D | 12 | 1/time | |
| $Z_{22}$ | VR | 15 | g/ha · time | |
| $Z_{23_{z}}$ | TRC | 15 | dimensionless | |
| $Z_{24_{z}}$ | PHRC | 15 | dimensionless | |
| $Z_{25_{z}}$ | WRC | 15 | dimensionless | |
| $Z_{26_{k}}$ | TNC(K) | 16 | g/ha | |
| $Z_{27_{i}}$ | DIMMO | 18 | g/ha · time | |
| $P_{1_{kf}}$ | CFEPCT(K,F) | 1 | dimensionless | .05 |
| $P_{2}$ | PC2PN | 7 | dimensionless | 4. |
| $P_{3}$ | BN | 8 | dimensionless | .10 |
| $P_{4}$ | BC2BNE | 8 | dimensionless | 1.25 |
| $P_{5}$ | EFC | 9 | dimensionless | .40 |
| $P_{6}$ | MAINC | 9 | 1/time | .0005 |

Table of Variable Names, continued

| SYMBOL | FORTRAN | EQUATION | UNITS | TYPICAL VALUES |
|---|---|---|---|---|
| $P_7$ | KMC | 10 | g/ha | 10000. |
| $P_8$ | KMN | 10 | g/ha | 10000. |
| $P_{9j}$ | GC(J) | 11 | 1/time | .005(SOM) |
| $P_{10}$ | D1 | 12 | 1/time | .020 |
| $P_{11}$ | D2 | 12 | 1/time | .002 |
| $P_{12f}$ | E2CPCT(F) | 13 | dimensionless | .5 |
| $P_{13d}$ | KHC(D) | 15 | 1/time | 10. |
| $P_{14}$ | BE | 15 | dimensionless | .0001 |
| $P_{15d}$ | KMR(D) | 15 | g/ha | 5.0 |
| $P_{16n}$ | BNFAC(N) | 17 | dimensionless | 1.2($WH_4$) |

# COMPUTER IMPLEMENTATION

## DATA REQUIREMENTS AND EXECUTION CHARACTERISTICS

The NITRO and SOILS subroutine write-ups should be referred to for notes on these related programs. For execution, one needs to make linkage with OPT and RAMP subroutines, also (Parnas, 1975; Lommen, 1974). NITRO is not essential, technically speaking.

Environmental zones must first be defined. There is one per horizon plus option for adding distinct zones for surface and standing dead (maximum NZONES = NHORIZ+2). If ISURF = NHORIZ, surface litter will be treated as part of horizon 1. Otherwise, ISURF should equal NHORIZ+1 (if surface and above-surface materials are considered at all).

CBIO biomass values should be one per horizon plus one value for surface (if considered at all and separate from horizon 1) and one value per standing dead type (if considered in addition to surface). GC growth rates are specific to the type of dead material with one value for soil detritus, one for SOM and one value for each separate other detritus type.

One should be doubly sure that CLITT has a non-zero value and that all common blocks (especially STAT and CHNG) are properly complete and aligned.

A flow chart of the decomposition submodel is provided in Figure 4.

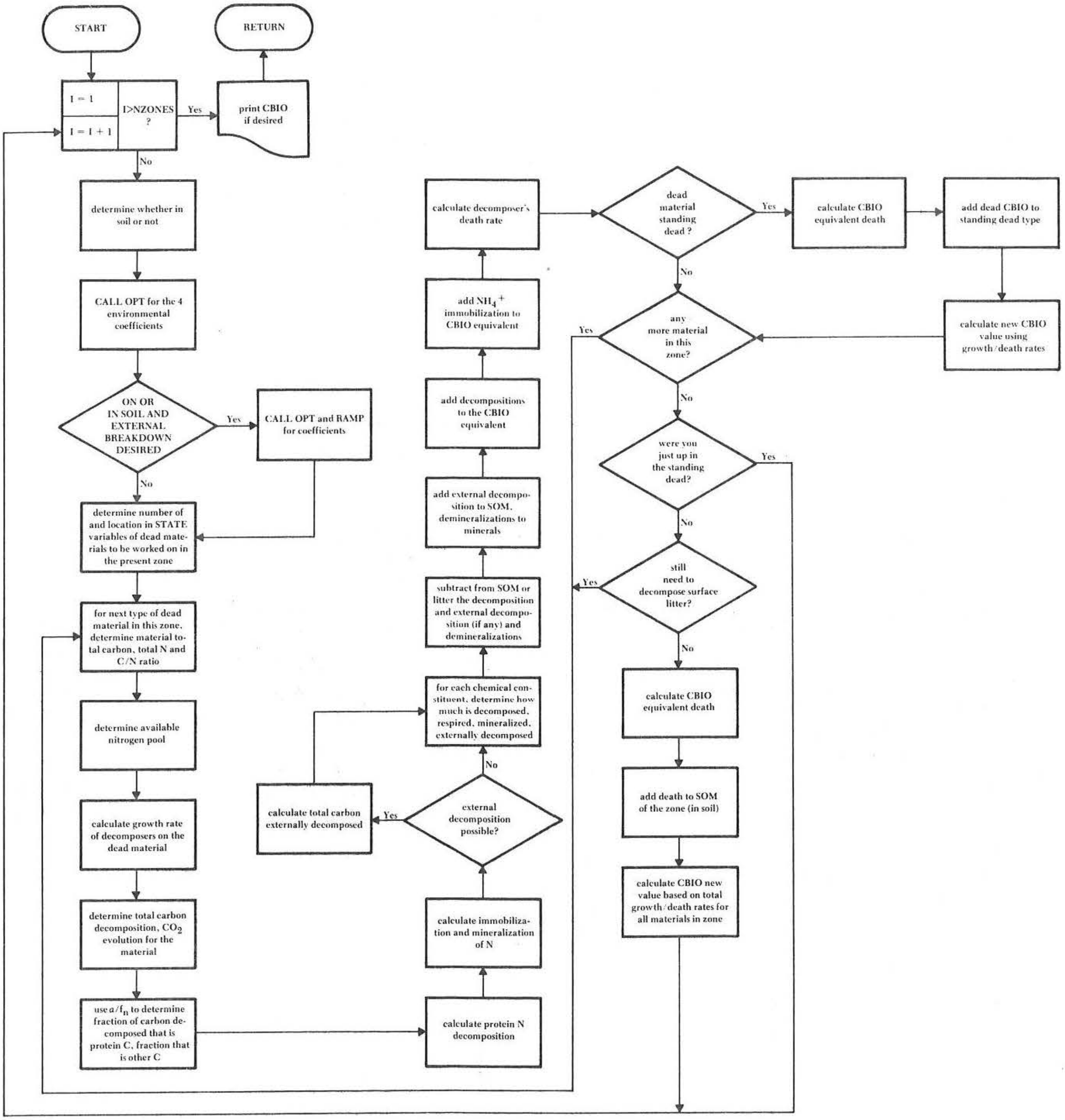

**Figure 4.** Flow chart of decomposition submodel.

## PARAMETER EXPLANATIONS

| | |
|---|---|
| BC2BNE | This is the expression $a/f_n$ which equals the fraction of carbon in decomposer cells divided by the product of fraction of nitrogen and assimilation efficiency (units C assimilated per unit C decomposed). |
| BE | Ratio of units external enzyme present per unit decomposer biomass. |
| BN | Units of nitrogen normally found per unit decomposer biomass (CBIO) in general. |
| BNFAC(N) | Immobilization preference factor for inorganic type of nitrogen N. |
| CBIO(K) | Some measure of total biomass of decomposer biomass *k*. |
| CFEPCT(K,M) | Normal concentration of M in decomposer type *k*, units constituent in per unit total biomass. |
| DUMBIO-(K,M) | Dummy or equivalent biomass corresponding to CBIO(K). Any net assimilation of constituent M by CBIO(K) is added to DUMBIO(K,M); any loss of M from CBIO(K) by death of CBIO(K) is subtracted from DUMBIO(K,M) and added to soil organic matter or other appropriate compartment. Materials in DUMBIO are neither decomposed nor decomposer but may be used in other ways (by ANIMAL subroutine, for instance). |
| D1 | Death rate under conditions of starvation. |
| D2 | Normal non-starvation death rate. |
| EFC | Efficiency of carbon assimilation, units assimilated by CBIO per unit decomposed. |
| E2CPCT(M) | Unit *f* mineralized per unit *f* decomposed. |
| GC(J) | Maximal growth rate on dead material type J by decomposer biomass (part of an exponential expression). |
| IAGN | Pointer for the AGAIN array used to specify exchange of nitrogen with the atmosphere. |
| ICO2 | Pointer for the AGAIN array used to specify exchange of carbon ($CO_2$) with the atmosphere. |
| INH4 | Position in the SMIN (N,INH4) array occupied by ammonium. |
| INIT | The consitutent number of organic N (usually 1). |
| IPC | The constituent number of protein or N-containing carbon compounds. |
| ISOM | Dead material residue number of soil organic matter in general (usually 1); GC (ISOM) is growth rate of decomposers on soil organic matter. |
| ISURF | Surface litter zone number. If ISURF = NHORIZ, then surface litter is considered part of the top horizon. Otherwise, ISURF must equal NHORIZ + 1. Normally ISURF = NHORIZ. |
| KA | Exchange route of AGAIN corresponding to the atmosphere. Normally KA = 1. |
| KHC(IX) | Maximal external breakdown rate by enzymes, unit broken down of dead material IX per unit enzyme. |
| KMC | Michaelis constant for carbon for regular decomposition (calculation of GRDEC rate). |
| KMN | Michaelis constant for nitrogen for regular decomposition (calculation of GRDEC rate). |
| KMR(IX) | Michaelis constant for carbon for external breakdown of dead material type IX. |
| MAINC | Maintenance carbon requirement of a CBIO biomass in units decomposition required per unit CBIO. |
| NNAMLS | If .EQ. 1, PARNAS namelist is printed out. |
| NNIT | Number of inorganic nitrogen pools plus 1. Value should be 4. |
| NR1 | Number of types of dead organic materials available to CBIO(K) when one is in the soil and attempting to utilize soil organic matter and dead roots. Value should usually be 2. |
| NZONES | Number of environmental zones. If only soil horizons are used, NZONES = NHORIZ. If standing dead is dealt with, add 1 to NHORIZ; if surface litter is ever separated from top horizon decomposition, add another 1 to NZONES. |
| PC2PN | Units of protein carbon normally found per unit protein nitrogen in protein (nitrogen-containing compounds) of dead organic matter in general. |
| PHC(JJ) | JJ = 1 gives the pH value below which growth is zero; JJ = 2, JJ = 3 give a range of pH's in which growth coefficient = 1; JJ = 4 gives pH value above which growth is zero. |
| PHCE(JJ) | Same as for PHC but for external breakdown. |
| SAC(JJ) | JJ = 1, JJ = 2 and 3 and JJ = 4 give the same type points as for pH, but this time for salinity. |
| TC(JJ) | JJ = 1, JJ = 2 and 3 and JJ = 4 give the same type points as for pH, but this time for temperature. |
| TCE(JJ) | Same as for TC but for external breakdown. |
| TNC(K) | Total inorganic nitrogen available to CBIO(K). |
| WC(JJ) | JJ = 1, JJ = 2 and 3, JJ = 4 give the same type points as for pH, but this time for water potential (an expression of oxygen content of soil). |
| WCE(JJ) | Same as for WC but for external breakdown. |
| WRTBIO | A logical switch which is set to "Time" if one desires print-out of CBIO values each simulation time unit. |

## LITERATURE CITED

LOMMEN, P. 1974. Soil submodel Version IV, general-purpose model. US/IBP Desert Biome Res. Memo. 74-51. 22 pp.

PARNAS, H. 1975. Model for decomposition of organic material by microorganisms. Soil Biol. and Biochem. (In press)

PARNAS, H., and J. RADFORD. 1974. A nitrogen submodel. US/IBP Desert Biome Res. Memo. 74-62. 12 pp.

## APPENDIX 1

### Program Listing

### *Subroutine* NITRO

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      SUBROUTINE NITRO
      DIMENSION T(5,4),PHK(5,4),SA(5,4),W(5,4),G(5),GM(5),GR(5),CM(7),
     1 BIOM(4,5),V(5),D(5),D1(5),D2(5),CFEPCT(4,6)
      COMMON/ACCINC/ AGAINQ(3,4),DUMAC(6)
      COMMON/SPEC/ SPDUM1(52),NHORIZ,SPDUM2(51),NFRELM,NFRAC1,
     1 SPDUM3(106),ISTD,JSTD,ILIT,JLIT,ILH,SPDUM4(11)
      COMMON/TOTALS/ TDUM1(417),ALIT(15),AORG(5),TDUM2(1022)
      COMMON/STAT/ SDUM1(1470),CLIT(15,6),CORG(5,6),CMIN(5,6),
     1 SDUM2(8),TCOVER,SDUM3(61),SMIN(5,4),SD4(81),FIXN2(5),DUMMY(144)
      COMMON/CHANGE/CDUM1(1470),CLITQQ(15,6),CORGQQ(5,6),CMINQQ(5,6),
     1 CDUM2(70),SMINQQ(5,4),SD4QQ(81),FIXN2Q(5),DUMMYQ(144)
      COMMON/SOINIT/ CI(5),AUTGRO,AUTNIT,SYMNIT(5),B1(5)
      COMMON/SOIDEC/ EXTDEC,CBIO(11)
      COMMON/SOIENV/ TEMP(7),PH(7),SS(7),WATPOT(7),TNC(6)
      LOGICAL SYMFIX,HETFIX,VOLATL,WRTNIT
      REAL K3,KM3,K4,KM4,MAIN3,MAIN4
      DATA SYMFIX/.TRUE./,HETFIX/.TRUE./,VOLATL/.TRUE./,WRTNIT/.FALSE./
C----------------------------------------------------------------------
C..........NAMELIST OF PARAMETERS
C..........FOR DETAILS, SEE 1973 BIOME SEPARATES
      NAMELIST/HANNA/          A3      ,A4      ,A5      ,BIOM    ,
     * BN     ,BNH4   ,BNO2   ,BNO3   ,B3      ,B4      ,CBFAC   ,CFEPCT,
     * CION   ,CM     ,D1     ,D2     ,FVNH4   ,GM      ,HETFIX,IAGN    ,
     * TCO2   ,INH4   ,INIT   ,INO2   ,INO3    ,IR      ,KA      ,KM3     ,KM4    ,
     * K3     ,K4     ,LDUM   ,MAIN3  ,MAIN4   ,NNAMLS,PHK       ,PHMAX   ,PHMIN  ,
     * SA     ,SYMFIX,T       ,TMAX   ,TMIN    ,VMAX    ,VOLATL,W         ,WRTNIT
      IL=ILH   ,
C----------------------------------------------------------------------
C..........NITROGEN TRANSFORMATIONS FOR EACH SOIL HORIZON
      DO 17 N=1,NHORIZ
      DO 5 I=1,IR
C..........ENVIRONMENTAL COEFFICIENTS FOR EACH TRANSFORMATION TYPE I
      CALL OPT(T(I,1),T(I,2),T(I,3),T(I,4),TEMP(N),TC)
      CALL OPT(PHK(I,1),PHK(I,2),PHK(I,3),PHK(I,4),PH(N),PHC)
      CALL OPT(SA(I,1),SA(I,2),SA(I,3),SA(I,4),SS(N),SC)
      CALL OPT(W (I,1),W (I,2),W (I,3),W (I,4),WATPOT(N),WC)
C..........GROWTH RATE FOR BIOMASS INVOLVED IN TRANSFORMATION I
      G(I)=GM(I)*TC*PHC*SC*WC
      GR(I)=0.0
      V(I)=0.0
      D(I)=D1(I)
    5 CONTINUE
C----------------------------------------------------------------------
C..........TOTAL SOIL CARBON IN DEAD MATERIALS
      TOTOC =AORG(N)+ALIT(IL)
C..........SYMBIOTIC FIXATION
      IF (.NOT.SYMFIX) GO TO 15
      GR(1)=G(1)*CI(N)/(CM(1)+CI(N))
      IF(CI(N).GT.0.0)D(1)=D2(1)
C..........FREE HETEROTROPHIC FIXATION
   15 IF (.NOT.HETFIX) GO TO 20
      GR(2)=G(2)*TOTOC/(CM(2)+TOTOC)
      IF (TOTOC .GT.0.0) D(2)=D2(2)
      V(2)=BIOM(2,N)*(1.-1./EXP(D(2)))
C..........OXIDATION OF NH4 TO NO2
   20 GR(3)=G(3)*SMIN(N,INH4)/(CM(3) +SMIN(N,INH4))
      IF (SMIN(N,INH4).GT.0.0) D(3)=D2(3)
      V6=(A3*GR(3)+MAIN3+K3*B3*SMIN(N,INH4)/
     *         (SMIN(N,INH4)+KM3))*BIOM(3,N)
      V6TOB3=AMIN1(V6,GR(3)*BN*BIOM(3,N)/A3)
      DEATH3=BIOM(3,N)*(1.-1./EXP(D(3)))
C..........OXIDATION OF NO2 TO NO3
      GR(4)=G(4)*SMIN(N,INO2)/(CM(4) +SMIN(N,INO2))
      IF (SMIN(N,INO2).GT.0.0) D(4)=D2(4)
      V7=(A4*GR(4)+MAIN4+K4*B4*SMIN(N,INO2)/
     *         (SMIN(N,INO2)+KM4))*BIOM(4,N)
      V7TOB4=AMIN1(V7,GR(4)*BN*BIOM(4,N)/A4)
      DEATH4=BIOM(4,N)*(1.-1./EXP(D(4)))
C..........DENITRIFICATION BY PART OF DECOMPOSER BIOMASS CBIO
      GG=G(5)*(SMIN(N,INO2)+SMIN(N,INO3))*CION/((SMIN(N,INO2)+
     1 SMIN(N,INO3)+CM(5))*(CION+WATPOT(N)))
      GR(5)=GG*TOTOC/(CM(6)+TOTOC)
      IF (TOTOC .GT.0.0) D(5)=D2(5)
      V8=A5*GR(5)*CBIO(N)/CBFAC
C..........NH3 VOLATILIZATION
      IF (N.GT.1.OR.(.NOT.VOLATL)) GO TO 14
      CALL RAMP(TMIN,TMAX,TEMP(N),TC8)
      CALL RAMP(PHMIN,PHMAX,PH(N),PHC8)
      CALL DCLIN(VMAX,TCOVER,SOCOC)
      V10=SMIN(N,INH4)*TC8*PHC8*SOCOC*FVNH4
      GO TO 19
   14  V10=0.0
C..........IMMOBILIZATION OF MINERAL NITROGEN BY FIXERS
C..........V111 IS GROWTH REQUIREMENT, V11-- ARE UTILIZATIONS OF PARTI-
C..........CULAR TYPES OF N BASED ON PREFERENCES
   19 IF (N.GT.1) V111=(GR(1)*BIOM(1,N)+GR(2)*BIOM(2,N))*BN
      IF (N.LE.1) V111=(GR(1)*BIOM(1,N)+GR(2)*BIOM(2,N)+AUTGRO)*BN
      V11=V111*TNC(N)/(TNC(N)+CM(7))
C----------------------------------------------------------------------
C..........RESULTANT CHANGES IN NITROGEN POOLS
C..........AMMONIUM
      IF (SMIN(N,INH4).LE.0.0) GO TO 30
      V11NH4=V11*BNH4*SMIN(N,INH4)/TNC(N)
      SMINQQ(N,INH4)=SMINQQ(N,INH4)-V11NH4-V6-V10
      GO TO 35
   30 V10=0.0
      V11NH4=0.0
      V6=0.0
C..........NITRITE
   35 IF (SMIN(N,INO2).LE.0.0) GO TO 40
      V11NO2=V11*BNO2*SMIN(N,INO2)/TNC(N)
   38 SMINQQ(N,INO2)=SMINQQ(N,INO2)-V11NO2+V6-V6TOB3-V7-V8*SMIN(N,INO2)
     */(SMIN(N,INO3)+SMIN(N,INO2))
      GO TO 45
   40 V7=0.0
      V11NO2=0.0
C..........NITRATE
      SMINQQ(N,INO2)=SMINQQ(N,INO2)+V6-V6TOB3
   45 IF (SMIN(N,INO3).LE.0.0) GO TO 50
      V11NO3=V11*BNO3*SMIN(N,INO3)/TNC(N)
   48 SMINQQ(N,INO3)=SMINQQ(N,INO3)-V11NO3+V7-V7TOB4-V8*SMIN(N,INO3)/
     *  (SMIN(N,INO3)+SMIN(N,INO2))
      GO TO 55
   50 V11NO3=0.0
      SMINQQ(N,INO3)=SMINQQ(N,INO3)+V7-V7TOB4
C..........GAIN IN ORGANIC NITROGEN
   55 AUTNIT=0.0
      IF (N.EQ.1) AUTNIT=AUTGRO*BN
      SYMNIT(N)=GR(1)*BIOM(1,N)*BN
C..........DHUMNI IS CONTRIBUTION OF N TO SOIL ORGANIC MATTER VIA DEATH
      DHUMNI=(V(2)+DEATH3+DEATH4)*BN
      CORGQQ(N,INIT)=CORGQQ(N,INIT)+DHUMNI
C----------------------------------------------------------------------
C..........CHANGES IN BIOMASSES AND IN THE CLIT(LDUM,*) EQUIVALENT
      DO 65 I=1,4
      A=BIOM(I,N)
      BIOM(I,N)=BIOM(I,N)*EXP(GR(I)-D(I))
      IF (I.LT.2) GO TO 65
      CHANGE=BIOM(I,N)-A
      DO 62 K=2,NFRELM
      IF (CLIT(LDUM,K).LE.0.0) GO TO 62
      CLITQQ(LDUM,K)=CLITQQ(LDUM,K)+CFEPCT(I,K)*CHANGE
      CORGQQ(N,K)=CORGQQ(N,K)-CFEPCT(I,K)*CHANGE
   62 CONTINUE
   65 CONTINUE
C..........CHANGE IN DECOMPOSERS DUE TO DENITRIFICATION
      DCBIO=(EXP(GR(5)-D(5))-1.)*CBIO(N)/CBFAC
      CBIO(N)=CBIO(N)+DCBIO
C..........COMPUTATIONS NEEDED TO INTERFACE WITH SIMULATION SYSTEM
      CLITQQ(LDUM,INIT)=CLITQQ(LDUM,INIT)+V111-AUTNIT-SYMNIT(N)-DHUMNI+
     *  V6TOB3+V7TOB4
      AGAINQ(KA,IAGN)=AGAINQ(KA,IAGN)+V111-V11NH4-V11NO2-V11NO3-V8-V10
      B1(N)=BIOM(1,N)
      FIXN2Q(N)=FIXN2Q(N)+V111-V11NH4-V11NO2-V11NO3
      IL=IL+1
      IF (WRTNIT) WRITE(6,3)N,DHUMNI,V11,V111,V11NH4,V11NO2,V11NO3,V6,
     * V7,V8,V10
    3 FORMAT(I5,10E10.5)
   17  CONTINUE
      RETURN
C----------------------------------------------------------------------
C..........NAMELIST READ/WRITE
      ENTRY SNINH
      READ(5,HANNA)
      IF(NNAMLS.LE.0)RETURN
      WRITE(6,HANNA)
      RETURN
      END
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### *Subroutine* DECOMP

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      SUBROUTINE DECOMP

      DIMENSION GC(12),KHC(10),KMR(10),BNFAC(4),E2CPCT(6),CFEPCT(11,6)
      DIMENSION TC(4),PHC(4),SAC(4),WC(4),TCE(4),PHCE(4),WCE(4)
      LOGICAL INSOIL,SOM,EXTDEC,WRTBIO
      REAL KMN,KMC,KMR,MAINC,KHC

      COMMON/ACCINC/ AGAINQ(3,4),DUMAC(6)
      COMMON/SPEC/ SPDUM1(52),NHORIZ,SPDUM2(51),NFRELM,NFRAC1,
     1 SPDUM3(106),ISTD,JSTD,ILIT,JLIT,ILH,SPDUM4(11)
      COMMON/TOTALS/TDUM1(190),CLITT(15),TDUM2(212),ALIT(15),AORG(5),
     1  TDUM3(1022)
      COMMON/STAT/ SDUM1(1470),CLIT(15,6),CORG(5,6),CMIN(5,6),
     1 SDUM2(70),SMIN(5,4),DUMBIO(11,6),CO2(15),DUMMY(149)
      COMMON/CHANGE/CDUM1(1470),CLITQQ(15,6),CORGQQ(5,6),CMINQQ(5,6),
     1 CDUM2(70),SMINQQ(5,4),DUMBIQ(11,6),CO2QQQ(15),DUMMYQ(149)

      COMMON/SOIENV/ TEMP(7),PH(7),SS(7),WATPCT(7),TNC(6)
      COMMON/SOIDEC/ EXTDEC,CBIO(11)

      DATA WRTBIO/.FALSE./

C----------------------------------------------------------------------
C..........NAMELIST OF PARAMETERS
C..........FOR EXPLANATIONS OF PARAMETER MEANINGS, SEE THE DESERT BIOME
C..........WRITE-UP(SEPARATE PUBLICATION FOR 1973) WHEREIN PARAMETERS
C..........ARE LISTED
      NAMELIST/PARNAS/ BC2BNE,BE    ,BN      ,BNFAC ,CBIO   ,CFEPCT,D1    ,
     * D2     ,DUMBIO,EFC    ,E2CPCT,GC      ,IAGN  ,TCO2   ,INH4  ,INIT  ,
     * IPC    ,ISOM  ,ISURF  ,KA    ,KHC     ,KMC   ,KMN    ,KMR   ,MAINC ,
     * NNAMLS,NNIT   ,NR1    ,NZONES,PC2PN   ,PHC   ,PHCE   ,SAC   ,
     * TC     ,TCE   ,WC     ,WCE   ,WRTBIO
      IX=0
      IL=ILH
C----------------------------------------------------------------------
C..........DECOMPOSITION FOR EACH ENVIRONMENTAL ZONE IN SOIL AND ABOVE
      DO 2000 I=1,NZONES
      D=D1
      TGR=0.0
      INSOIL=.TRUE.
      IF (I.GT.NHORIZ) INSOIL=.FALSE.
C..........DETERMINE ENVIRONMENTAL COEFFICIENTS FOR PRESENT ZONE
      CALL OPT(TC(1),TC(2),TC(3),TC(4),TEMP(I),TCC)
      CALL OPT(PHC(1),PHC(2),PHC(3),PHC(4),PH(I),PHCC)
      CALL OPT(SAC(1),SAC(2),SAC(3),SAC(4),SS(I),SCC)
      CALL OPT(WC(1),WC(2),WC(3),WC(4),WATPCT(I),WCC)
      IF (I.GT. ISURF .OR. .NOT.EXTDEC) GO TO 15
C..........ENVIRONMENTAL COEFFICIENTS FOR ENZYMES INVOLVED IN EXTERNAL
C..........BREAKDOWN OF LITTER AND DEAD ROOTS
      CALL OPT(TCE(1),TCE(2),TCE(3),TCE(4),TEMP(I),TRC)
      CALL OPT(PHCE(1),PHCE(2),PHCE(3),PHCE(4),PH(I),PHRC)
      CALL RAMP(WCE(1),WCE(2),WATPCT(I),WRC)
C----------------------------------------------------------------------
C..........DETERMINE THE NUMBER OF TYPES OF DEAD MATERIAL TO DECOMPOSE
C..........IN THE PRESENT ZONE.
   15 IR=0
      NR=NR1
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      IF (INSOIL) GO TO 1000
      IF (I.NE.ISURF) GO TO 18
C..........EXECUTION COMES TO THIS POINT IF SURFACE LITTER IS DEALT WITH
C..........AS A PART OF THE TOP SOIL HORIZON ZONE
   16 IR=ILIT-1
      NR=JLIT
      GO TO 1000
   18 IR=ISTD-1
      NR=JSTD
C-----------------------------------------------------------------------
 1000 IR=IR+1
      VR=0.0
      DMINR=0.0
      DIMMO=0.0
      SOM=.FALSE.
      L=IL
C..........FIND VALUES FOR TOTAL CARBON, TOTAL NITROGEN AND PROTEIN CAR-
C..........BON FOR THE APPROPRIATE TYPE OF DEAD MATERIAL OR SOIL ORGANIC
C..........MATTER
      IF((.NOT.INSOIL).OR.IR.NE.ISOM) GO TO 20
      SOM=.TRUE.
      RCARB=AORG(I)
      RNIT=CORG(I,INIT)
      PROTC=CORG(I,IPC)
      GO TO 30
   20 IF (.NOT.INSOIL) L=IR
      RCARB=ALIT(L)
      RNIT=CLIT(L,INIT)
      PROTC=CLIT(L,IPC)
   30 CONTINUE
      IF (RCARB.LE.0.0) GO TO 300
C..........CARBON/NITROGEN RATIO
      CN=0.0
      IF (RNIT.GT.0.0) CN=RCARB/RNIT
C-----------------------------------------------------------------------
C..........K IS THE BIOMASS NUMBER WITH WHICH ONE DECOMPOSES THE PRESENT
C..........DEAD MATERIAL BEING WORKED ON.  J DETERMINES THE GROWTH RATE
C..........OF BIOMASS' K IN PART AND DEPENDS ON TYPE OF DEAD MATERIAL
      K=I
      IF (I.GT.ISURF) K=ISURF+IR-ISTD+1
      IF (INSOIL) J=IR
      IF (.NOT.INSOIL) J=J+1
C..........AVAILABLE NITROGEN POOL
      IF (I.LE.ISURF) RNITNC=RNIT+TNC(K)
      IF (I.GT.ISURF) RNITNC=RNIT
      GRC= GC(J)*TCC*PHCC*SCC*WCC
C..........GRDEC IS GROWTH RATE OF K ON PRESENT DEAD MATERIAL TYPE
      GRDEC=GRC*RCARB*RNITNC/((KMC+RCARB)*(KMN+RNITNC))
      TGR=TGR+GRDEC
C..........TOTAL CARBON DECOMPOSITION
      DORGC=(GRDEC/EFC+MAINC)*CBIO(K)
      DCO2=(1.-EFC)*DORGC
      CO2QQQ(L)=CO2QQQ(L)+DCO2
C..........PROTEIN CARBON DECOMPOSITION
      IF (CN.GE.PC2BNE) GO TO 103
      DPROTC=DORGC*PROTC/RCARB
      GO TO 105
  103 DPROTC=PC2PN*BN*GRDEC*CBIO(K)*RNIT/RNITNC
C..........OTHER CARBON DECOMPOSITION
  105 DOTHRC=DORGC-DPROTC
C..........PROTEIN NITROGEN DECOMPOSITION
      DORGN=DPROTC/PC2PN
C..........MINERALIZATION/IMMOBILIZATION
      DMINR=DORGN-BN*GRDEC*CBIO(K)*RNIT/RNITNC
      DIMMO=BN*GRDEC*CBIO(K)*(RNITNC-RNIT)/RNITNC
C..........EXTERNAL BREAKDOWN
      IF (SOM.OR.I.GT.ISURF.OR.(.NOT.EXTDEC)) GO TO 110
      IX=IX+1
      KEX=KHC(IX)*TRC*PHRC*WRC
      VR=KEX*BE*CBIO(K)*RCARB/(KMR(IX)+RCARB)
  110 CONTINUE
C-----------------------------------------------------------------------
C..........CHANGES IN CONCENTRATIONS OF DEAD MATERIAL CONSTITUENTS
      II=I
      IF (.NOT.INSOIL) II=1
      DO 200 M=1,NFRELM
      IF ((SOM.AND.CORG(II,M).LE.0.).OR.(.NOT.SOM.AND.CLIT(L,M).LE.0.))
     *          GO TO 200
      DLOS=0.0
      EXTLOS=0.0
      IF (.NOT.SOM) EXTLOS=(CLIT(L,M) /CLITT(L))*VR
      IF (M.EQ.INIT) DLOS=DLOS+DORGN
      DMINRL=0.0
C..........CFEPCT DETERMINES THE REQUIREMENT OF BIOMASS K FOR CONSTITUENT
C..........M RELATIVE TO TOTAL CARBON DECOMPOSITION. E2CPCT IS LIKE AN
C..........INEFFICIENCY OF UTILIZATION OF CONSTITUENT M--UNITS M MINERAL-
C..........IZED PER UNIT M ASSIMILATED
      IF (M.NE.INIT.AND.M.LT.NFRAC1) DMINRL=E2CPCT(M)*CFEPCT(K,M)*DORGC
      IF (M.EQ.IPC) DLOS=DLOS+DPROTC
      IF (M.EQ.IPC.OR.M.LT.NFRAC1) GO TO 140
      IF (SOM) DLOS=DLOS+(CORG(II,M)/(AORG(I)-PROTC))*DOTHRC
      IF (.NOT.SOM) DLOS=DLOS+(CLIT(L,M) /(ALIT(L)-PROTC))*DOTHRC
C..........ADD AND SUBTRACT CHANGES
  140 IF (SOM) CORGQQ(I,M)=CORGQQ(I,M)-DLOS-DMINRL
      IF (.NOT.SOM) CLITQQ(L,M)=CLITQQ(L,M)-DLOS-EXTLOS-DMINRL
      CORGQQ(II,M)=CORGQQ(II,M)+EXTLOS
      CMINQQ(II,M)=CMINQQ(II,M)+DMINRL
C..........RESPIRATION
      R=0.0
      IF (M.GE.NFRAC1) R=DCO2*(DLOS/DORGC)
C..........DUMBIO IS A STATE VARIABLE EQUIVALENT TO CBIO
      DUMBIQ(K,M)=DUMBIQ(K,M)+DLOS-R
      AGAINQ(KA,ICO2)=AGAINQ(KA,ICO2)-R
  145 IF (M.NE.INIT) GO TO 200
      IF (DIMMO.LE.0.0.OR.I.GT.ISURF) GO TO 160
      DO 150 N=2,NNIT
      IF (SMIN(II,N) .LE.0.0) GO TO 150
      DIM=DIMMO*BNFAC(N)*SMIN(II,N)/TNC(K)
      SMINQQ(II,N) =SMINQQ(II,N) -DIM
      DUMBIQ(K,M)=DUMBIQ(K,M)+DIM
  150 CONTINUE
  160 IF (SOM) CORGQQ(II,M)=CORGQQ(II,M)-DMINR
      IF (.NOT.SOM) CLITQQ(L,M)=CLITQQ(L,M)-DMINR
      SMINQQ(II,INH4)=SMINQQ(II,INH4)+DMINR
  200 CONTINUE
C..........DEATH RATE OF DECOMPOSERS
      IF (RCARB.GT.0.0) D=D2
  300 IF (I.LE.ISURF) GO TO 1500
C..........BIOMASS OF DECOMPOSERS IN STANDING DEAD
      VD=CBIO(K)*(1.-1./EXP(D))
      DO 1400 M=1,NFRELM
      IF (DUMBIO(K,M).LE.0.0) GO TO 1400
      DUMBIQ(K,M)=DUMBIQ(K,M)-CFEPCT(K,M)*VD
      CLITQQ(L,M)=CLITQQ(L,M)+CFEPCT(K,M)*VD
 1400 CONTINUE
      CBIO(K)=CBIO(K)*EXP(GRDEC-D)
      D=D1
C..........IF THERE ARE ANY MORE TYPES OF DEAD MATERIAL AVAILABLE FOR
C..........THIS ZONE, GO GET THE NEXT TYPE. ELSE, GO TO NEXT ZONE
 1500 IF (IR.LT.NR) GO TO 1000
C-----------------------------------------------------------------------
      IF (I.GT.ISURF) GO TO 2000
      IF (INSOIL.AND.ISURF.EQ.NHORIZ.AND.I.EQ.1) GO TO 1600
C..........BIOMASS OF SURFACE AND/OR SOIL DECOMPOSER POPULATIONS
      VD=CBIO(K)*(1.-1./EXP(D))
      DO 1550 M=1,NFRELM
      IF (DUMBIO(K,M).LE.0.0) GO TO 1550
      DUMBIQ(K,M)=DUMBIQ(K,M)-CFEPCT(K,M)*VD
      CORGQQ(II,M)=CORGQQ(II,M)+CFEPCT(K,M)*VD
 1550 CONTINUE
      CBIO(K)=CBIO(K)*EXP(TGR-D)
 1600 IF (.NOT.INSOIL) GO TO 2000
C..........DO THIS WHEN SURFACE LITTER IS BEING DECOMPOSED BY HORIZON 1
C..........POPULATION
      IL=IL+1
      IF (ISURF.NE.NHORIZ.OR.I.NE.1) GO TO 2000
      INSOIL=.FALSE.
      GO TO 16
 2000 CONTINUE
C-----------------------------------------------------------------------
      IF (WRTBIO) WRITE(6,222) (CBIO(K),K=1,10)
  222 FORMAT(2X,10E12.3)
      RETURN
C-----------------------------------------------------------------------
C..........NAMELIST INPUT/WRITE-OUT
      ENTRY SNIN
      READ(5,PARNAS)
      IF(NNAMLS.EQ.1)WRITE(6,PARNAS)
      RETURN
      END
```

## *Subroutine* OPT

```
      SUBROUTINE OPT(AMIN1,AMAX1,AMAX2,AMIN2,RX,FR)
      IF(RX.LE.AMIN1.OR.RX.GE.AMIN2)GO TO 110
      IF(RX.GE.AMAX1.AND.RX.LE.AMAX2)GO TO 101
      IF(RX.GT.AMIN1.AND.RX.LT.AMAX1)GO TO 102
      IF(RX.GT.AMAX2.AND.RX.LT.AMIN2)GO TO 103
  110 FR=0.0
      GO TO 104
 101  FR=1.0
      GO TO 104
 102  FR=(RX-AMIN1)/(AMAX1-AMIN1)
      GO TO 104
 103  FR=(RX-AMAX2)/(AMIN2-AMAX2)
 104  RETURN
      END
```

## *Subroutine* DCLIN

```
      SUBROUTINE DCLIN(AMAXX,RX,FRAC)
      MX=AMAXX
      IF(MX.EQ.0)GO TO 302
      IF(RX.GE.AMAXX)GO TO 300
      FRAC=1.0-RX/AMAXX
      GO TO 301
  300 FRAC=0.0
      GO TO 301
  302 FRAC=1.0
  301 RETURN
      END
```

## *Subroutine* RAMP

```
      SUBROUTINE RAMP(AMINX,AMAXX,RX,FRAC)
      IF(RX.GE.AMAXX)GO TO 1
      IF(RX.LE.AMINX)GO TO 2
      FRAC=(RX-AMINX)/(AMAXX-AMINX)
      GO TO 3
 1    FRAC=1.0
      GO TO 3
 2    FRAC=0.0
 3    RETURN
      END
```

# APPENDIX 2

## INPUT/OUTPUT EXAMPLE

### *Data Listing*

```
   CHEERS TO GOLDA

 LICHEN HEATH WITH DATA FOR DECOMPOSITION RUN 1
   0    0    0    3    7   10    0    0    4    0    7    0    0    0
   1 1979   40    0    6    0
   0    0    1    0    0
NITROGEN    ANIONS       CATIONS      PROTEIN C   RESERVE C   STRUCTURAL C
DEAD LICHEN              DEAD MOSS                WOODY LITTER
HERBACEOUS LITTER        DEAD ROOTS 0-2CM         DEAD ROOTS 2-8CM
DEAD ROOTS 8-18 CM       DEAD ROOTS 18-35 CM      DUMMY MICROBES(N)
DUMMY MICROBES(D)
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
  1.00      1.00      1.00      1.85      2.5       2.5
  1.00      1.00      1.00      1.85      2.5       2.5
    0.        0.        0.        2.00      2.00      2.00
   0    0    1    4    5    8
  20.       80.       180.      350.
    2500.      750.     1500.     8595.    47400.   144000.   DEAD LICHEN
     358.       40.      224.     1232.     2710.    13978.   DEAD MOSS
     946.       52.      220.     3252.      188.    30960.   LITTER WOOD
   14320.      755.     3800.    49230.    84450.   314320.   LITTER HERBACEOUS
     217.       12.       44.      745.      783.     7440.   ROOTS-2
    1807.      100.      368.     6210.     3191.    61999.   ROOTS8
    1156.       63.      235.     7975.     2042.    39679.   ROOTS-18
     433.       24.       89.     1490.      766.    14880.   ROOTS-35
 1000.     1000.     10000.    10000.    10000.    10000.       DUMMY MICROBES
1100000. 1100000.  1100000.  1100000.  1100000.  1100000.  DUMMY MICROBES(D)
  956377.    31140.   166080.  3287550.   864450. 16608000.   ORGA. MATTER 0-2
    1469.     3000.    77800.      5.5         .         .   MINERALS 0-2
  387928.    14040.    74880.  1333500.   257700.  7768800.   ORG.MATTER 2-8
      87.     3100.    28900.      11.         .         .   MINERALS 2-8
  797237.    28800.   153600.  2740500.   523500. 15936000.   ORG. MATTER 8-18
      66.    16000.    27200.      13.         .         .   MINERALS 8-1
  266467.    16320.    87040.   915980.   172020.  9792000.   ORG. MATTER 18-35
      36.    27200.    40800.       0.         .         .   MINERALS 18-35

10433
TOTAL SOM CARBON IN TOP 0-2CM
GRAMS PER HECTARE
10419104201042210425
TOTAL CARBON IN LITTER TYPES
GRAMS PER HECTARE
DEAD MOSS
WOODY LITTER
DEAD ROOTS 0-2CM
DEAD ROOTS 18-35CM
01696
AMMONIUM IN TOP 2CM
GM/HA
 1701 1706
NO2 AND NO3 IN TOP 2CM
GRAMS PER HECTARE
NO2 0-2CM
NO3 0-2CM
 1781 1782 1783 1784
CO2 EVOLUTION — CUMULATIVE CARBON
GRAMS PER HECTARE
0-2 CM
2-8 CM
8-18 CM
18-35 CM
 1792 1793 1794 1795
NITROGEN EXCHANGE WITH ATMOSPHERE  (+INPUT,-OUTPUT)
GM/HA
0-2 CM
2-8 CM
8-18 CM
18-35 CM
 $IN
  I=1,
  MDUM=10,
  SMIN=5*000000.,1428.,77.,41.,21.,0.,  5*0.,  41.,10.,25.,15.,0.,
  TCOVER=.50,
  P=20*  4.0, 20*  4.3, 20*  4.8, 20*  5.2,
  S=140*6.0,
  T=20* 11.0, 20*  9.9, 20*  9.5, 20*  9.2,
  W=20*-10.0, 20* -8.0, 20* -8.0, 20* -8.0,
  $END
 $HANNA
  A3=16., A4=16., A5=.50,
  CFEPCT=4*0., 4*.10, 4*.15, 4*.10, 4*.30, 4*.05,
  BIOM= 70.,  44.,  44.,  77.,  0.0,
        70.,  44.,  44.,  77.,  0.0,
        70.,  44.,  44.,  77.,  0.0,
    150.,  50.,  50.,  150.,  0.,
  BN=.10,  BNH4=1.0,  BNO2=.10,  BNO3=.30,  B3=.0005,  B4=.0005,
  CBFAC=2.0,  CION=-.00001,
  CM= 10., 10000., 100., 1000., 1000., 10000., 1000.,
  D1=5*.02, D2=5*.002, FVNH4=.01,
  GM=1.4,  1.4,  .70,  7.0,  .0001,
  HETFIX=.TRUE.,  IACN=1,  ICO2=3,  INH4=2,  INIT=1,  INO2=3,  INO3=4,
  IR=5,  KA=1,  KM3=1.0,  KM4=1.0,  K3=1.0,  K4=1.0,
  LDUM=9,
  MAIN3=.00005,  MAIN4=.00005,
  NNAMLS=1,
  PHK= 5*0.0,  5*7.0,  5*9.0,  5*11.0,
  PHMAX= 9.0,  PHMIN=7.0,
  SA= 5*0.0,  5*0.0,  5*4.0,  5*10.,
  SYMFIX=.TRUE.,
  T=5*0.0,  5*25.,  5*35.,  5*45.,
  TMAX=50.,  TMIN=10.,  VMAX=.85,  VOLATL=.TRUE.,
  W=5*-15.,  5*-2.0,  5*-.10,  5*0.0,
  WRTNIT=.TRUE.,
  $END
 $PARNAS
  BC2BNE=12.5,BE=.0001, BN=.10, BNFAC=0., 1.0,.10,.30,
  CBIO=90000.,90000.,11.,5.,
  CEEPCT=11*0., 11*.10, 11*.15, 11*.10, 11*.30, 11*.05,
```

```
DUMBIO=66*100000.,
D1=.02, D2=.002,
EFC=0.4,
E2CPCT=0., 5*.10,
GC=.050, .050, .01, .05, .05, .03,
IAGN=1, ICO2=4, INH4=2, INIT=1, IPC=4, ISOM=1, ISURF=4,
KA=1, KHC=4*5., 20.,10.,2.0,5.0,     KMC=10000., KMN=10000.,
KMR=10*5.0,  MAINC=.0005, NNAMLS=1, NNIT=4, NR1=2,
NZONES=4, PC2PN=4.,
PHC=0.0,6.0,8.0,10.0,
PHCE=0.0,7.0,8.0,9.5,
RESPRT=3*0.,.30,.50,.20,
SAC=0.0,0.0,4.0,10.0,
TC=0.0,25.,35.,50.,
TCE=0.0,30.,35.,45.,
WC=-15.0,-4.0,-2.0,-.00,
WCE=-15.,-0.0,
WRTBIO=.TRUE.,
 $END
```

## Simulation Run

```
  LICHEN HEATH WITH DATA FOR DECOMPOSITION RUN 1

INITIAL REPORT ON JAN   1 1978                                                                     1.092 SECONDS ELAPSED

CONSTITUENTS OF DEAD ORGANIC MATERIAL, G. OR KCAL. PER HECTARE
    TYPE OF MATERIAL          NITROGEN     ANIONS      CATIONS      PROTEIN C    RESERVE C   STRUCTURAL C   TOTAL C    DRY MATTER
DEAD LICHEN                    2500.00      250.00      1500.00      8595.00     47405.00     144000.00   200000.00    498663.25
DEAD MOSS                       358.00       40.00       224.00      1232.00      2710.00      13979.00    17920.00     44621.20
WOODY LITTER                    946.00       52.00       220.00      3252.00       188.00      30960.00    34400.00     85104.20
HERBACEOUS LITTER             14320.00      755.00      3800.00     49230.00     84450.00     314320.00   448000.00   1106875.48
DEAD ROOTS 0-2CM                217.00       12.00        44.00       745.00       383.00       7440.00     8568.00     21208.75
DEAD ROOTS 2-8CM               1807.00      100.00       368.00      6210.00      3191.00      61999.00    71400.00    176738.50
DEAD ROOTS 8-18 CM             1156.00       63.00       235.00      3975.00      2042.00      39679.00    45696.00    113110.25
DEAD ROOTS 18-35 CM             433.00       24.00        89.00      1490.00       766.00      14880.00    17136.00     42417.50
DUMMY MICROBES(N)              1000.00     1000.00     10000.00     10000.00     10000.00       1000.00    30000.00     80500.00
DUMMY MICROBES(D)           1100000.00  1100000.00   1100000.00   1100000.00   1100000.00    1100000.00  3300000.00  10834999.87
         TOTAL              1122737.00  1102296.00   1116480.00   1184729.00   1251135.00    1737256.00  4173120.00  13004238.87

SOIL VARIABLES
                               NITROGEN      ANIONS       CATIONS      PROTEIN C    RESERVE C   STRUCTURAL CTOTAL C    ORG.D.M.
ORGANIC MATTER CONSTITUENTS
   FROM   0. TO   20. MM.     956377.00    31140.00    166080.00   3287550.00    864450.00 16608000.00 20760000.00 41520000.00
   FROM  20. TO   80. MM.     387928.00    14040.00     74880.00   1333500.00    257700.00  7768800.00  9360000.00 18720000.00
   FROM  80. TO  180. MM.     797237.00    28800.00    153600.00   2740500.00    523500.00 15936000.00 19200000.00 38400000.00
   FROM 180. TO  350. MM.     266467.00    16320.00     87040.00    915980.00    172020.00  9792000.00 10880000.00 21760000.00
         TOTAL               2408009.00    90300.00    481600.00   8277530.00   1817670.00 50104800.00 60200000.0012040000.00
IN MINERAL FRACTION
   FROM   0. TO   20. MM.       1469.00     3000.00     77800.00
   FROM  20. TO   80. MM.         87.00     3100.00     28900.00
   FROM  80. TO  180. MM.         66.00    16000.00     27200.00
   FROM 180. TO  350. MM.         36.00    27200.00     40800.00
         TOTAL                  1658.00    49300.00    174700.00

TOTAL, SOIL AND DEAD
    ORGANIC MATERIAL         3532404.00  1241896.00  1772780.00   9462259.00   3068805.00 51842056.00 64373120.0013340423 8.00

TOTAL IN ECOSYSTEM           3532404.00  1241896.00  1772780.00   9462259.00   3068805.00 51842056.00 64373120.0013340423 8.00

SOIL WATER POTENTIAL, ATM.
   FROM   0. TO   20. MM.           .00
   FROM  20. TO   80. MM.           .00
   FROM  80. TO  180. MM.           .00
   FROM 180. TO  350. MM.           .00                                                                                 .232 SECONDS ELAPSED
      .902+05     .901+05     .110+02     .501+01     .000        .000        .000        .000            .000          .000
   1 .17005+00 .11808+00 .19847+00 .11479+00 .00000     .98873-03 .14870+02 .00000     .28603-08 .00000
   2 .10990+00 .34210-01 .42743+00 .30278-01 .00000     .11797-02 .93842+01 .00000     .12162-08 .00000
   3 .10111+00 .00000    .00000    .00000    .00000     .00000    .10700+02 .00000     .39249-12 .00000
   4 .31240+00 .18363-01 .52845+00 .10712-01 .00000     .22954-02 .00000    .00000     .11335-12 .00000
      .902+05     .902+05     .110+02     .501+01     .000        .000        .000        .000            .000          .000
   1 .33219-01 .12309+00 .20721+00 .11840+00 .12503-03 .10334-02 .15142+02 .40300+01 .38424-08 .00000
   2 .32345-01 .36215-01 .45343+00 .28132-01 .39137-03 .12507-02 .87877+01 .19816+01 .23353-08 .00000
   3 .22709-01 .00000    .00000    .00000    .00000     .00000    .86287+01 .24126+01 .55488-12 .00000
   4 .30758+00 .19622-01 .56486+00 .11444-01 .00000     .24532-02 .00000    .00000     .11337-12 .00000
      .903+05     .902+05     .110+02     .501+01     .000        .000        .000        .000            .000          .000
   1 .33816-01 .12831+00 .21634+00 .12207+00 .22855-03 .11865-02 .15418+02 .69449+01 .48157-08 .00000
   2 .33347-01 .38344-01 .48102+00 .25884-01 .71629-03 .15891-02 .81367+01 .33836+01 .33651-08 .00000
   3 .22801-01 .00000    .00000    .00000    .00000     .00800    .66548+01 .37844+01 .68358-12 .00000
   4 .30295+00 .20966-01 .60378+00 .12226-01 .00000     .26218-02 .00000    .00000     .11339-12 .00000
      .904+05     .902+05     .110+02     .501+01     .000        .000        .000        .000            .000          .000
   1 .34469-01 .13376+00 .22587+00 .12581+00 .31706-03 .14320-02 .15698+02 .91533+01 .57800-08 .00000
   2 .34413-01 .40606-01 .51029+00 .23572-01 .98289-03 .21614-02 .74401+01 .43619+01 .43033-08 .00000
   3 .22885-01 .00000    .00000    .00000    .00000     .00000    .49062+01 .44254+01 .78155-12 .00000
   4 .29851+00 .22401-01 .64538+00 .13061-01 .00000     .28020-02 .00000    .00000     .11342-12 .00000
      .905+05     .902+05     .110+02     .501+01     .000        .000        .000        .000            .000          .000
   1 .35173-01 .13943+00 .23582+00 .12962+00 .39466-03 .17612-02 .15983+02 .10873+02 .67352-08 .00000
   2 .35541-01 .43008-01 .54133+00 .21239-01 .11958-02 .29433-02 .67109+01 .50050+01 .51485-08 .00000
   3 .22955-01 .00000    .00000    .00000    .00000     .00000    .34683+01 .45497+01 .85315-12 .00000
   4 .29427+00 .23935-01 .68985+00 .13953-01 .00000     .29946-02 .00000    .00000     .11343-12 .00000
      .905+05     .903+05     .110+02     .502+01     .000        .000        .000        .000            .000          .000
   1 .35920-01 .14535+00 .24620+00 .13348+00 .46427-03 .21695-02 .16271+02 .12243+02 .76810-08 .00000
   2 .36729-01 .45559-01 .57427+00 .18928-01 .13585-02 .39139-02 .59653+01 .53762+01 .59007-08 .00000
   3 .23009-01 .00000    .00000    .00000    .00000     .00000    .23652+01 .43316+01 .90352-12 .00000
   4 .29022+00 .25572-01 .73738+00 .14904-01 .00000     .32003-02 .00000    .00000     .11345-12 .00000
      .906+05     .903+05     .110+02     .502+01     .000        .000        .000        .000            .000          .000
   1 .36708-01 .15152+00 .25705+00 .13739+00 .52803-03 .26548-02 .16564+02 .13360+02 .86175-08 .00000
   2 .37978-01 .48267-01 .60921+00 .16683-01 .14738-02 .50536-02 .52219+01 .55252+01 .65612-08 .00000
   3 .23046-01 .00000    .00000    .00000    .00000     .00000    .15673+01 .39131+01 .93785-12 .00000
   4 .28638+00 .27321-01 .78819+00 .15920-01 .00000     .34202-02 .00000    .00000     .11347-12 .00000
      .907+05     .903+05     .111+02     .502+01     .000        .000        .000        .000            .000          .000
   1 .37534-01 .15796+00 .26837+00 .14136+00 .58758-03 .32168-02 .16861+02 .14287+02 .95445-08 .00000
   2 .39288-01 .51141-01 .64627+00 .14546-01 .15451-02 .63435-02 .44999+01 .54933+01 .71331-08 .00000
   3 .23067-01 .00000    .00000    .00000    .00000     .00000    .10162+01 .34022+01 .96068-12 .00000
   4 .28274+00 .29188-01 .84249+00 .17004-01 .00000     .36551-02 .00000    .00000     .11348-12 .00000
      .907+05     .904+05     .111+02     .502+01     .000        .000        .000        .000            .000          .000
   1 .38397-01 .16467+00 .28019+00 .14537+00 .64420-03 .38568-02 .17161+02 .15074+02 .10462-07 .00000
   2 .40663-01 .54192-01 .68559+00 .12550-01 .15759-02 .77648-02 .38177+01 .53177+01 .76211-08 .00000
   3 .23076-01 .00000    .00000    .00000    .00000     .00000    .64804+00 .28739+01 .97561-12 .00000
   4 .27932+00 .31182-01 .90054+00 .18162-01 .00000     .39060-02 .00000    .00000     .11350-12 .00000
      .908+05     .904+05     .111+02     .502+01     .000        .000        .000        .000            .000          .000
   1 .39296-01 .17166+00 .29254+00 .14942+00 .69889-03 .45768-02 .17466+02 .15754+02 .11370-07 .00000
   2 .42105-01 .57429-01 .72730+00 .10721-01 .15709-02 .92995-02 .31903+01 .50324+01 .80316-08 .00000
   3 .23073-01 .00000    .00000    .00000    .00000     .00000    .40770+00 .23746+01 .98529-12 .00000
   4 .27612+00 .33310-01 .96259+00 .19396-01 .00000     .41741-02 .00000    .00000     .11351-12 .00000
      .909+05     .904+05     .111+02     .502+01     .000        .000        .000        .000            .000          .000
   1 .40231-01 .17896+00 .30542+00 .15350+00 .75249-03 .63803-02 .17774+02 .16353+02 .12268-07 .00000
   2 .43619-01 .60863-01 .77155+00 .90760-02 .15352-02 .10931-01 .26285+01 .46689+01 .83719-08 .00000
```

```
3 .23061-01 .00000    .00000    .00000    .00000    .00000    .25341+00 .19289+01 .99155-12 .00000
4 .27313+00 .35583-01 .10289+01 .20714-01 .00000    .44606-02 .00000    .00000    .11352-12 .00000
  .910+05   .905+05   .111+02   .503+01   .000      .000      .000      .000                .000        .000
1 .41201-01 .18656+00 .31888+00 .15760+00 .80566-03 .62712-02 .18096+02 .16892+02 .13157-07 .00000
2 .45208-01 .64505-01 .81849+00 .76203-02 .14744-02 .12642-01 .21378+01 .42559+01 .86592-08 .00000
3 .23042-01 .00000    .00000    .00000    .00000    .00000    .15576+00 .15460+01 .99562-12 .00000
4 .27038+00 .38009-01 .10998+01 .22120-01 .00000    .47666-02 .00000    .00000    .11352-12 .00000
  .910+05   .905+05   .111+02   .503+01   .000      .000      .000      .000                .000        .000
1 .42208-01 .19450+00 .33292+00 .16173+00 .85899-03 .72543-02 .18402+02 .17384+02 .14036-07 .00000
2 .46890-01 .68368-01 .86829+00 .63515-02 .13942-02 .14422-01 .17189+01 .38186+01 .88748-08 .00000
3 .23016-01 .00000    .00000    .00000    .00000    .00000    .94792-01 .12262+01 .99830-12 .00000
4 .26787+00 .40598-01 .11756+01 .23613-01 .00000    .50936-02 .00000    .00000    .11353-12 .00000
  .911+05   .905+05   .111+02   .503+01   .000      .000      .000      .000                .000        .000
1 .43252-01 .20277+00 .34759+00 .16586+00 .91223-03 .93352-02 .18721+02 .17842+02 .14905-07 .00000
2 .48641-01 .72464-01 .92112+00 .52604-02 .13005-02 .16259-01 .13683+01 .37779+01 .90539-08 .00000
3 .22997-01 .00000    .00000    .00000    .00000    .00000    .57233-01 .96458+00 .10001-11 .00000
4 .26560+00 .43752-01 .12566+01 .25219-01 .00000    .54428-02 .00000    .00000    .11353-12 .00000
  .912+05   .906+05   .111+02   .503+01   .000      .000      .000      .000                .000        .000
1 .44377-01 .21140+00 .36290+00 .16933+00 .96790-03 .95201-02 .19044+02 .18273+02 .15764-07 .00000
2 .50496-01 .76906-01 .97716+00 .47725-02 .11983-02 .18147-01 .10801+01 .29502+01 .91952-08 .00000
3 .22953-01 .00000    .00000    .00000    .00000    .00000    .34762-01 .75381+00 .10014-11 .00000
4 .26359+00 .46711-01 .13472+01 .26925-01 .00000    .58159-02 .00000    .00000    .11353-12 .00000
  .912+05   .906+05   .111+02   .503+01   .000      .000      .000      .000                .000        .000
1 .45453-01 .22039+00 .37380+00 .17410+00 .10242-02 .10916-01 .19370+02 .18696+02 .16614-07 .00000
2 .52454-01 .81408-01 .10366+01 .35510-02 .10923-02 .20080-01 .84663+00 .25476+01 .93056-08 .00000
3 .22917-01 .00000    .00000    .00000    .00000    .00000    .20558-01 .58601+00 .10024-11 .00000
4 .26193+00 .49458-01 .14357+01 .28742-01 .00000    .62144-02 .00000    .00000    .11352-12 .00000
STATE( 1490) PERMITS ONLY  .6163614247 OF THE PROPOSED UNIT CHANGE AT  17 +  .000 DAYS
  .917+05   .906+05   .111+02   .504+01   .000      .000      .000      .000                .000        .000
1 .46612-01 .22990+00 .39557+00 .17956+00 .10773-02 .11870-01 .19713+02 .19015+02 .17140-07 .00000
2 .54523-01 .86315-01 .10997+01 .32314-02 .10527-02 .21768-01 .73152+00 .23212+01 .93594-08 .00000
3 .22878-01 .00000    .00000    .00000    .00000    .00000    .15441-01 .50420+00 .10030-11 .00000
4 .26036+00 .52935-01 .15346+01 .30698-01 .00000    .66410-02 .00000    .00000    .11354-12 .00000
  .914+05   .907+05   .111+02   .504+01   .000      .000      .000      .000                .000        .000
1 .47811-01 .23992+00 .41300+00 .18601+00 .11309-02 .12775-01 .20069+02 .19311+02 .17473-07 .00000
2 .56712-01 .91536-01 .11666+01 .31223-02 .10507-02 .23372-01 .66875+00 .21897+01 .93893-08 .00000
3 .22839-01 .00000    .00000    .00000    .00000    .00000    .13039-01 .45387+00 .10036-11 .00000
4 .25917+00 .56457-01 .16404+01 .32795-01 .00000    .70974-02 .00000    .00000    .11356-12 .00000
  .915+05   .907+05   .111+02   .504+01   .000      .000      .000      .000                .000        .000
1 .49052-01 .25011+00 .43119+00 .19017+00 .11352-02 .14396-01 .20407+02 .19744+02 .18319-07 .00000
2 .59073-01 .97019-01 .12376+01 .25392-02 .94084-03 .25521-01 .51873+00 .18559+01 .94557-08 .00000
3 .22799-01 .00000    .00000    .00000    .00000    .00000    .77929-02 .35497+00 .10042-11 .00000
4 .25827+00 .60277-01 .17534+01 .35000-01 .00000    .75831-02 .00000    .00000    .11354-12 .00000
  .916+05   .907+05   .111+02   .502+01   .000      .000      .000      .000                .000        .000
1 .50378-01 .35320+00 .60377+00 .26313+00 .17096-02 .21892-01 .28089+02 .27289+02 .32474-07 .00000
2 .61488-01 .11015+00 .14063+01 .22041-02 .89552-03 .29697-01 .42790+00 .16700+01 .10184-07 .00000
3 .22757-01 .00000    .00000    .00000    .00000    .00000    .47101-02 .28581+00 .10543-11 .00000
4 .25768+00 .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
STATE( 1690) PERMITS ONLY  .6173847988 OF THE PROPOSED UNIT CHANGE AT  20 +  .000 DAYS
  .918+05   .908+05   .111+02   .501+01   .000      .000      .000      .000                .000        .000
1 .52188-01 .37427+00 .64689+00 .27397+00 .18292-02 .24616-01 .28772+02 .27940+02 .33696-07 .00000
2 .64299-01 .11729+00 .14983+01 .19786-02 .84805-03 .32049-01 .36262+00 .14879+01 .10214-07 .00000
3 .14683+00 .00000    .00000    .00000    .00000    .00000    .00000    .24257+00 .10551-11 .00000
4 .25355+00 .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
  .920+05   .908+05   .111+02   .499+01   .000      .000      .000      .000                .000        .000
1 .54178-01 .39678+00 .68628+00 .28709+00 .19512-02 .27052-01 .29488+02 .28544+02 .34484-07 .00000
2 .67271-01 .12492+00 .15964+01 .19011-02 .84011-03 .34785-01 .32793+00 .13853+01 .10232-07 .00000
3 .14409+00 .00000    .00000    .00000    .00000    .00000    .00000    .21925+00 .10557-11 .00000
4 .24950+00 .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
  .922+05   .909+05   .111+02   .498+01   .000      .000      .000      .000                .000        .000
1 .56162-01 .42015+00 .72805+00 .29459+00 .21028-02 .31360-01 .30157+02 .29403+02 .36429-07 .00000
2 .70447-01 .13296+00 .17009+01 .15040-02 .72903-03 .37249-01 .24611+00 .11326+01 .10265-07 .00000
3 .14138+00 .00000    .00000    .00000    .00000    .00000    .00000    .16457+00 .10564-11 .00000
4 .24553+00 .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
  .924+05   .909+05   .111+02   .496+01   .000      .000      .000      .000                .000        .000
1 .58297-01 .44491+00 .77238+00 .30170+00 .22594-02 .36184-01 .30829+02 .30212+02 .38344-07 .00000
2 .73878-01 .14151+00 .18123+01 .11853-02 .62840-03 .40213-01 .18399+00 .91984+00 .10288-07 .00000
3 .13874+00 .00000    .00000    .00000    .00000    .00000    .00000    .12326+00 .10571-11 .00000
4 .24163+00 .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
  .926+05   .910+05   .112+02   .495+01   .000      .000      .000      .000                .000        .000
1 .60537-01 .47115+00 .81940+00 .30834+00 .24226-02 .41573-01 .31503+02 .30988+02 .40229-07 .00000
2 .77429-01 .15062+00 .19309+01 .93055-03 .53832-03 .43291-01 .13703+00 .74258+00 .10304-07 .00000
3 .13615+00 .00000    .00000    .00000    .00000    .00000    .00000    .92130-01 .10578-11 .00000
4 .23781+00 .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
  .928+05   .910+05   .112+02   .493+01   .000      .000      .000      .000                .000        .000
1 .62898-01 .49894+00 .86928+00 .31441+00 .25935-02 .47577-01 .32175+02 .31743+02 .42084-07 .00000
2 .81264-01 .16030+00 .20573+01 .72762-03 .45850-03 .46496-01 .10171+00 .59620+00 .10314-07 .00000
3 .13361+00 .00000    .00000    .00000    .00000    .00000    .00000    .68721-01 .10584-11 .00000
4 .23406+00 .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
  .930+05   .911+05   .112+02   .482+01   .000      .000      .000      .000                .000        .000
1 .65354-01 .52839+00 .92220+00 .31981+00 .27728-02 .54257-01 .32844+02 .32484+02 .43908-07 .00000
2 .85349-01 .17060+00 .21920+01 .56652-03 .38839-03 .49844-01 .75251-01 .47627+00 .10320-07 .00000
3 .13112+00 .00000    .00000    .00000    .00000    .00000    .00000    .51170-01 .10591-11 .00000
4 .23039+00 .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
  .932+05   .912+05   .112+02   .490+01   .000      .000      .000      .000                .000        .000
1 .67943-01 .55960+00 .97834+00 .32440+00 .29613-02 .61675-01 .33506+02 .33212+02 .45700-07 .00000
2 .89707-01 .18155+00 .23355+01 .43901-03 .32730-03 .53352-01 .55524-01 .37866+00 .10322-07 .00000
3 .12868+00 .00000    .00000    .00000    .00000    .00000    .00000    .38046-01 .10598-11 .00000
4 .22678+00 .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
  .934+05   .912+05   .112+02   .489+01   .000      .000      .000      .000                .000        .000
1 .70659-01 .59266+00 .10379+01 .32807+00 .31594-02 .69900-01 .34156+02 .33929+02 .47462-07 .00000
2 .94341-01 .19320+00 .24884+01 .33830-03 .27444-03 .57036-01 .40875-01 .29969+00 .10322-07 .00000
3 .12629+00 .00000    .00000    .00000    .00000    .00000    .00000    .28256-01 .10605-11 .00000
4 .22375+00 .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
  .936+05   .913+05   .112+02   .488+01   .000      .000      .000      .000                .000        .000
1 .73509-01 .62770+00 .11011+01 .33066+00 .33673-02 .79009-01 .34790+02 .34633+02 .49191-07 .00000
2 .99284-01 .20559+00 .26512+01 .25888-03 .22900-03 .60913-01 .30037-01 .23616+00 .10319-07 .00000
3 .12394+00 .00000    .00000    .00000    .00000    .00000    .00000    .20968-01 .10612-11 .00000
4 .21978+00 .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
  .937+05   .913+05   .112+02   .486+01   .000      .000      .000      .000                .000        .000
1 .76500-01 .66484+00 .11681+01 .33204+00 .35851-02 .89083-01 .35401+02 .35320+02 .50889-07 .00000
2 .10455+00 .21877+00 .28243+01 .19629-03 .19019-03 .65001-01 .22044-01 .18531+00 .10315-07 .00000
3 .12164+00 .00000    .00000    .00000    .00000    .00000    .00000    .15553-01 .10618-11 .00000
4 .21638+00 .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
  .939+05   .914+05   .112+02   .485+01   .000      .000      .000      .000                .000        .000
1 .79640-01 .70420+00 .12392+01 .33204+00 .38128-02 .10021+00 .35982+02 .35985+02 .52553-07 .00000
2 .11017+00 .23278+00 .30097+01 .14693-03 .15722-03 .69317-01 .16165-01 .14481+00 .10310-07 .00000
3 .11939+00 .00000    .00000    .00000    .00000    .00000    .00000    .11533-01 .10625-11 .00000
4 .21305+00 .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
  .941+05   .914+05   .112+02   .483+01   .000      .000      .000      .000                .000        .000
1 .82935-01 .74591+00 .13147+01 .33048+00 .40498-02 .11248+00 .36523+02 .36623+02 .54184-07 .00000
2 .11615+00 .24767+00 .32067+01 .10795-03 .12938-03 .73880-01 .11848-01 .11273+00 .10303-07 .00000
3 .11718+00 .00000    .00000    .00000    .00000    .00000    .00000    .85517-02 .10632-11 .00000
4 .20978+00 .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
  .943+05   .915+05   .112+02   .482+01   .000      .000      .000      .000                .000        .000
1 .86393-01 .79013+00 .13947+01 .32718+00 .42954-02 .12600+00 .37013+02 .37224+02 .55780-07 .00000
2 .12253+00 .26350+00 .34166+01 .77071-04 .10599-03 .78709-01 .86843-02 .87428-01 .10296-07 .00000
3 .11501+00 .00000    .00000    .00000    .00000    .00000    .00000    .63421-02 .10639-11 .00000
4 .20657+00 .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000    .00000
  .945+05   .915+05   .112+02   .480+01   .000      .000      .000      .000                .000        .000
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    1 .90023-01 .83700+00 .14796+01 .32196+00 .45485-02 .14086+00 .37437+02 .37778+02 .57340-07 .00000
    2 .12932+00 .28033+00 .36403+01 .52504-04 .86421-04 .83824-01 .63672-02 .67579-01 .10287-07 .00000
    3 .11288+00 .00000   .00000   .00000   .00000   .00000   .00000   .47046-02 .10646-11 .00000
    4 .20343+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000
      .947+05   .916+05   .112+02   .479+01   .000    .000    .000    .000            .000        .000
    1 .93832-01 .99688+00 .15697+01 .31463+00 .48073-02 .15713+00 .37777+02 .38271+02 .58864-07 .00000
    2 .13657+00 .29822+00 .38786+01 .32838-04 .70121-04 .89245-01 .46716-02 .52079-01 .10277-07 .00000
    3 .11080+00 .00000   .00000   .00000   .00000   .00000   .00000   .34913-02 .10653-11 .00000
    4 .20034+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000
      .949+05   .916+05   .112+02   .477+01   .000    .000    .000    .000            .000        .000
    1 .97829-01 .93935+00 .16652+01 .30500+00 .50692-02 .17510+00 .38008+02 .38685+02 .60348-07 .00000
    2 .14429+00 .31723+00 .41325+01 .16964-04 .56591-04 .94993-01 .34316-02 .40027-01 .10267-07 .00000
    3 .10876+00 .00000   .00000   .00000   .00000   .00000   .00000   .25920-02 .10659-11 .00000
    4 .19731+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000
STATE( 1707) PERMITS ONLY  .6530394093 OF THE PROPOSED UNIT CHANGE AT  36 +  .000 DAYS
      .951+05   .917+05   .112+02   .476+01   .000    .000    .000    .000            .000        .000
    1 .10202+00 .99561+00 .17666+01 .30232+00 .53451-02 .19195+00 .38353+02 .39118+02 .61391-07 .00000
    2 .15252+00 .33760+00 .44030+01 .83309-05 .49964-04 .10113+00 .28012-02 .33540-01 .10261-07 .00000
    3 .18254+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .10666-11 .00000
    4 .19475+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000
      .953+05   .917+05   .112+02   .475+01   .000    .000    .000    .000            .000        .000
    1 .10643+00 .10558+01 .18742+01 .31067+00 .56528-02 .20658+00 .38959+02 .39686+02 .61918-07 .00000
    2 .16129+00 .35951+00 .46312+01 .51355-05 .49140-04 .10770+00 .25714-02 .31090-01 .10262-07 .00000
    3 .17897+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .10673-11 .00000
    4 .19143+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000
STATE( 1697) PERMITS ONLY  .4596620612 OF THE PROPOSED UNIT CHANGE AT  37 +  .000 DAYS
      .955+05   .918+05   .112+02   .473+01   .000    .000    .000    .000            .000        .000
    1 .11106+00 .11091+01 .21298+01 .33567+00 .63953-02 .23983+00 .42203+02 .43056+02 .67132-07 .00000
    2 .25106+00 .40151+00 .52439+01 .00000   .48568-04 .12031+00 .00000   .28869-01 .10765-07 .00000
    3 .17539+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000
    4 .18858+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000
      .957+05   .919+05   .112+02   .472+01   .000    .000    .000    .000            .000        .000
    1 .11630+00 .12766+01 .22693+01 .33411+00 .67717-02 .26245+00 .42552+02 .43589+02 .68104-07 .00000
    2 .25979+00 .42872+00 .56051+01 .00000   .43824-04 .12848+00 .00000   .24692-01 .10761-07 .00000
    3 .17191+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000
    4 .18578+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000
STATE( 1505) PERMITS ONLY  .6230490580 OF THE PROPOSED UNIT CHANGE AT  38 +  .000 DAYS
      .959+05   .919+05   .112+02   .470+01   .000    .000    .000    .000            .000        .000
    1 .12193+00 .13591+01 .24179+01 .32685+00 .71508-02 .28822+00 .42671+02 .44005+02 .69188-07 .00000
    2 .26923+00 .45765+00 .59912+01 .00000   .38312-04 .13718+00 .00000   .20580-01 .10755-07 .00000
    3 .16851+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000
    4 .18303+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000
      .962+05   .920+05   .111+02   .469+01   .000    .000    .000    .000            .000        .000
    1 .12766+00 .14474+01 .25763+01 .32945+00 .75647-02 .31269+00 .43044+02 .44509+02 .69900-07 .00000
    2 .27958+00 .48878+00 .64040+01 .00000   .36354-04 .14652+00 .00000   .18490-01 .10754-07 .00000
    3 .16517+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000
    4 .18034+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000
      .964+05   .921+05   .111+02   .467+01   .000    .000    .000    .000            .000        .000
    1 .13381+00 .15401+01 .27451+01 .29741+00 .78901-02 .34915+00 .42064+02 .44375+02 .71495-07 .00000
    2 .29074+00 .52125+00 .68451+01 .00000   .27140-04 .15629+00 .00000   .13571-01 .10737-07 .00000
    3 .16190+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000
    4 .17769+00 .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000   .00000
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 LICHEN HEATH WITH DATA FOR DECOMPOSITION RUN 1

REPORT NO. 1 ON FEB  9 1978 (I.E., AFTER  39 DAYS OF SIMULATION)                           4.123 SECONDS ELAPSED

CONSTITUENTS OF DEAD ORGANIC MATERIAL, G. OR KCAL. PER HECTARE
   TYPE OF MATERIAL       NITROGEN     ANIONS     CATIONS    PROTEIN C   RESERVE C  STRUCTURAL C  TOTAL C   DRY MATTER
DEAD LICHEN                2467.16     219.32     1453.97     8463.66    46677.59   141790.38   196931.62   490968.14
DEAD MOSS                   340.43        .50      164.75     1161.70     2079.98    10728.40    13970.09    34675.79
WOODY LITTER                891.31        .10      142.16     3033.25      158.00    26019.25    29210.50    72088.22
HERBACEOUS LITTER         13995.00     650.68     3641.24    47936.87    82447.27   306865.89   437250.03  1080253.02
DEAD ROOTS 0-2CM            209.78        .00         .00      716.11      231.05     4488.22     5435.38    13332.74
DEAD ROOTS 2-8CM           1659.87      44.79      284.58     5624.29     2941.13    57144.16    65709.57   162607.38
DEAD ROOTS 8-18 CM         1155.99      62.99      234.99     3974.96     2041.98    39678.58    45695.51   113109.03
DEAD ROOTS 18-35 CM         433.00      24.00       89.00     1490.00      765.99    14879.89    17135.89    42417.21
DUMMY MICROBES(N)          1115.19    1132.78    10199.16    10132.77    10398.33    10066.39    30597.48    82354.54
DUMMY MICROBES(D)       1102783.59 1096574.44  1097861.62  1102733.06  1097954.89  1127144.50  3327832.44 10902024.25
      TOTAL             1125051.31 1100709.58  1114071.47  1185266.67  1245696.19  1738805.62  4169768.47 12993830.25

SOIL VARIABLES
                          NITROGEN     ANIONS     CATIONS     PROTEIN C    RESERVE C   STRUCTURAL CTOTAL C    ORG.O.M.
ORGANIC MATTER CONSTITUENTS
  FROM   0. TO   20. MM.  955442.41    31558.74   166710.35  3284468.37   865464.12 16587913.87 20737846.25 41475692.50
  FROM  20. TO   80. MM.  386854.00    14377.28    75386.50  1329812.60   258794.98  7745560.69  9334168.12 18668336.25
  FROM  80. TO  180. MM.  797239.97    28802.81   153604.19  2740502.12   523508.39 15936000.00 19200010.50 38400021.00
  FROM 180. TO  350. MM.  266476.48    16310.99    87026.49   915970.87   171992.98  9791993.62 10879957.37 21759914.75
      TOTAL              2406012.84    91049.81   482727.52  8270753.81  1819760.44 50061468.00 60151982.00120303963.00
IN MINERAL FRACTION
  FROM   0. TO   20. MM.    1274.48     3493.47    78566.19
  FROM  20. TO   80. MM.      82.21     3443.39    29415.07
  FROM  80. TO  180. MM.      65.97    16000.04    27200.05
  FROM 180. TO  350. MM.      35.56    27200.00    40800.01
      TOTAL                 1458.22    50136.90   175981.32

TOTAL, SOIL AND DEAD
   ORGANIC MATERIAL      3532522.34   124189 6.28 1772780.30  9456020.37  3065456.62  5180273.50 64321750.00133297793.00

TOTAL IN ECOSYSTEM       3532522.34   1241896.28 1772780.30  9456020.37  3065456.62  5180273.50 64321750.00133297793.00


ACCUMULATED NET GAIN OR LOSS TO ECOSYSTEM
                                   WATER    MINERAL SOIL   NITROGEN    ANIONS      CATIONS      TOTAL C
 TO OR FROM ATMOSPHERE               .00             .00     118.79        .00          .00    -51374.07
 BY RUN-OFF OR RUN-ON                .00             .00        .00        .00          .00          .00
 TO OR FROM SUBSOIL                  .00             .00        .00        .00          .00          .00

      TOTAL                          .00             .00     118.79        .00          .00    -51374.07

SOIL WATER POTENTIAL, ATM.
  FROM   0. TO   20. MM.        .00
  FROM  20. TO   80. MM.        .00
  FROM  80. TO  180. MM.        .00
  FROM 180. TO  350. MM.        .00

ACCUMULATED PRECIPITATION TO FEB  9 1978 INCLUSIVE IS    .0 MM. - THAT IS     .0 TONS PER HECTARE       .259 SECONDS ELAPSED
```
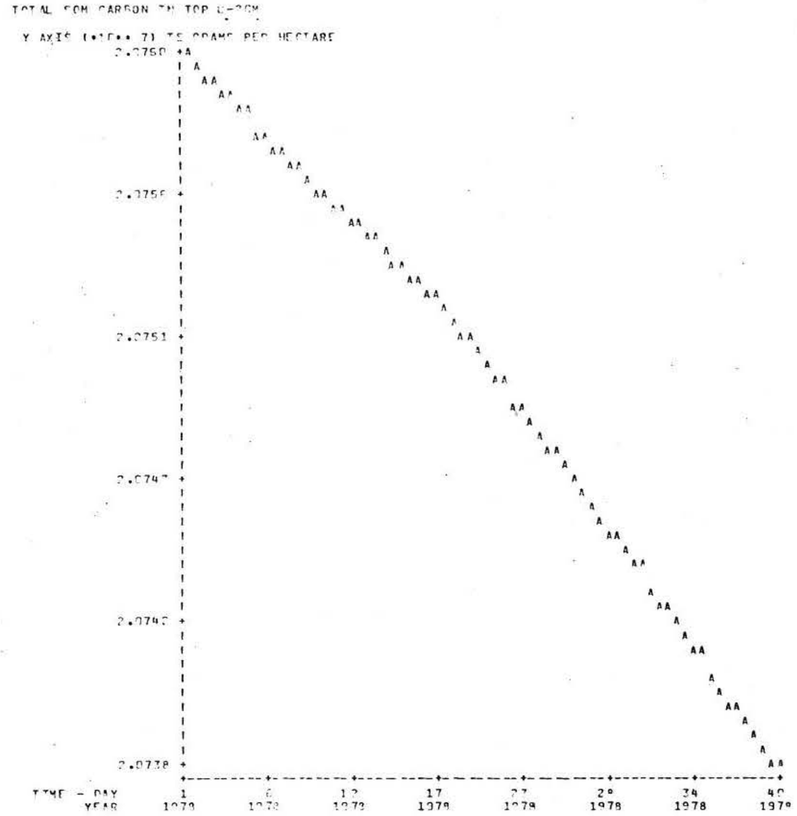
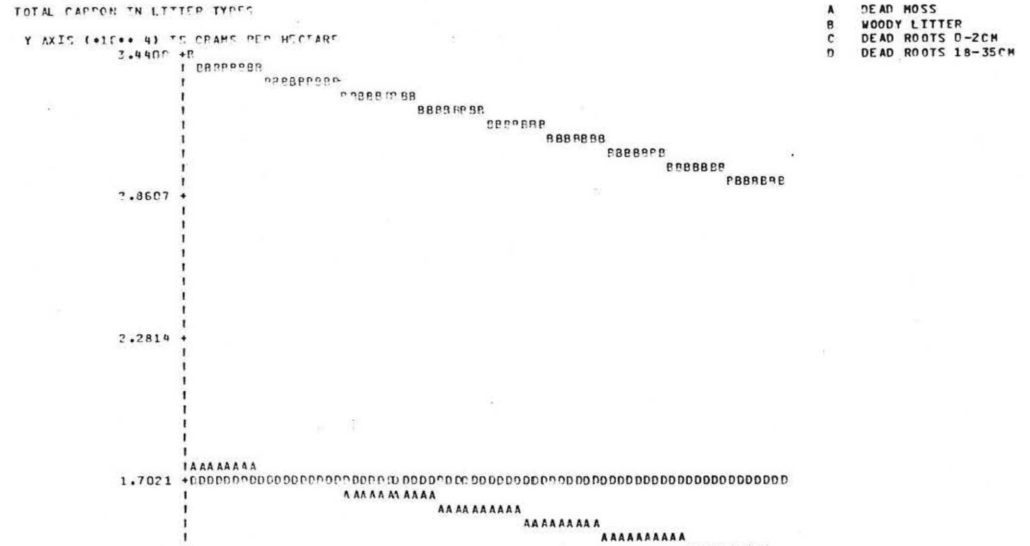
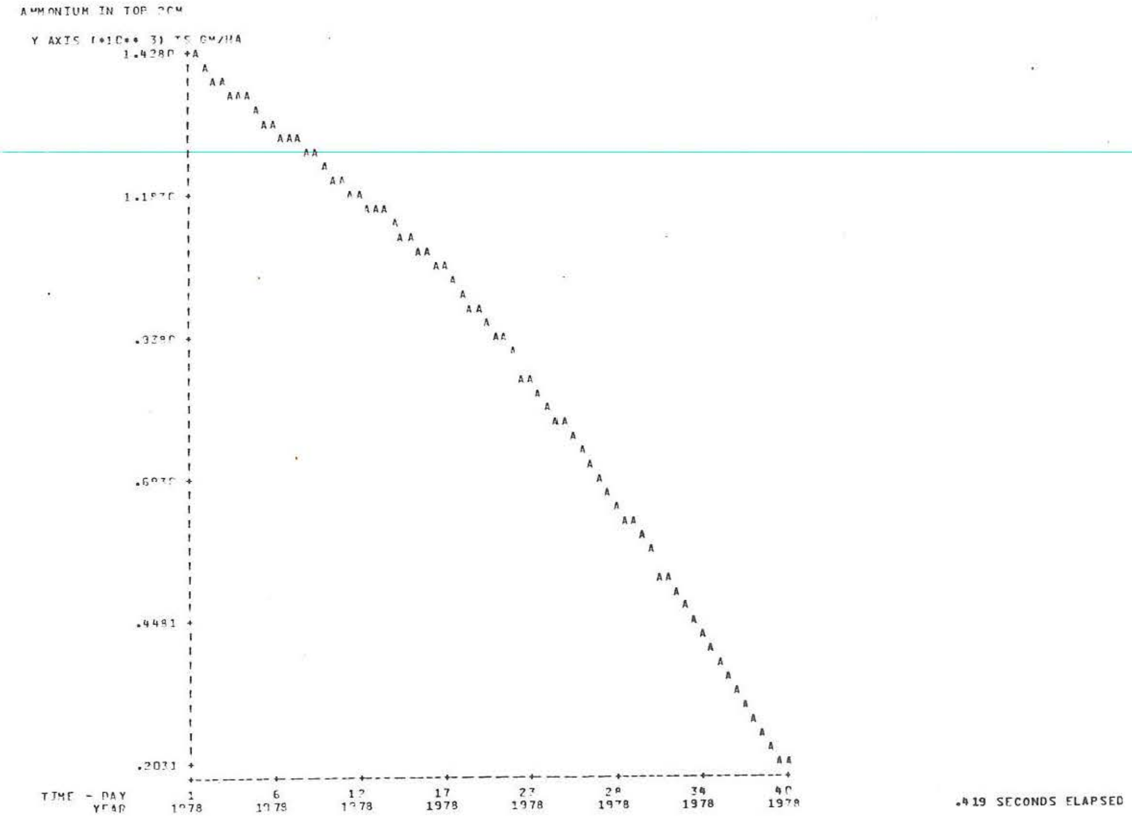
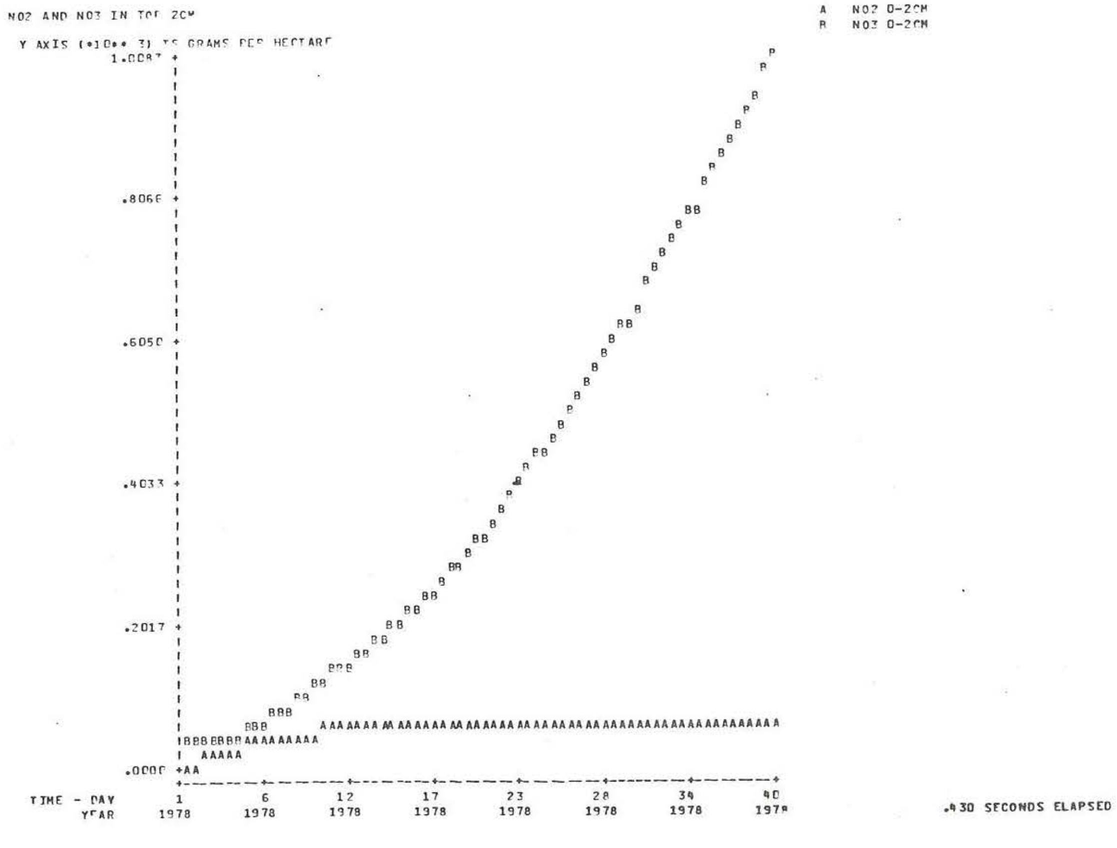



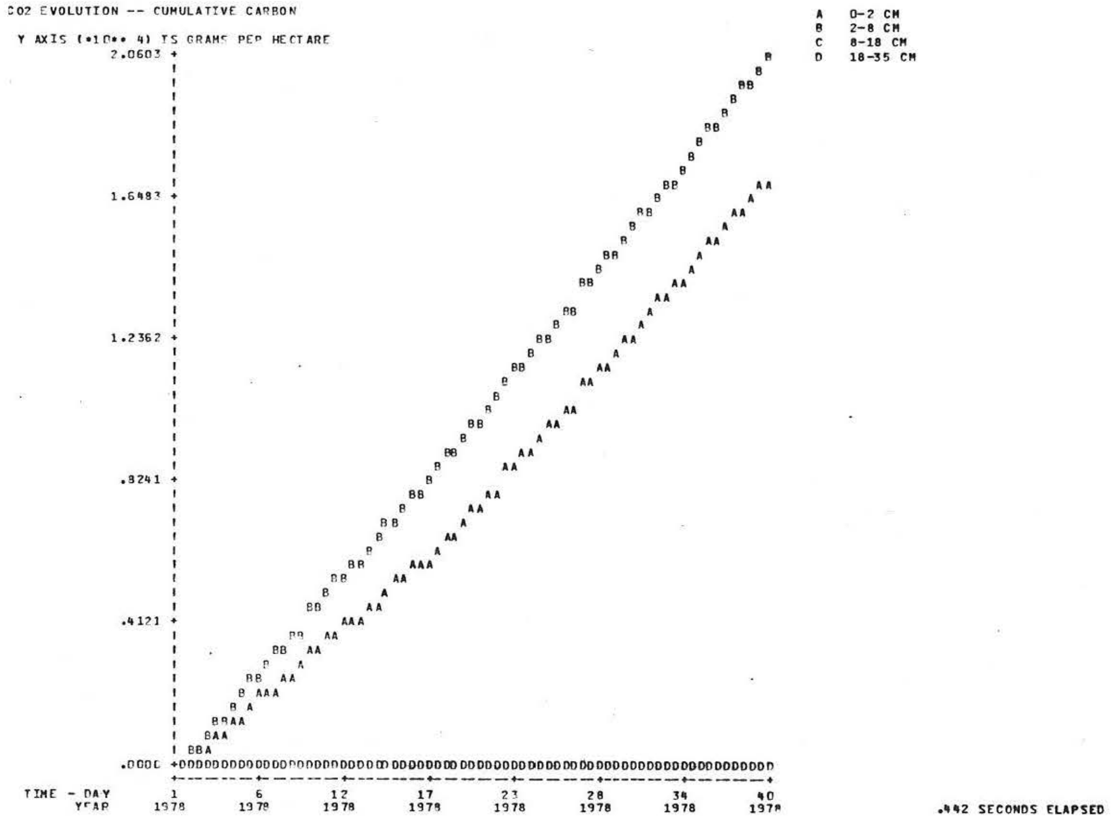
.420 SECONDS ELAPSED

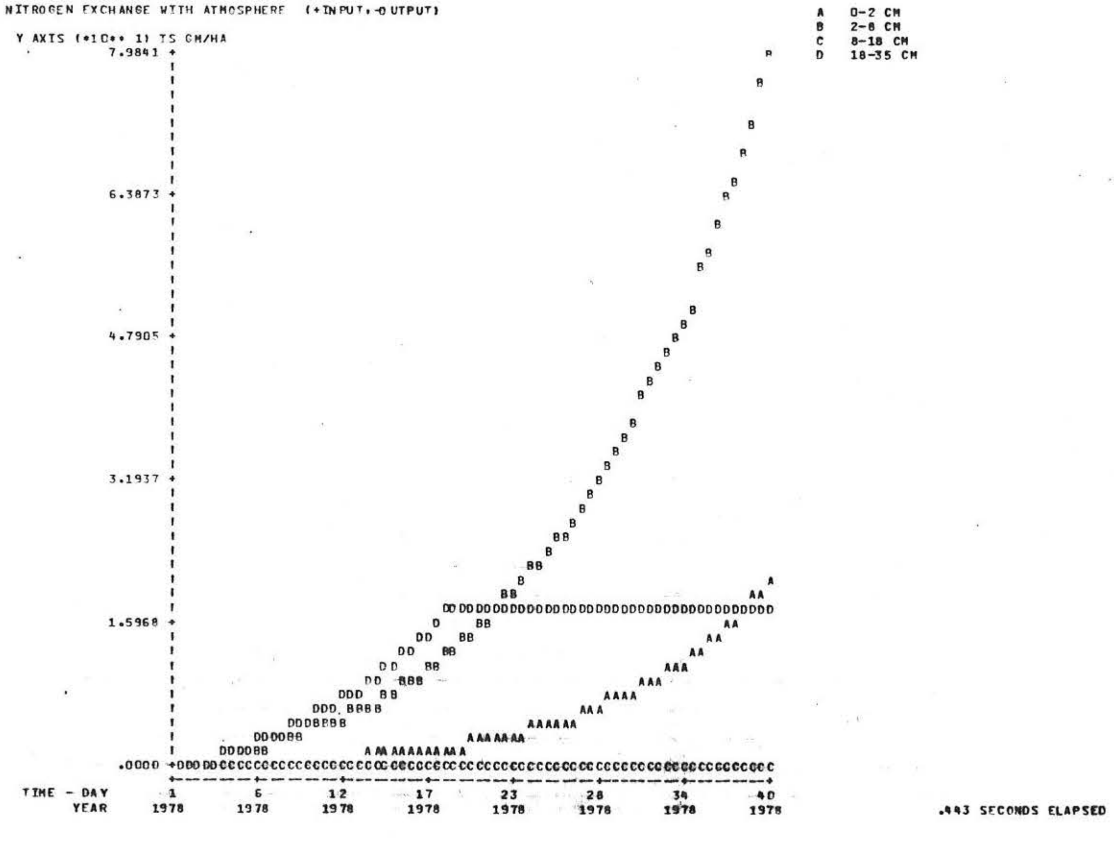


.444 SECONDS ELAPSED


AMMONIUM IN TOP 2CM
Y AXIS (*10** 3) IS GM/HA
1.4280
1.1870
.9380
.6930
.4481
.2031
TIME - DAY
YEAR
1
1978
6
1978
12
1978
17
1978
23
1978
28
1978
34
1978
40
1978
.419 SECONDS ELAPSED


NO2 AND NO3 IN TOP 2CM
A NO2 0-2CM
B NO3 0-2CM
Y AXIS (*10** 3) IS GRAMS PER HECTARE
1.0087
.8066
.6050
.4033
.2017
.0000
TIME - DAY
YEAR
1
1978
6
1978
12
1978
17
1978
23
1978
28
1978
34
1978
40
1978
.430 SECONDS ELAPSED


CO2 EVOLUTION -- CUMULATIVE CARBON
Y AXIS (*10** 4) IS GRAMS PER HECTARE
2.0603
1.6483
1.2362
.8241
.4121
.0000
A 0-2 CM
B 2-8 CM
C 8-18 CM
D 18-35 CM
TIME - DAY
YEAR
1 1978
6 1978
12 1978
17 1978
23 1978
28 1978
34 1978
40 1978
.442 SECONDS ELAPSED


NITROGEN EXCHANGE WITH ATMOSPHERE (+INPUT,-OUTPUT)
Y AXIS (*10** 1) IS GM/HA
7.9841
6.3873
4.7905
3.1937
1.5968
.0000
A 0-2 CM
B 2-8 CM
C 8-18 CM
D 18-35 CM
TIME - DAY
YEAR
1 1978
6 1978
12 1978
17 1978
23 1978
28 1978
34 1978
40 1978
.443 SECONDS ELAPSED

**1973 PROGRESS REPORT**

# PHYSIOLOGICAL SECTION FOR THE ANIMAL SUBMODEL, GENERAL-PURPOSE MODEL

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# INTRODUCTION

This portion of the animal submodel is being designed to interface closely with the demographic section and thus to be used in association with other submodels in the Desert Biome whole-ecosystem model as described elsewhere. This report summarizes the progress made to date in the conceptualization of the structural framework for the physiological sub-section and presents a discussion of the problems of physiological-demography interface and programming routine for one part of the animal physiological submodel.

# DESCRIPTION OF COMPONENTS CONSIDERED

The vast number of species and the paucity of data on physiological and demographic processes of these species preclude the use of species as components in an ecosystem model at this time. Consequently, we decided to organize consumers into functional groups of species. The criteria applied to the formation of a particular functional group were: (1) The species included have common physiological characteristics especially with regard to water requirements and type of food consumed; (2) Demographic responses as far as is known are directly linked to the physiological characteristics in criteria no. 1; (3) That the assemblage of organisms in each group be significant components in at least one of the desert sites (significance determined on the basis of biomass, energy turnover, or identified rate regulators). The functional groups erected for inclusion in the model with representative taxa are shown in Table 1.

The breakdown in Table 1 is only a tentative division into functional groups based on the behavior and physiology of the organisms placed in each group. However, based on this grouping, the form of physiological functions were developed for several functional groups.

## FUNCTIONAL GROUP I

### WATER-INDEPENDENT, SEED-CONSUMING RODENTS

*Reproduction*

Reproduction is determined for two cohorts: adults and juveniles. Reproduction is considered to result in a constant increment to adult biomass because a fraction of the adult population is receptive at all times if mean monthly air temperatures exceed 0 C. If mean monthly air temperatures are lower than 0 C for part of the year, reproduction is keyed by photoperiod.

Juvenile recruitment into the population is a constant percentage of adult biomass $\cong 5\%$ adult biomass. Peak recruitment into the adult population occurred during one or two periods as a function of the length of the growing season (90 day growth and recruitment) and of reproductive phenology of annual and perennial plants. The form of reproduction function is shown in Figure 1.

*Plant to Animal Transfer (Assume Diet of 100% Seeds)*

Seed removal by rodents is equal to seed consumption plus storage and is a function of seed availability. It is assumed that rodents forage for 4 $\text{hr}\cdot\text{day}^{-1}$. Consumption (c) is a function of animal size and is adjusted for lactation by the percent of the population lactating at time t. Consumption of lactating animals = c x 4. Consumption is equal to energy requirements for maintenance for 20 hr plus activity costs for 4 hr. Since these animals live in subterranean burrows in nests (Kenagy, 1973), maintenance metabolism can be calculated as standard metabolic rate at mean annual soil temperature at 30 cm. No temperature-related increase in metabolic rate is included since it is assumed that the increased heat production due to activity supplies body temperature regulatory heat requirements. Since seeds are assumed to make up 100% of the diet, fecal losses are assumed minimal and an assimilation percent of 80 is used. Figures 2 and 3 show the form of relationship of metabolism to size and the form of seed removal function, respectively.

**Table 1.** Functional groupings of consumers in desert ecosystems. Each functional group is shown with its primary food source, general water requirements and representative taxa. Groups for which sufficient data are available to support the group designation are indicated by an asterisk

| Functional Group | Water requirements | Primary food source | Representative Taxa |
|---|---|---|---|
| 1. Heteromyid rodents * | independent, metabolic water | seeds and fruits | *Dipodomys, Perognathus* |
| 2. Omnivorous rodents * | dependent, succulent plant parts | fruits, leaves, seeds and insects | *Peromyscus* sp. |
| 3. Lagomorphs * | dependent, succulent plant parts | leaves, bark | *Lepus, Sylvilagus* |
| 4. Harvester ants * | partially independent on insect availability, metabolic water | seeds, fruits | *Pogonomyrmex, Pheidole* |

| | | | |
|---|---|---|---|
| 5. Sucking bugs * | dependent on food | plant juices | various Homoptera |
| 6. Leaf chewing insects* | dependent on leaf water content | plant leaves | Acrididae, Chrysomelidae |
| 7. Omnivorous ground-dwelling arthropods * | dependent on water content of food | floral parts, leaves stems, alive & dead | Attine ants, Tenebrionidae Gryllidae, Millipedes |
| 8. Omnivorous ants * | dependent on water content prey and food | insects, pollen, plant exudates | *Myrmecocystus, Formica, Iridomyrmex, Solenopsis* |
| 9. Detritivores * | independent or partially independent on metabolic plus preformed water | plant parts, feces | Termitidae Gnathamitermes |
| 10. Nectivorous insects | dependent on water in food, plant phenology | Plant exudates, floral nectar, honey dew, pollen | Pompillidae, Apoidae Diptera |
| 11. Ground-dwelling sucking predators | | | Arachnoidae, Scorpoinida Scolopendromorpha, *Mastigoproctus giganteus* |
| 12. Flying predatory arthropods | | | Hemiptera, Coleoptera Diptera |
| 13. Small mammal predators | dependent on water in food | rodents, insects, eggs birds | skunk, badger, kit fox |
| 14. Large mammal predators | dependent on water in food | lagamorphs, large rodents young ungulates | coyotes, bob-cat |
| 15. Raptors | dependent on water in food | rodents, birds, insects | Swainson's hawk, red-tail hawk, shrike |
| 16. Lizards * | dependent on water in food | insects | *Cnemidophorus, Uta, Phrynosoma* |
| 17. Insectivorous birds | dependent on water in food | insects | shrike, kingbird, desert sparrow |
| 18. Seed eating birds * | dependent on free water and insects | seeds and insects | Horned lark, lark bunting |
| 19. Large herbivores | dependent on free water | grasses, forbs and shrubs. | cattle, sheep |

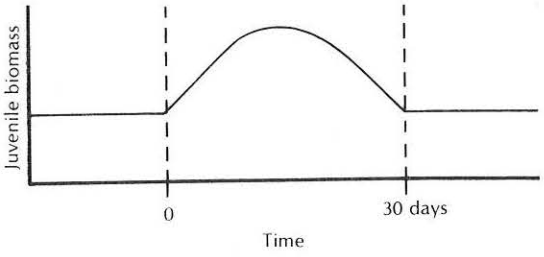

**Figure 1.** Form of reproduction function.

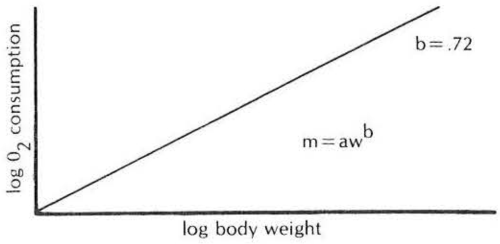

**Figure 2.** Form of relationship of metabolism to size.

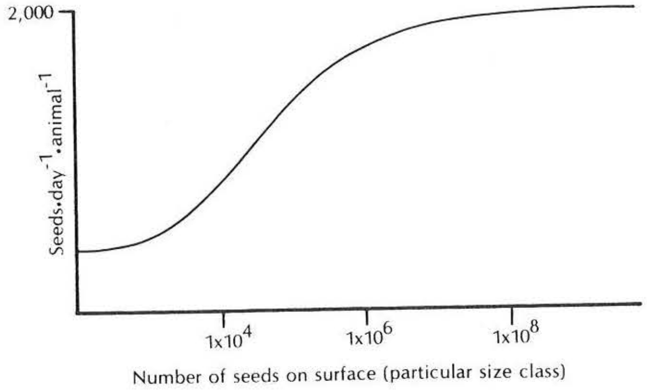

**Figure 3.** Form of seed removal function.

### *Growth and Maintenance*

It is assumed that growth is equal to a constant (k) when seed storage reserves are greater than 0 and/or removal is greater than consumption and mean ambient temperature is greater than 5 C. This allows for growth (fetal growth) and population increase as long as food is available. When consumption is greater than seed removal and seed storage reserves are 0, the value of k is negative and proportional to the maintenance deficit. Figure 4 shows the form of growth to food available and storage relationship.

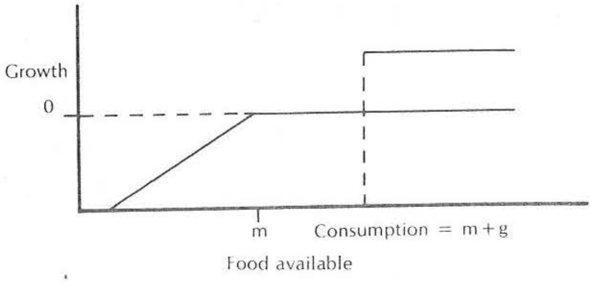

**Figure 4.** Form of growth to food available and storage relationship.

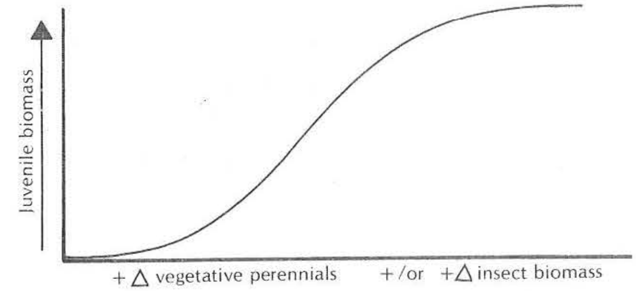

**Figure 5.** Form of relationship between plant and insect food availability and reproduction in water-dependent, omnivorous rodents.

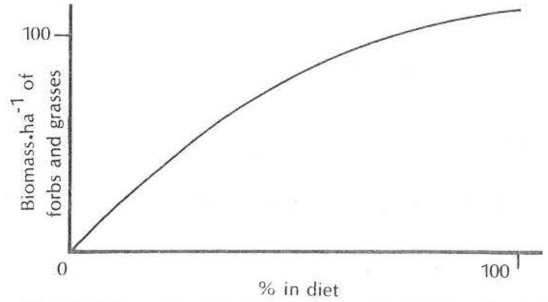

**Figure 6.** Form of the function describing the percent composition of forbs and grasses in diets of lagomorphs and biomass of these plants·ha$^{-1}$.

## FUNCTIONAL GROUP II

### WATER-DEPENDENT OMNIVOROUS RODENTS

### *Reproductive Increment*

Reproductive increment is 0 unless there is a positive biomass increment added to vegetative perennials, then juvenile biomass is a function of the positive increment in new growth of perennial plants and/or a positive increment in insect biomass. Reproduction is tied to availability of water in new growth vegetation or insects since this species group is water dependent on preformed water in food (Fig. 5).

### *Plant to Animal Transfers*

When increment to vegetative perennials is positive, 10 to 25% of the consumptive needs are from new perennial vegetation; percent in diet f (new perennial biomass). When insect biomass increment is positive, 0-15% of consumptive needs is from insect biomass; percent in diet f(insect biomass). Remainder of the diet is obtained from fruits and seeds on the soil surface.

### *Consumption*

Consumption is a function of size and lactation as in Group I.

### *Fecal Loss*

Fecal loss is equal to ($f_1$ x % assimilation of vegetation) + ($f_2$ x % assimilation of insects) + ($f_3$ x % assimilation of seeds) where f = fractional biomass in diet of rodents.

### *Growth*

Growth is a constant for adults if Δ vegetation > 0. If Δ vegetation = 0, growth = 0. Juvenile growth is a constant $k_2$ if food availability is greater than some threshold value.

## FUNCTIONAL GROUP III

### LAGOMORPHS

Lagomorphs are treated differently than omnivorous rodents because: (1) they rarely use subterranean shelters and as a consequence sense their thermal environment; and (2) because they browse and graze on grasses, forbs and shrubs with shifting food preference (Fig. 6).

Some assumptions regarding lagomorphs are: (1) they will forage preferentially on new growth forbs and grasses. When these are not available they browse on bark and woody material from plants with a favorable water potential in the tissues; (2) reproduction is keyed by photoperiod and allows production of two litters on hot deserts and one litter on cold deserts; (3) excretory losses as percent of material consumed is a function of materials eaten -- green forbs and grasses result in less than 20% excretory loss while loss from bark and woody stems is greater than 30%; (4) metabolic rate is a function of mean daily temperature and body size and must be corrected for lactation after females produce young; (5) there is a probability of starvation which is a function of crude protein available in the diet which also is probably linked with tissue (Fig. 7); (6) adult growth equals 0 -- growth is positive in the equation only in juveniles or during periods of reproduction and is negative during starvation. consumption, MR = metabolic rate maintenance, E = elimination, G = growth).

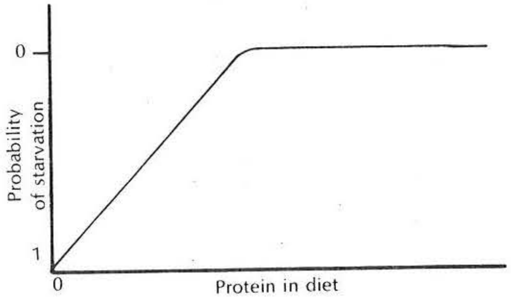

**Figure 7.** Function describing probability of starvation in lagomorphs as a function of protein in diet.

## FUNCTIONAL GROUP IV

### HARVESTER ANTS

Modelling social insect physiology is complicated in that the activity and behavior which must be predicted are related to foraging activity. While important, population growth, reproduction and other activities of colonies in nests below the ground are difficult to study and may be treated as constants or functions of surface activity.

Assumptions are: (1) Foraging occurs when relative humidity (weather station height) is greater than 50%; (2) When foraging occurs, rate of seed removal is a function of ambient temperature, number of foragers · colony$^{-1}$, number of colonies · ha$^{-1}$, colony satiation, and seed availability as indicated by equation 1:

$$dr/dt = f(T_a) \cdot f(N_f) \cdot f(D_c) \cdot f(-S_a) \qquad (1)$$

(dr = seed removal rate, $T_a$ = ambient temperature, $N_f$ = foragers·colony$^{-1}$, $D_c$ = density of colonies, $-S_a$ = satiation % based on seed storage.

## PROGRAMMING SCHEME FOR ANIMAL PHYSIOLOGICAL SUBMODEL

```
1 CONSUMPTION = 0.838 * (S ** 0.695) * 5
C Size-dependent consumption
C Seed biomass converted to calories
C See Golley (1961) and Chew and Chew (1965, 1970) for values
  IF BIRTH.EQ.1 CONSUMPTION = CONSUMPTION x 4
C Litter of young produced and lactation occurring
  ASSIMILATION = 0.8 * CONSUMPTION
C See Chew and Chew (1970)
  MAINTENANCE = 70.5 * (S ** 0.734) ÷ 0.86
C Basal metabolic rate plus activity at a rate of one-fourth metabolic rate (Chew and Chew, 1970)
  IF BIRTH.EQ.1 MAINTENANCE = MAINTENANCE x 4
C Expense of lactation
  IF SURFACE SEEDS.GT.10 * 6 SEED REMOVAL = K
  SEED REMOVAL = 7.6 * (SURFACE SEEDS ** 0.18)
  IF GROUP.EQ.2 SEED REMOVAL = 2.39 * x (SURFACE SEEDS ** 0.21)
C Seed removal related to seed availability
9 STORAGE = STORATE + (SEED REMOVAL - CONSUMPTION)
  IF STORAGE.LT.0 GO TO 2
C Less food available on surface or in storage than required for maintenance assimilation
  GO TO 3
C Food requirements met
2 ASSIMILATION = ASSIMILATION* (1 - [CONSUMPTION - SEED REMOVAL] ÷ CONSUMPTION)
  IF GROUP.EQ.2.AN.TEMP.LT.10 MAINTENANCE = MAINTENANCE ÷ 8
  ASSIMILATION = 0
C Assimilation, when minimum food requirements are not met Perognathus go into torpor (Hoover, 1973)
3 GROWTH = ASSIMILATION — MAINTENANCE
C Kcal in growth, either a + or — number
  IF BIRTH.EQ.1 YOUNG = YOUNG + GROWTH ÷ 1.03
C Kcal in growth which goes to youth after birth, in grams (Chew and Chew, 1970)
C Go to CHECK if young are weanable
  GO TO 4
  IF GROUP.EQ.2 P = S
  IF S.GT.40g.OR.P.GT.20g REPRODUCTION = REPRODUCTION + GROWTH
  PREGNANT DAYS = PREGNANT DAYS + 1
C Adult energy expended on developing on fetal components
  IF PREGNANT DAYS.EQ.30 S = 40, P = 20
  NUMYOUNG = REPROD ÷ 3
  IF GROUP.EQ.2 NUMYOUNG = REPROD
  BIRTH = 1
```

```
C   30 days is term and young are born and adult weight is
    reduced by the amount of young to 40 g
    IF S.EQ.40 GO TO 1
    IF P.EQ.20 GO TO 1
    S = S + (GROWTH ÷ 1.5)
C   Energy expended for growth converted to grams
    GO TO 1
    IF GROUP.EQ.1 NUMBER = 25
    IF GROUP.EQ.2 NUMBER = 10
    IF YOUNG ÷ NUMYOUNG.GT.NUMBER BIRTH =
    0, PREGDAYS = 0
C   Young are weaned adult growth then goes to repro-
    duction
    GO TO 1
```

## PROBLEMS OF INTERFACING DEMOGRAPHY AND PHYSIOLOGY

In atempting to construct the logic scheme for programming the functional relationships decribed in the previous section, we soon realized that we needed inputs from the demographic sections of the animal submodel. We worked around this problem in part by making guesses about probable forms of demographic functions and using constants wherever possible. Future efforts in construction of an animal submodel will have to focus considerable attention on this problem.

## GENERAL REFERENCES

While digging through the literature to develop the forms of the relationships presented, the following papers in addition to Desert Biome progress reports and our data proved to be most useful:

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