Technical Report No. 156

ELM: VERSION 1.0

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GRASSLAND BIOME

U.S. International Biological Program

August 1972

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U.S. INTERNATIONAL BIOLOGICAL PROGRAM

MEMORANDUM

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FROM: Barbara J. Hendricks, Manager of Publications BJH

SUBJECT: Technical Report No. 156

DATE: August 15, 1972

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ABSTRACT

This report contains a description of a model called "ELM." The report focuses on the structure and organization of the model rather than on the specific application of the model to a particular research site. The purpose of this report is primarily to provide an information document on the progress of this modelling activity. It is not considered to be complete in terms of a functional ecosystem model, but it does purport to describe completely a structure and organization for the development of such a total ecosystem model, and does present details of the development of some portions of that model.

This model will be used as a starting point by the liaison staff at the Natural Resource Ecology Laboratory from which to develop a model for each of the Comprehensive Network Sites. This application will obviously involve not only tuning of what currently exists, but also development of new material as necessary.

CHAPTER 1. INTRODUCTION

1.1 INTRODUCTION

This model is the third total system model that the U.S. IBP Grassland Biome study has initiated. Fig. 1.1 shows the relationship between the ELM model and its predecessors.

	PWNEE	LINEAR	ELM
DATE OF INITIATION (APPROX)	1969	1970	1971
LANGUAGE USED	FORTRAN	CSMP	SIMCOMP
LINEARITY	NONLINEAR	LINEAR	NONLINEAR
EQUATIONS	DIFFERENTIAL	DIFFERENTIAL	DIFFERENCE
"MOBILITY"	SITE-SPECIFIC	SITE-SPECIFIC	PARAMETERIZED

Fig. 1.1. Comparison of Grassland Biome total systems models.

The initiation of a third total system modelling effort when two others are ongoing requires some justification. Part of this justification stems simply from the need to make a fresh start after spending 2 years learning about the development and implementation of large-scale ecosystem models. We have discovered many things, such as pragmatic details regarding the relative amounts of time spent implementing a model, as compared to the amount of time running the developed model. Since the former has, in our experience, taken far more time and manpower, a primary consideration in the development of this model was to produce something which is easy to implement and modify. That is the reason for the introduction of SIMCOMP (Gustafson and Innis, 1972*a*,*b*). The FORTRAN model (Bledsoe et al., 1971) is not easy to work with in this sense. It is quite large and difficult to modify in a short period of time. The CSMP (Continuous System Modelling

Program) model (Patten, 1972) is easy to modify and is a reasonable simulation language, but was not available on the computer that we used (CDC 6400). Furthermore, we did not feel that the linearity restriction of the CSMP model was acceptable.

A final major concern was that the earlier models were designed to be site-specific. This is legitimate if one accepts the premise that experience with details is necessary in order to develop generalities. The ELM model was designed to apply to the variety of sites in the U.S. IBP Grassland Biome network. These sites range from Washington to New Mexico west of the Mississippi.

1.2 OBJECTIVES AND QUESTIONS

The objective of this modelling activity is to develop a total system model of the biomass dynamics for a grassland which, via parameter change, can be representative of the sites in the U.S. IBP Grassland Biome network, and with which there can be relatively easy interaction.

There are several key points in this objective which deserve further elaboration. First, the term *total system* is used in the sense that each of the abiotic, producer, consumer, and decomposer sections of the system are represented. A total system model is one which is all encompassing without being all inclusive. Second, the term *biomass dynamics* identifies our principal concern as being that of carbon (or energy) flow within the system. Flows of nutrients and water are important, but are not the principal concern. Third, *representative* is used to indicate that the model is valid provided that it can predict the direction and order of magnitude of the response of the system to certain perturbations, as well as predict the "normal" dynamics. Finally, the *relatively easy interaction* is to assure that teams of modellers and biologists can decide on major changes in the system, implement them, and get results from the computer in a working session of 2 or 3 hr. We have interpreted this to mean that once the biological input has been decided upon, we should be able to run the model and get output within 30 min.

The objective serves to specify the direction of the effort, but it is still too general to provide a basis for a number of the decisions that have to be made in the development of a model. In order to have a basis for these decisions, the following six specific questions were chosen as points which the first version of the ELM model had to address.

1. What is the effect on net or gross primary production as a result of the perturbations: (i) variations in the level and type of herbivory, (ii) variations in the precipitation or applied moisture and temperatures, and (iii) variations in added nitrogen or phosphorus?

2. How is the carrying capacity of a grassland affected by these perturbations?

3. Are the results of an appropriately driven model run consistent with field data taken in the Grassland Biome program? If not, why not?

4. What are the changes in the composition of the producers as a result of these perturbations?

5. What are the qualitative differences in primary production between grassland sites, and how are they affected by the perturbation?

6. What are the qualitative differences of practical herbivory practices between sites, and how are they affected by these perturbations?

Additionally, it was decided that the first version of this model had to address perturbations of a "reasonable" sort, that is, variations that are common in these grasslands. It was also decided that we would not have satisfied some larger set of objectives until the model was able to address perturbations of an "unreasonable" sort, by which we meant those variations which are encountered only rarely in these grasslands, such as once in tens of years. We have explicitly excluded from our consideration the extremely rare perturbations of glaciation, earthquake, etc. The model results which are presented here represent the application of this model to one of the sites in the U.S. IBP Grassland Biome study, i.e., the Intensive Site (Pawnee Site) at the Pawnee National Grassland.

The development of any model such as this is never complete, and we certainly are not claiming that this one is complete by presuming to publish this technical report. The developmental process is a continual evolution in which different stages and plateaus are reached at different times. The plateau that is reached now is that of (i) clearly identifying and accepting the objectives and questions listed above and (ii) having clearly identified a structure which is described below and with which this collection of objectives and questions can be addressed. There have been and will continue to be a number of contributors to this effort and communication among these individuals is important. The direction of the modelling effort in the central program of the Grassland Biome study is of interest to many participants; and communication with them, even though they may not be directly involved in the modelling effort, is equally important.

1.3 OVERVIEW

One can identify five major components of this model as shown in Fig. 1.2. Each of these components is discussed in detail in Chapters 2 through 6 of this report. In this section some of the differences between this model and its predecessors and some of the philosophy behind the development of this model will be presented. As Fig. 1.1 indicates, both of the predecessors to this modelling effort were differential equation models. The actual implementation of these was to write differential equations for the components of the various parts of the ecological system that were represented, and to solve these differential equations simultaneously subject to certain initial conditions. Each one of these differential equations can be written basically as shown in the symbolic equation 1.1.

$$\dot{X} = \Sigma \text{ inputs} - \Sigma \text{ outputs} \tag{1.1}$$

In equation 1.1, each of the inputs and outputs is measured in the units of X ÷ time. Thus, if X is in g/m^2, then an input would have to be measured in $g/unit^2/time$. This equation shows that the flow orientation, i.e., orientation toward the input and output, is more fundamental than the orientation toward differential equations in the sense that the differential equation can always be derived from the inputs and outputs. However, the inputs and outputs cannot necessarily be derived from the differential equation. This simple observation is the basis of a number of modelling activities (Forrester, 1961; Pugh, 1961; Gustafson and Innis, 1972*a*,*b*) which develop individual models or compilers based on an orientation toward the flows. This allows one to specify flows as input to the system and have the system write the differential or difference equations and solve them. The SIMCOMP language in which this model is written was so developed. The discussion which follows will focus on the flows that occur within the system rather than the differential equations for the individual components.

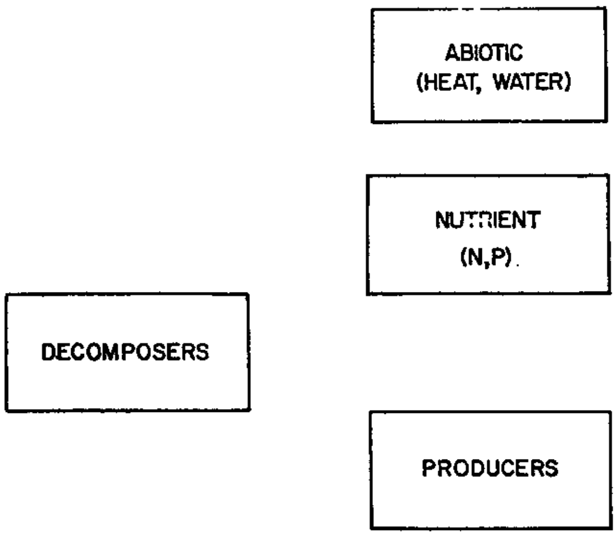

Fig. 1.2. Major subsystems of the ELM model.

1.4 TIME RESOLUTION

The compatibility of the several components of any simulation model in terms of size resolution, time resolution, input requirements, output requirements, etc., is a fundamental but often ignored consideration. One gets the impression that some differential equation modellers feel that this problem is eliminated by using differential equations as opposed to difference equations. The reason, presumably, goes something like, "if we take the limit as the time step goes to 0, then all things are infinitely resolved with respect to time, and therefore the time resolution problem is eliminated." However, these people are often unwilling to include instantaneous or short-term variations in a system which they do not feel affects the long-term dynamics of such a system.

In the development of SIMCOMP and the implementation of this particular model, we have chosen to focus on difference equations to assure that modellers and experimenters alike are well aware of the time increment in which they are describing the model. This model is not concerned with diurnal changes in the system, but only with changes which occur at the minimum of a 24-hr period and up to a period of perhaps 40 to 100 years.

This approach has several facets. First, it avoids the introduction of the derivative where the derivative may or may not contribute significantly to the argument. In particular, it avoids the necessity of introducing the concept of derivatives in discussing the development of models with people who are not acquainted with the differential calculus (Innis, 1972*b*). Secondly, it keeps the time frame of concern in the modelling effort always before us. This is a mixed blessing because at times it would be convenient not to have to be so particularly concerned with the representation of mechanisms in such a way that they operate within a specified time frame. In the long run, however, this specificity is most advantageous. Third, the specificity, with respect to the modelling interval of interest, is useful in deciding on mechanisms that need to be incorporated into the model and in seeking data which might be useful in the modelling effort.

Further discussion of the modelling philosophies incorporated here will be found in Forrester (1961), Innis (1972*a*,*b*), and Gustafson and Innis (1972*a*,*b*).

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CHAPTER 2. ABIOTIC SECTION (HEAT AND WATER)

2.1 INTRODUCTION

The abiotic section stochastically simulates daily weather observations which are used as driving variables for heat flow and water flow submodels. The heat flow submodel is primarily concerned with predicting soil temperature, while the water flow submodel determines the evaporative water loss and soil water for seven layers. The atmospheric variables which are stochastically simulated in subroutine STCHP are the maximum and minimum air temperature, daily rainfall and the daily average cloud cover, relative humidity, and wind speed.

The atmospheric submodel simulates the occurrence of rainfall using first-order Markov chains which are calculated for monthly time periods, while the other parameters are simulated using conditional probability relationships which are calculated for monthly time periods (see Fig. 2.1). Particular care is taken to ensure that the weather observations are internally consistent for long periods of time (1 to 20 years). The daily weather observations are statistically comparable with observed climatological data used as input for the Markov chains and conditional probability relationships. The submodel is structured so that it is easy to replace the stochastically simulated observations with an observed time series of daily weather observations. An observed time series should be used to drive the ecosystem model when the results of the simulation are compared with observed biological data.

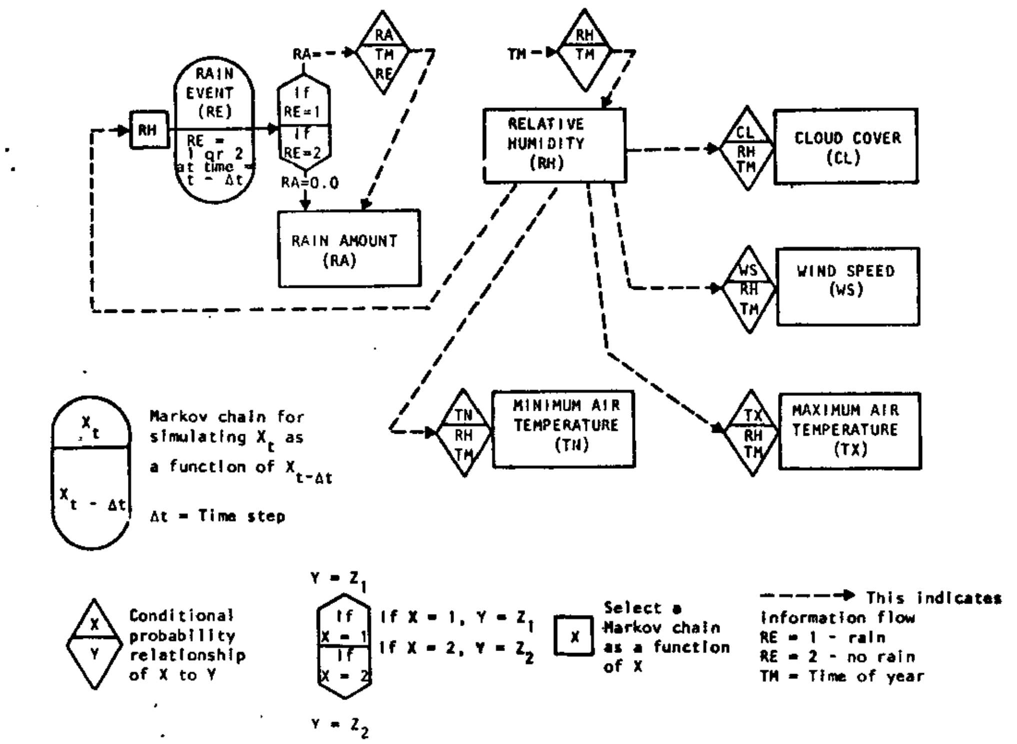

Fig. 2.1. Atmospheric simulation submodel.

The water flow submodel simulates the flow of water in the vegetation canopy and the soil water layers (see Fig. 2.2). Rainfall interception by vegetation, infiltration of rainfall into the soil water layers, and evaporation of water from the vegetation canopy and soil water layers are the physical processes considered by the submodel. The atmospheric parameters and the biotic state variables strongly influence all these processes. The submodel is specifically designed to simulate the feedback loops between the biotic and abiotic state variables.

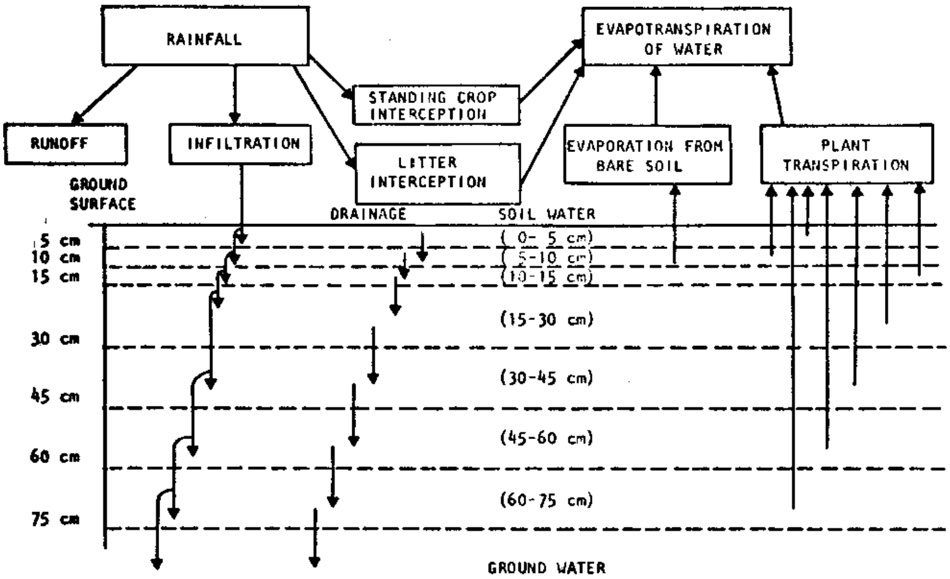

Fig. 2.2. Water flow submodel.

The heat flow submodel simulates the air temperature within the canopy and the soil temperature for 12 points in the soil profile (see Fig. 2.3). The soil temperature profile is determined using the Fourier heat conduction equation, while the daily average canopy air temperature is predicted as a function of the average daily air temperature (1.5 m), the potential evapotranspiration rate, and the aboveground vegetation biomass. This section also simulates the average daytime air temperature and the solar radiation parameters.

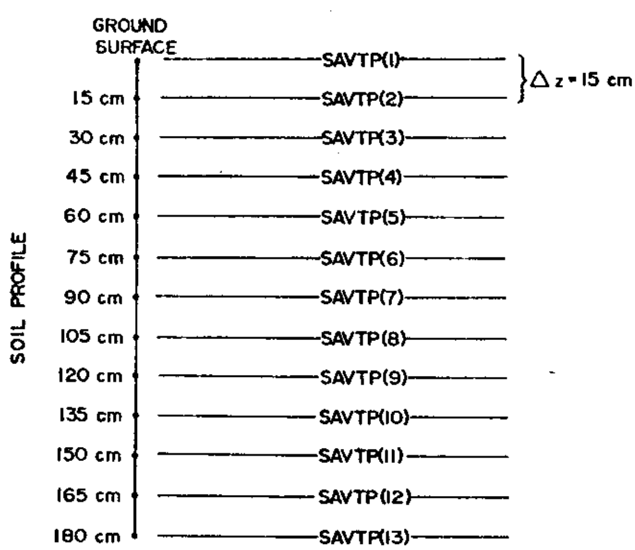

Fig. 2.3. Heat flow submodel: Soil temperature profile.

2.2 ATMOSPHERIC SIMULATION SUBMODEL

The simulation of daily weather for extended periods of time is accomplished with a stochastic model of daily rainfall amounts, maximum and minimum air temperature, average daily relative humidity, cloud cover, and wind speed. The variables simulated by the submodel are considered as driving variables for the ecosystem, and no feedback from the biotic to the abiotic components of the ecosystem is included. Fig. 2.1 illustrates the procedure used to predict the abiotic variables. The relative humidity is stochastically predicted at the start of each time step. The rainfall amount is simulated as a function of the forecast relative humidity for the day. Cloud cover, wind speed, and the maximum and minimum air temperature are then forecast using the conditional probability relationships that relate these parameters to relative humidity. The submodel is thus structured so that the forecast relative humidity will influence the values simulated for the other atmospheric parameters in accordance with experience at the Pawnee Site. The structure of atmospheric simulation submodels at the other Comprehensive Network Sites may have to be modified if the correlation between the atmospheric parameters at these sites is significantly different from those observed at the Pawnee Site.

Seven years of daily weather observations at Cheyenne, Wyoming, were used to calculate the statistical relationships utilized in the simulation model. The statistical relationships are calculated for monthly time periods. The abiotic model is structured so that the average daily air temperature and daily rainfall are the minimum number of driving variables needed for the heat flow and water flow submodels.

```
      NOBSD = 1
C...DETERMINE THE DRIVING VARIABLES FOR THE WATER AND HEAT FLOW MODELS
C...IF NOBSD=1 THE DRIVING VARIABLES ARE SIMULATED STOCHASTICALLY, IF NOBSD
C...=2 OBSERVED WEATHER DATA IS USED TO DRIVE THE MODEL.
      PRIP=0.   $IF(NOBSD.EQ.1) CALL STCHP
      IF(NOBSD.EQ.2) GO TO 40096    $GO TO 40097
40096 CONTINUE
C...OBSERVED MAXIMUM AND MINIMUM AIR TEMPERATURE AND RAINFALL DATA ARE
C...USED TO DRIVE THE ABIOTIC MODEL
40097 CONTINUE



C...READ IN THE STATISTICAL RELATIONSHIPS THAT ARE USED BY THE
C...STOCHASTIC SIMULATION MODEL(READ THE DATA FROM A FILE THAT HAS BEEN
C...STORED IN THE COMPUTER)
C...----APPLICATION TO THE SITES---- THE STATISTICAL RELATIONSHIPS USED BY
C...THIS MODEL MUST BE CALCULATED FROM A TIME SERIES OF DAILY WEATHER
C...OBSERVATIONS AT THE PARTICULAR SITE(CL,WS,TMX,TMN,RH,R1,R2,A,B).
      IF(TIME.EQ.0.0) READ(7,200)CL
      IF(TIME.EQ.0.0) READ(7,200)WS
      IF(TIME.EQ.0.0) READ(7,200)TMX
      IF(TIME.EQ.0.0) READ(7,200)TMN
  200 FORMAT(1H ,13(F5.3,1X))
      RAN=RANF(0)
      NNO=MON
C...DETERMINE WHICH RELATIVE HUMIDITY FREQUENCY DISTRIBUTION IS
C...USED TO CALCULATE THE RELATIVE HUMIDITY(RHP)
      IF(PMOD(NNO).EQ.1.) GO TO 800    $IF(PMOD(NNO).EQ.2.) GO TO 600
      IF(PMOD(NNO).EQ.3.) GO TO 700
C...USE THE UNMODIFIED RELATIVE HUMIDITY DISTRIBUTION TO GENERATE THE
C...CLASS INTERVAL OF RELATIVE HUMIDITY
  800 DO  1  I=2,11
      IF(RAN.LE.RH(MON,I).AND.RAN.GT.RH(MON,I-1))GO TO 2
 1    CONTINUE
 2    RH1=I-2  $RAN=RANF(0)
      GO TO 605
C...USE THE THE FREQUENCY DISTRIBUTION IN WHICH THE AVERAGE RELATIVE
C...HUMIDITY HAS BEEN INCREASED BY 15 PERCENT.
  600 DO  601  I=2,11
      IF(RAN.LE.R1(MON,I).AND.RAN.GT.R1(MON,I-1))GO TO 602
  601 CONTINUE
  602 RH1=I-2   $RAN=RANF(0)
      GO TO 605
C...USE THE RELATIVE HUMIDITY FREQUENCY DISTRIBUTION IN WHICH THE AVERAGE
C...RELATIVE HUMIDITY HAS BEEN DECREASED BY 15 PERCENT
  700 DO  701  I=2,11
      IF(RAN.LE.R2(MON,I).AND.RAN.GT.R2(MON,I-1))GO TO 702
  701 CONTINUE
  702 RH1=I-2  $RAN=RANF(0)
  605 CONTINUE
      RHP=(RH1+ RAN*1.)*10.
      NRH=RHP/20. + 1.   $IF(NRH.GT.5) NRH=5.
```

2.2.1 Relative Humidity

Relative humidity is forecast in one of 10 class intervals (0-10%, 11-20%, 21-30%, 31-40%, 41-50%, 51-60%, 61-70%, 71-80%, 81-90%, and 91-100%) by using the monthly frequency distributions for relative humidity in the class intervals. This forecast class interval is obtained using a random number from a rectangular distribution (0 to 1), and the cumulative frequency distribution is derived from the relative humidity frequency distribution for the appropriate month. This is accomplished by using the generated random number as the ordinate of the cumulative frequency distribution and then by choosing the class interval of relative humidity from the abscissa. Any further reference to the use of a random process by which a class interval of a parameter is selected from a frequency distribution will refer to the process described above. The actual value of relative humidity (to the nearest 1%) is simulated, using the random process in conjunction with the cumulative frequency distribution generated, by assuming that each relative humidity within the forecast class interval has an equal probability.

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```
C... DETERMINE IF RAINFALL WILL OCCUR
      RAN=RANF(0)     $I=1    $DRY=0.0      $IF(PRA.EQ.1.) I=2
C...DETERMINE IF RAINFALL WILL OCCUR
      IF(RAN.LE.A(I,NRH,MON)*PRF)  DRY=1.
      RHHH=0.0
      IF(DRY.EQ.1.)GO TO 60   $PRIP=0.0   $PRA=0.0   $GO TO 11
   60 RAN=RANF(0)        $IF=1.
C...CALCULATE THE RAINFALL AMOUNT(PRIP)
      IF(RAN.LT.B(NNO,1))GO TO 14
      DO  12  I=1,9
      IF(RAN.GT.B(NNO,I).AND.RAN.LE.B(NNO,I+1)) GO TO 15
   12 CONTINUE
   15 IF=I+1
   14 RAN=RANF(0)
      PRIP=           C(IF,1) + C(IF,2)*RAN  $PRA=1.0
   11 CONTINUE
```

2.2.2 Rainfall

The occurrence of rainfall is simulated using first-order Markov chains which are calculated using data stratified with respect to five class intervals of relative humidity (0-20%, 21-40%, 41-60%, 61-80%, and 81-100%). The first-order Markov class is specified through the use of a transition matrix ($P_{\Delta t}$).

$$P_{\Delta t} = \begin{array}{c} \\ R \\ NR \end{array} \begin{array}{c} \begin{array}{cc} R & NR \end{array} \\ \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \end{array}$$

where

R = rain.

NR = no rain.

A_{ij} = the probability for the occurrence or non-occurrence of rainfall ($j = 1$, $j = 2$) given the occurrence or non-occurrence of rainfall ($i = 1$, $i = 2$) at time $t-\Delta t$ (Δt = 24 hr for this matrix).

Rainfall is simulated using the appropriate frequency distribution, [$\{A_{11}A_{12}\}$ or $\{A_{21}A_{22}\}$] determined from the Markov chain which corresponds to the forecast class interval of relative humidity in conjunction with the random process. Rainfall amounts for days with measurable rainfall are simulated using frequency distributions for 10 class intervals of rainfall amounts

(0.0-0.1, 0.11-0.20, 0.21-0.30, 0.31-0.50, 0.51-0.70, 0.71-0.90, 0.91-1.5, 1.6-2.5, 2.6-4.5, and $\geq$ 4.51 inches)

```
C...SIMULATE THE MAXIMUM AIR TEMPERATURE(TMP)
      RAN=RANF(0)     $DO  7  I=2,23
      IF(RAN.LE.TMX(MON,NRH,I).AND.RAN.GT.TMX(MON,NRH,I-1)) GO TO 8
  7   CONTINUE
  8   TMI=I-2  $RAN=RANF(0)
      TMP=-5.  +(TMI+ RAN*1.)*5.
      IF(TMP.GT.100.) CALL PXT(1.,P9)
      IF(TMP.LT.0.0) CALL PXT(-1.,P9)
      IF(TMP.GT.100..OR.TMP.LT.0.0) TMP=TMP + P9
C...SIMULATE THE MINIMUM AIR TEMPERATURE(TNP)
      RAN=RANF(0)     $DO  9  I=2,23
      IF(RAN.LE.TMN(MON,NRH,I).AND.RAN.GT.TMN(MON,NRH,I-1)) GO TO 10
  9   CONTINUE
  10  TNI=I-2  $RAN=RANF(0)
      TNP=-35.  + (TNI + RAN*1.)*5.

      IF(TNP.GT.70.) CALL PXT(1.,P9)
      IF(TNP.LT.-30.) CALL PXT(-1.,P9)
      IF(TNP.GT.70..OR.TNP.LT.-30.)TNP=TNP + P9
  532 CONTINUE
      TNN=TMP    $IF(TMP.LT.TNP) TMP=TNP  $IF(TMP.LT.TNP)TNP=TNN


C*****************************************************************

      SUBROUTINE PXT(P8,P9)
C...THIS SUBROUTINE IS USED TO DETERMINE THE MAXIMUM AND MINIMUM TEMPERATURE
C...AT THE UPPER AND LOWER LIMITS OF THE FREQUENCY DISTRIBUTION(+10 OR-10
C...DEGREES FAHRENHEIT AT THE MOST CAN BE ADDED TO THE TEMPERATURE AT THE
C...EXTREMES)
C...THIS SUBROUTINE CALCULATES A CUMULATIVE FREQUENCY DISTREBUTION
C...FROM A FREQUENCY DISTREBUTION WHICH ASSUMES THAT THE PROBABILITY FOR
C...TEMPERATURES GREATER THAN THE END POINT VALUES DECREASES LINEARLY TO
C...ZERO AT 10 DEGREES BEYOND THE END POINT VALUES. THE NUMBER OF DEGREES
C...ADDED TO THE END POINT VALUE IS THEN CALCULATED BY THIS SUBROUTINE.
      DIMENSION PM(11)
      PM(1)=0.   $DO  1  I=2,11
      PQ=(I-1)
  1   PM(I)=PM(I-1) + 1.-.1*PQ
      DO  3  I=2,11
  3   PM(I)=PM(I)/PM(11)
      RAN=RANF(0)
      DO  2  I=1,10
      IF(RAN.GT.PM(I).AND.RAN.LE.PM(I+1)) GO TO 5
  2   CONTINUE
      I=10
  5   P9=P8*I
      RETURN   $END
C*****************************************************************
```

in conjunction with the random processes. The actual value of the rainfall amount is determined by using the same technique used to calculate the actual value of relative humidity.

2.2.3 Cloud Cover, Wind Speed, and Maximum and Minimum Air Temperature

Average daily cloud cover, wind speed, and maximum and minimum temperature are simulated as functions of the forecast relative humidity using the conditional probability relationship which relates class intervals of these parameters to the relative humidity. The frequency distributions for 10 class intervals of cloud cover, 6 class intervals of wind speed, 22 class intervals of maximum air temperature, and 22 class intervals of minimum air temperature (see Fig. 2.4) are calculated for 5 class intervals of relative humidity. The frequency distribution which corresponds to the forecast relative humidity is used in conjunction with the random process to determine the simulated class interval for these parameters. The variable values are determined using the same technique employed to calculate the actual value of the relative humidity. The value for maximum air temperature less than 0°F or greater than 100°F and minimum air temperature greater than 70°F or less than -30°F is simulated by randomly selecting the temperature from a frequency distribution in which the probability for temperatures less than the lower extreme (0°F, -30°F) and greater than the upper extreme (100°F, 70°F) decreases linearly to zero at 10°F beyond the extreme values. The stochastic simulation model can be used at other Network Sites by using conditional probability relationships and Markov chains determined from observed data at the particular sites or at nearby first-order weather stations. This calls for at least 5 years of observations of daily relative humidity, wind speed, cloud cover, rainfall, and maximum and minimum air temperatures.

10 CLASS INTERVALS OF CLOUD COVER:

0 to 10%, 11 to 20%, 21 to 30%, 31 to 40%, 41 to 50%

51 to 60%, 61 to 70%, 71 to 80%, 81 to 90%, 91 to 100%.

6 CLASS INTERVALS OF WIND SPEED:

0 to 5, 6 to 10, 11 to 15, 16 to 20, 21 to 25, 26 to 30 mph.

22 CLASS INTERVALS OF MAXIMUM AIR TEMPERATURE:

<0, 1 to 5, 6 to 10, ..., 96 to 100, >100°F.

22 CLASS INTERVALS OF MINIMUM AIR TEMPERATURE:

<-30, -29 to -25, -24 to -20, ..., 66 to 70, >70°F.

Fig. 2.4. Class intervals for cloud cover, wind speed, and maximum and minimum air temperature.

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```
C                     *        WATER FLOW MODEL                            *
C                     ***********************************************************
      RAIN = PRIP * 2.54
      PTZP=0.0
      PBM=X(2)+X(3)+X(4)+X(5)+X(6)+X(20)+X(21)+X(22)+X(23)+X(24)+X(25)
C...CALCULATE THE LEAF AREA INDEX FOR THE STANDING CROP(PLAI)
      PLAI=PBM/150.
      IF(NDAY.EQ.1)   PRIPT=0.
      PRIPT=PRIPT+PRIP
C...CALCULATE THE AVERAGE HEIGHT OF VEGETATION (PH) AND PERCENTAGE OF AREA
C...COVERED BY VEGETATION(PC)
      PISC=PILT=0.0  $IF(PRIP.LE.0.0) GO TO 40000
      PC=PLAI  $IF(PC.GT.1.) PC=1.
      PH=ATANF(300.,12.,34.,.002,PBM)  $IF(PH.LE.0.0) PH=0.0
      PHC=PC*PH
C...CALCULATE THE AMOUNT OF WATER INTERCEPTED BY THE STANDING CROP(PISC)
      IF(PHC.LE.8.5) PA=.9 + .04*PHC
      IF(PHC.GT.8.5) PA=1.22 + (PHC-8.5)*.35
      IF(PHC.LF.3.0) PB=PHC*.333  $IF(PHC.GT.3.0) PB=1. +(PHC -3.)*.182
      PISC=PA*.026*PRIP + .037*PB  $IF(PISC.GT.PRIP) PISC=PRIP
      PRIP=PRIP -PISC          $IF(PRIP.EQ.0.0) GO TO 40000
C...CALCULATE THE AMOUNT OF WATER INTERCEPTED BY LITTER(PILT)
      ZZH=(-1.+.45*ALOG10(X(41) + 1.))*ALOG(10.)
      PILT=(.015*PRIP + .025)*EXP(ZZH)
      IF(PRIP.LE.PILT) PILT=PRIP  $PRIP=PRIP-PILT
40000 CONTINUE
      IF(NDAY.EQ.1)   PILTT=PISCT=0.0
      PILTT=PILTT + PILT     $PISCT=PISCT + PISC
      PRIP=PRIP*2.54  $PILT=PILT*2.54  $PISC=PISC*2.54
      PISC1=PISC1 + PISC   $PILT1=PILT1 + PILT
```

2.3 WATER FLOW SUBMODEL

This submodel is concerned with the flow of water in the vegetation canopy and the soil water layers. The allocation of rainfall to the soil water layers and the vegetation canopy and the evaporation of water from these are the most important processes considered. Fig. 2.2 displays the overall flow diagram of the submodel. The program is generalized so that it can handle an arbitrary number of soil water layers in which the depth of the layers are specified.

2.3.1 Allocation of Precipitation

Rainfall that falls on the vegetation canopy can either be intercepted by the standing crop or the litter, infiltrated into the soil, or transported from the area as runoff.

2.3.1.1 Interception by vegetation. Standing vegetation and litter intercept rainfall before it reaches the ground. The vegetation is considered to hold the intercepted water until it is evaporated into the air. Evaporation of intercepted water proceeds at the potential evapotranspiration rate until all of this water is evaporated. This submodel uses the equations developed by Corbett and Crouse (1968) for estimating the intercepted water loss by standing crop and litter. Corbett and Crouse's equations predict interception by the standing crop and litter as a function of precipitation amount, height of vegetation, and the percentage of area covered by vegetation. Equations 2.1 and 2.2 and the functional relationships for PA, PB, and D are derived to give a continuous mathematical representation of Corbett and Crouse's equations as a function of PC·PH and PRIP.

Corbett and Crouse's equations are used in the form:

$$PISC = PA\ 0.026\ PRIP + 0.37\ PB \qquad (2.1)$$

$$PILT = (0.015\ PRIP + 0.025)D \qquad (2.2)$$

where

$$PA = \begin{cases} 0.9 + 0.04\ PC \cdot PH & \text{if } PC \cdot PH \le 8.5 \\ 1.22 + (PC \cdot PH - 8.5)0.35 & \text{if } PC \cdot PH > 8.5 \end{cases}$$

$$PB = \begin{cases} PC \cdot PH\ 0.33 & \text{if } PC \cdot PH \le 3.0 \\ 1 + (PC \cdot PH - 3.0)0.182 & \text{if } PC \cdot PH > 3.0 \end{cases}$$

$$D = e^{[(-1. + 0.45 \log_{10} (X(41) + 1)) \ln (10.0)]}$$

PISC = interception by standing crop (inches).

PILT = interception by litter (inches).

PC = fractional area covered by vegetation.

PH = average height of vegetation (inches).

PRIP = storm size (inches).

X(41) = average litter biomass (g/m^2).

$$PH = ATANF\ (300.0,\ 12.0,\ 34.0,\ 0.002,\ PBM) \qquad (2.3)$$

where

PBM = standing crop biomass (g/m^2).

$ATANF(a, b, c, d, x) = b + \frac{c}{\pi} ATANF(\pi d(x-a))$.

a = "x" location of the inflection point.

b = "y" location of the inflection point.

c = step size (distance from maximum to minimum).

d = slope of the line at the inflection point.

x = value of independent variable.

```
C...CALCULATE THE INFILTRATION RATE AND DETERMINE THE AMOUNT OF WATER THAT
C...DRAINS FROM THE SOIL WATER LAYERS UNDER HIGH SOIL WATER CONDITIONS(
C...GREATER THAN FIELD CAPACITY)
      SMOS(1)=SMOS(1) + PRIP
      DO  40002  I=1,NLYS    $PQZM=PSO1(I,2)*PSO1(I,5)/100.
      IF(SMOS(I).GT.PQZM) GO TO 40003    $GO TO 40002
40003 SMOS(I+1)=SMOS(I+1) + (SMOS(I)-PQZM)    $SMOS(I)=PQZM
40002 CONTINUE
```

$$PC = \begin{cases} PLAI & \text{if } PLAI \le 1.0 \\ 1 & \text{if } PLAI > 1.0 \end{cases} \qquad (2.4)$$

where

$PLAI = PBM/150.0.$

The relationship of leaf area index (PLAI) to standing crop biomass is based upon data presented by Kvet and Marshall (1971), while the functional relationship of vegetation height to standing crop biomass (equation 2.3) is based upon personal communication with J. K. Lewis.

These equations can be used to estimate intercepted water loss by the grasses at the other Network Sites. Intercepted water loss by shrubs and other vegetation types may have to be represented using other relationships.

2.3.1.2 Infiltration and soil water drainage. Rainfall not intercepted by the vegetation or lost from the area as runoff will infiltrate into the soil. If the soil water in the top layer is greater than the field capacity, then the excess water flows into the second soil water layer (drainage under high soil water conditions). Similarly, if the soil water in the second layer exceeds the field capacity, then the excess water will flow into the next lower soil water layer. This process continues until there is insufficient water to bring the next lower soil water layer up to field capacity. If the top seven soil water layers are at field capacity, any excess water will drain into the ground water (layer 8). Fig. 2.2 presents a graphical description of this model. A mathematical description of this model is presented below:

$$SMOS(1) = SMOS(1) + PRIP \qquad (2.5)$$

```
C...CALCULATE THE FIELD CAPACITY FOR THE SOIL WATER LAYERS(PSO1(I,2))
      DO  40001  I=1,NLYS   $PPT=PSO1(I,1)
C...SITE SPECIFIC EQUATIONS--THE FUNCTIONAL RELATIONSHIP OF THE FIELD CAPACITY
C...TO THE DEAD ROOT BIOMASS WILL HAVE TO BE MODIFIED AS A FUNCTION OF SOIL
C...TYPE.
C...IF PPT=2 THE SOIL WATER LAYER IS IN THE B HORIZON, IF PPT=1 THE SOIL WATER
C...LAYER IS IN THE A HORIZON
      IF(PPT.EQ.2) PSO1(I,2)=28.5 + X(42)*PSO1(I,3)/(80.*PSO1(I,5)/15.)
      IF(PPT.EQ.1) PSO1(I,2)=16.  + X(42)*PSO1(I,3)/(250.*PSO1(I,5)/15.)
40001 CONTINUE


C...CALCULATE THE SOIL WATER TENSION(TE) IN BARS
C...---SITE SPECIFIC EQUATIONS--THE RELATIONSHIP OF THE SOIL WATER TENSION
C...TO THE VOLUMETRIC SOIL WATER CONTENT(Q) IS A FUNCTION OF SOIL TYPE
C...CALCULATE TE FOR THE SOIL WATER LAYERS IN THE A HORIZON(IP=1)
      IP=PSO1(I,1)  $TE=0.
      IF(IP.EQ.1.AND.Q.GE.PSO1(I,2))   TE=(60.-Q)*.3/(60.-PSO1(I,2))
      IF(IP.EQ.1.AND.Q.LT.PSO1(I,2)) TE=.3+(PSO1(I,2)-Q)*2.7/(PSO1(I,2)-
     111.5)
      IF(IP.EQ.1.AND.Q.LT.11.5) TE=3. + (11.5-Q)*3.40
      IF(IP.EQ.1.AND.Q.LT.8.0) TE=15. + (8.-Q)*20.
C...CALCULATE TE FOR THE SOIL WATER LAYERS IN THE B HORIZON(IP=2)
      IF(IP.EQ.2.AND.Q.GE.PSO1(I,2))TE=(60.-Q)*.3/(60.-PSO1(I,2))
      IF(IP.EQ.2.AND.Q.LT.PSO1(I,2))TE=.3+(PSO1(I,2)-Q)*2.7/(PSO1(I,2)-
     117.1)
      IF(IP.EQ.2.AND.Q.LT.17.1) TE=3. + (17.1-Q)*3.0
      IF(IP.EQ.2.AND.Q.LT.13.) TE=15.  + (13.-Q)*18.
      IF(TE.LE.0.0) TE=0.01
```

$$\text{SMOS(I)} = \begin{cases} \text{SMOS(I)} + (\text{SMOS(I-1)} - \text{PQZM}) & \text{if SMOS(I-1)} > \text{PQZM} \\ \text{SMOS(I)} & \text{if SMOS(I-1)} \leq \text{PQZM} \end{cases} \quad (2.6)$$

$$\text{SMOS(I-1)} = \begin{cases} \text{PQZM} & \text{if SMOS(I-1)} \geq \text{PQZM} \\ \text{SMOS(I-1)} & \text{if SMOS(I-1)} < \text{PQZM} \end{cases} \quad (2.7)$$

for I = 2, 7

where

SMOS(I) = soil water for the I^{th} soil water layer (cm) for I = 1, 2, ..., 7.

PRIP = rainfall minus interception water loss (cm).

PQZM = amount of water in I-1 soil water layer at field capacity (cm).

Equations 2.5, 2.6, and 2.7 are solved in the sequence indicated. The field capacity for the I^{th} soil water layer (PSOI(I,2)) is determined as a function of the physical characteristics of the layers and the amount of dead root biomass (see lines 8 and 9 of the FORTRAN code on the facing page). Line 8 of the FORTRAN code is used for soil water layers above 15 cm (A horizon), while line 9 is used for soil water layers below 15 cm (B horizon). The model assumes that wilting point does not change as a function of root biomass and that the moisture tension at the field capacity will be equal to -.3 bars. The soil water tension vs. volumetric soil water content curve changes with respect to changes in the field capacity according to the equations below:

$$TE = \begin{cases} \dfrac{(60.0 - Q)0.3}{(60.0 - PS01(I,2))} & \text{if } Q \geq PS01(I,2) \\[2ex] 0.3 + \dfrac{(PS01(I,2) - Q)2.7}{(PS01(I,2) - 17.1)} & \text{if } 17.1 \leq Q < PS01(I,2) \\[2ex] 3.0 + (17.1 - Q)3.0 & \text{if } 13.0 \leq Q < 17.1 \\[1ex] 15.0 + (13.0 - Q)18.0 & \text{if } Q < 13.0 \end{cases} \qquad (2.8)$$

for I = 4, 5, 6, 7 (B horizon).

$$TE = \begin{cases} \dfrac{(60.0 - Q)0.3}{(60.0 - PS01(I,2))} & \text{if } Q \geq PS01(I,2) \\[2ex] 0.3 + \dfrac{(PS01(I,2) - Q)2.7}{(PS01(I,2) - 11.5)} & \text{if } 11.5 \leq Q < PS01(I,2) \\[2ex] 3.0 + (11.5 - Q)3.4 & \text{if } 8.0 \leq Q < 11.5 \\[1ex] 15.0 + (8.0 - Q)20.0 & \text{if } Q < 8.0 \end{cases} \qquad (2.9)$$

for I = 1, 2, 3 (A horizon).

where

TE = soil water tension for the I^{th} soil water layer (bars).

Q = volumetric water content of the I^{th} soil water layer (%).

PS01(I,2) = field capacity for the I^{th} soil water layer.

A graph of soil water tension vs. volumetric soil water content is presented in Fig. 2.5 for the B horizon with a field capacity equal to 28% by volume.

```
C...CALCULATE THE SOIL WATER DRAINAGE FROM SOIL WATER LAYERS WHEN THE
C...MOISTURE CONTENT OF THE SOIL IS LESS THAN OR EQUAL TO THE FIELD
C...CAPACITY.
      DO  40100  I=1,NLYS
      PQZM=PSO1(I,2)*PSO1(I,5)*.01
      DRAIN(I)=PRD*EXP((SMOS(I)-PQZM)*15./PSO1(I,5))
      PQMZ=PSO1(I,4)*PSO1(I,5)*.01    $IF(SMOS(I).LE.PQMZ) DRAIN(I)=0.0
      SMOS(I)=SMOS(I) - DRAIN(I)
40100 SMOS(I+1)=SMOS(I+1) + DRAIN(I)
```

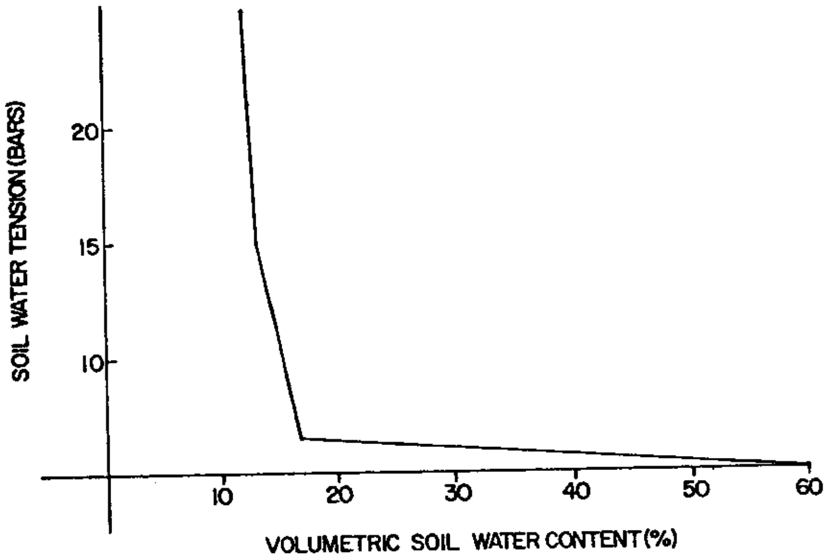

Fig. 2.5. Soil water tension vs. volumetric soil water content for a B horizon soil with a field capacity equal to 28% by volume.

Water drainage from the Ith layer (DRAIN(I)) when the soil water is less than or equal to field capacity is simulated using a modified version of Black's equation (1969) in which the drainage decreases exponentially with decreasing soil water (see line 6 of the FORTRAN code on the facing page).

The infiltration of water and the drainage of water between soil water layers is set up for soil water layers of arbitrary depth. The application of this model to other sites requires that the following parameters be defined for the site:

1. Fraction of roots (PS01(I,3)) and the wilting point (PS01(I,4)) in each soil water layer.
2. The number of soil water layers (NLYS, NLYA) and the depth of the soil water layers (DEPTH, DAHOR, PS01(I,5)).

```
      PEVAP1=PEVAP
C...EVAPORATE WATER FROM THE INTERCEPTED WATER (PISC1,PILT1)
      IF(PEVAP.LE.PISC1)GO TO 40009
      GO TO 40008
40009 PISC1=PISC1-PEVAP  $PTZP=PEVAP   $GO TO 40010
40008 PEVAP1=PEVAP1-PISC1 $PISC1=0.0 $IF(PEVAP1.LE.PILT1)GO TO 40007
      GO TO 40006
40007 PILT1=PILT1-PEVAP1$PTZP=PEVAP  $GO TO 40010
40006 PEVAP1=PEVAP1-PILT1 $PILT1=0.0
```

3. Soil water tension curves for the A and B soil horizons and the relationship of the field capacity to the dead root biomass.
4. Drainage coefficient (PRD) as a function of the soil type.

2.3.1.3 Runoff. The net runoff from a particular area is a function of the rainfall rate, slope of the area, soil types within the area, infiltration rate of the soils, and many other physical characteristics of an area. A variety of mathematical models have been developed for simulating runoff from particular areas (Cartmill, 1970; Kohler and Richards, 1962; Chow, 1964; Palmer, 1965; Smith, 1971). In the application of any of these models to a particular area, it is important to consider the physical characteristics of the area. In particular, it is observed that there is very little net runoff from the Pawnee Site. Locally, there are areas where runoff is observed; however, this model considered a plot of land which is representative of the average physical characteristics at the Pawnee Site. With this justification the model assumes that net runoff from the Pawnee Site is zero. At the other Network Sites, it is likely that runoff submodels will have to be developed which will be highly dependent upon the physical characteristics of those sites.

2.3.2 Evaporative Water Loss

The evaporation of water intercepted by the vegetation, evaporation of water from bare ground, and transpirational water loss are the three mechanisms used to estimate evaporative water loss.

Evaporation from bare soil and transpiration water loss are determined separately because there is information that water loss from bare soil is primarily limited to the soil water in the top 15 cm (Cooper, 1969), while

```
C...DETERMINE IF THE BARE SOIL OR TRANSPIRATION METHOD IS USED TO
C...EVAPORATE WATER FROM THE SOIL PROFILE
      IF(PEVAS.LT.PEVAT) GO TO 40005
      IF(PEVAS.GT.PEVAP1) PEVAS=PEVAP1
      IF(NDAY.EQ.1)  EVAST= EVATT =0.
      PTZP=PEVAS
      EVAST= EVAST + PEVAS/2.54
      ZR=0.0
C...EVAPORATE WATER FROM THE SOIL WATER LAYERS IN THE A HORIZON(BARE SOIL
C...EVAPORATION METHOD)
      DO  40200  I=1,NLYA    $Q=SMOS(I)*100./PSO1(I,5)
```

The intervening FORTRAN code will be presented in the following pages.

```
C...EVAPORATE WATER FROM THE SOIL WATER LAYERS USING THE TRANSPIRATION
C...WATER LOSS METHOD
40005 IF(PEVAT.GT.PEVAP1) PEVAT=PEVAP1  $ZR=0.0  $DO  40012  I=1,NLYS
```

transpiration water loss may come from any soil water layer that has living plant roots. Evaporative water loss is estimated using the bare soil techniques as long as the evaporation rate estimated for bare soil (PEVAS) is greater than or equal to the transpiration rate (PEVAT), while the transpiration rate is used when PEVAS is less than PEVAT (see lines 3 through 14 in the FORTRAN listing on the facing page). This continuous switching mechanism is based upon the concept that water loss by transpiration is significantly different from the evaporation water loss by bare soil only when the plant root system starts to absorb a significant amount of water from the lower soil water layers. This concept assumes that evaporation water loss estimated from bare soil and the transpiration water loss are equivalent when the soil water in the top soil water layer is high. This assumption is based upon the fact that over 50% of the plant root biomass is found in the top 15 cm of the soil at all but one (Bridger) of the eight IBP Grassland Biome sites.

2.3.2.1 Interception by vegetation. The model assumes that evaporative water loss will be subtracted from the water intercepted by the vegetation before water is lost from the soil water. The evaporation rate will thus proceed at the potential evapotranspiration rate as long as there is any intercepted water available. The evaporative water loss is assumed to be from the standing crop intercepted water supply in preference to the water intercepted by litter. If the intercepted water supply is less than the daily water loss estimated by the potential evapotranspiration rate, then either the bare ground evaporation model or the transpiration water loss model are used to remove water from the soil with the restriction that daily evaporation water loss will not exceed the rate estimated by the potential

```
C...CALCULATE THE BARE SOIL EVAPORATION WATER LOSS(PEVAS)
C...--SITE SPECIFIC EQUATION-- THE FUNCTIONAL RELATIONSHIP BETWEEN PEVAP AND PA,
C...PB,PC AND PD ARE SITE SPECIFIC EQUATIONS(VARY WITH THE SOIL TYPE)
      PA=ATANF(.625,14.9,13.,1.5,PEVAP)
      IF(PEVAP.GT..50) PA= 13.5+(PEVAP-.50)*11.
      IF(PA.GT.15.0) PA=15.0
      PB=.5
      IF(PEVAP.GE..75) PC=1.
      IF(PEVAP.LT..75) PC=1. +(.75-PEVAP)
      IF(PEVAP.LE..55) PC=1.2
      IF(PEVAP.GE..65) PD=.30
      IF(PEVAP.LT..65) PD=.20 + (PEVAP-.55)
      IF(PEVAP.LT..55) PD=.20 + (.55-PEVAP)/1.25
      IF(PEVAP.LT..3) PD=.40
C...DETERMINE THE VOLUMETRIC WATER CONTENT OF THE A HORIZON(PSM)
      SMH=0.0  $DO  40089  I=1,NLYA
40089 SMH=SMOS(I)+ SMH       $PSM=SMH*100./DAHOR
      PEVA=ATANF(PA,.5,PC,PD,PSM)
      IF(PEVA.LT.0.0) PEVA=0.0
      IF(PEVA.GT.1.0) PEVA=1.0
      PEVAS=PEVA*PEVAP
```

evapotranspiration rate (see lines 3 through 9 in the FORTRAN listing on page 30).

2.3.2.2 *Evaporation from bare soil.* The bare soil evaporation model assumes that evaporative water loss is limited to the soil water in the top 15 cm of the soil (the 15 cm depth (DAHOR) is a site-specific parameter for the Pawnee Site) and that depth of the A horizon of the soil corresponds to DAHOR. The evaporative water loss is estimated as a function of the potential evapotranspiration rate and the volumetric soil water content in the 0 to 15 cm layer by using the data presented in an article by Denmead and Shaw (1962). Denmead and Shaw's article presents experimental data that define the influence of the volumetric soil water content and potential evapotranspiration rate upon the ratio of the actual evaporation rate to the potential evapotranspiration rate for a particular soil type (Colorado silty loam). This relationship has been modified for the particular soil type found in microwatershed no. 3 at Pawnee National Grassland and is represented mathematically using equation 2.10.

$$\text{PEVA} = \text{PEVAS}/\text{PEVAP} = \text{ATANF}(\text{PA}, \text{PB}, \text{PC}, \text{PD}, \text{PSM}) \tag{2.10}$$

where

PEVA = ratio of PEVAS to PEVAP.

PEVAS = bare soil evaporation rate (cm/day).

PEVAP = potential evapotranspiration rate (cm/day).

PSM = volumetric soil water content of the A horizon (%).

```
C...CALCULATE THE POTENTIAL EVAPOTRANSPIRATION RATE (PEVAP)-- IF NOBSD=1
C...PENNMANS(1948) EQUATION IS USED. IF NOBSD=2 THORNTHWAITES EQUATION
C...(1939) IS USED
      PTEMP=(TMIN+2.0*TMAX)/3.0
      IF(NOBSD.EQ.1) GO TO 40098        $PEA=1.   $PTE=34.
C...---SITE SPECIFIC PARAMETERS-- PEA,PTE ARE SITE SPECIFIC PARAMETERS THAT
C...ARE A FUNCTION OF THE MEAN MONTHLY TEMPERATURES OF THE PARTICULAR SITE
      IF(PTEMP.LE..05)PTEMP=.05
      PEVAP=2.8*(10.*PTEMP/PTE)**PEA/30.
      GO TO 40099
40098 CALL PENN
40099 CONTINUE

C**********************************************************************

      SUBROUTINE PENN
C...THIS SUBROUTINE CALCULATES THE POTENTIAL EVAPOTRANSPN RATE(PEVAP)
C...USING PENNMANS 1948 EQUATION.
      WDB=WSP*24.
      R=.20   $CL=1.-CLP/100.
      ZQQ=ZZQQ=PTEMP
      CALL CLASS(ZQQ,ZQ1)  $ZQ8=RHP*ZQ0/100.
      T2=(ZZQQ+ 273.)*.01    $T2=T2*T2*T2*T2    $B1=.201*T2
      ME=ZZQQ + 1.  $IF(ME.LE.1) ME=1.   $B=RADS(ME)
      E=.35*(ZQQ-ZQ8)*(1.+ .0098*WDB)
      H= SOLA1*(1.-R)*(.18+.55*CL)-B1*(.56-.092*SQRT(ZQ8))*(.10+.90*CL)
      PEVAP=(B*H+.27*E)/(B+.27)   $PEVAP=PEVAP/10.
      IF(PEVAP.LE.0.0) PEVAP=0.01
      RETURN   $END
C**********************************************************************

      SUBROUTINE CLASS(ZQQ,ZQ1)
C...THIS SUBROUTINE CALCULATES THE SATURATION VAPOR PRESSURE OF WATER(ZQ1-MB
C...,ZQQ-MM OF HG) FOR AIR AT TEMPERATURE (ZQQ)----------THE CLAUSIUS-
C...CLAPEYRON EQUATION (HESS,1959) IS USED TO CALCULATE THE SATURATION
C...VAPOR PRESSURE
      ZQQ=ZQQ+273.  $C=ALOG(6.11)   $X1=597.3*18.*4.19/8.314
      X2=1./273.   $X3=1./ZQQ   $X4=X1*(X2-X3)  $D1=X4 + C
      ZQ1=EXP(D1)  $ZQQ=ZQ1*25.4/33.87
      RETURN   $END
C**********************************************************************
```

$$PA = \begin{cases} \text{ATANF}(0.625,\ 14.9,\ 13.0,\ 1.5,\ \text{PEVAP}) & \text{if PEVAP} \le 0.5 \text{ cm/day} \\ 13.5 + (\text{PEVAP} - .50)0.11 & \text{if PEVAP} > 0.5 \text{ cm/day} \end{cases}$$

If PA > 15.0, then PA = 15.0

PB = 0.5

$$PC = \begin{cases} 1.2 & \text{if PEVAP} \le 0.55 \\ 1.0 + (0.75 - \text{PEVAP}) & \text{if } 0.55 < \text{PEVAP} < 0.75 \\ 1.0 & \text{if PEVAP} \ge 0.75 \end{cases}$$

$$PD = \begin{cases} 0.40 & \text{if PEVAP} < 0.30 \\ 0.20 + (0.55 - \text{PEVAP})/1.25 & \text{if } 0.55 > \text{PEVAP} \ge 0.30 \\ 0.20 + (\text{PEVAP} - 0.55) & \text{if } 0.65 > \text{PEVAP} \ge 0.55 \\ 0.30 & \text{if PEVAP} \ge 0.65 \end{cases}$$

The graphical representation of equation 2.10 for various values of PEVAP is presented in Fig. 2.6. This demonstrates that the ratio of PEVAS/PEVAP is related sigmoidally to the volumetric soil water content. PEVAP was determined using a modified version of Penman's (1948) or Thornthwaite's (1944) potential evapotranspiration equations (equations 2.11 and 2.12).

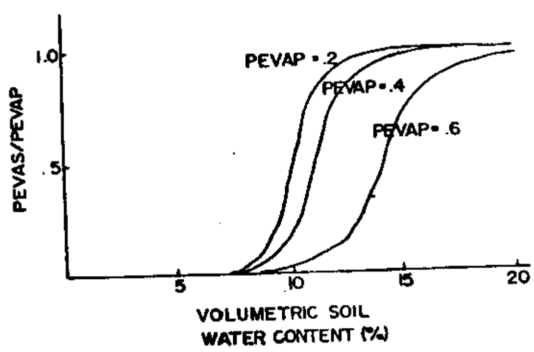

Fig. 2.6. This figure demonstrates the influence of the potential evapotranspiration rate (PEVAP - cm/day) and the volumetric soil water content upon the ratio of PEVAS to PEVAP.

$$PEVAP = [(B \cdot H + 0.27 \cdot E)/(B + 0.27)]/10.0 \tag{2.11}$$

$$E = 0.35(ZQQ - ZQ8)(1.0 + 0.0098\ WDB)$$

$$H = SOLA1(1-R)(0.18 + 0.55\ CL) - B1(0.56 - 0.092\ ZQ8^{.5}) \cdot (0.10 + 0.90\ CL)$$

where

B = slope of the saturated vapor pressure curve of air at absolute temperature (°F).

ZQQ = saturated vapor pressure at mean air temperature (mm Hg).

ZQ8 = saturated vapor pressure of the mean dew point temperature (mm Hg).

WDB = mean and velocity 2 m above the ground (miles/day).

SOLA1 = intensity of solar radiation on a horizontal surface (mm of water evaporated per day) outside the earth's atmosphere.

R = percentage of reflecting surface (albedo).

CL = ratio of actual duration of bright sunshine to maximum possible duration of bright sunshine (1 - CLP/100.0).

CLP = average daily cloud cover (%).

$$PEVAP = 2.8(10.0 \cdot PTEMP/PTE)^{PEA}/30.0 \tag{2.12}$$

where

PTEMP = mean daily air temperature (°C).

$$PTE = \sum_{i=1}^{12} (t_i/5)^{1.54}$$

$$PEA = 6.75 \times 10^{-7} PTE^3 - 7.71 \times 10^{-5} PTE^2 + 0.0179\ PTE + 0.492$$

(PTE = 34, PEA = 1.0 for tne Pawnee Site).

t_i = mean monthly air temperature for the i^{th} month (°C).

```
C...EVAPORATE WATER FROM THE SOIL WATER LAYERS IN THE A HORIZON(BARE SOIL
C...EVAPORATION METHOD)
      DO  40200  I=1,NLYA    $Q=SMOS(I)*100./PSO1(I,5)
C...CALCULATE THE SOIL WATER TENSION(TE) IN BARS
C...---SITE SPECIFIC EQUATIONS--THE RELATIONSHIP OF THE SOIL WATER TENSION
C...TO THE VOLUMETRIC SOIL WATER CONTENT(Q) IS A FUNCTION OF SOIL TYPE
      Q=SMOS(I)*100./PSO1(I,5)     $IP=PSO1(I,1)  $TE=0.
C...CALCULATE TE FOR THE SOIL WATER LAYERS IN THE A HORIZON(IP=1)
      IF(IP.EQ.1.AND.Q.GE.PSO1(I,2))    TE=(60.-Q)*.3/(60.-PSO1(I,2))
      IF(IP.EQ.1.AND.Q.LT.PSO1(I,2)) TE=.3+(PSO1(I,2)-Q)*2.7/(PSO1(I,2)-
     111.5)
      IF(IP.EQ.1.AND.Q.LT.11.5) TE=3. + (11.5-Q)*3.40
      IF(IP.EQ.1.AND.Q.LT.8.0) TE=15. + (8.-Q)*20.
C...CALCULATE TE FOR THE SOIL WATER LAYERS IN THE B HORIZON(IP=2)
      IF(IP.EQ.2.AND.Q.GE.PSO1(I,2))TE=(60.-Q)*.3/(60.-PSO1(I,2))
      IF(IP.EQ.2.AND.Q.LT.PSO1(I,2))TE=.3+(PSO1(I,2)-Q)*2.7/(PSO1(I,2)-
     117.1)
      IF(IP.EQ.2.AND.Q.LT.17.1) TE=3. + (17.1-Q)*3.0
      IF(IP.EQ.2.AND.Q.LT.13.) TE=15.  + (13.-Q)*18.
      IF(TE.LE.0.0) TE=0.01
C...CALCULATE THE RATIO OF THE ROOT DENSITY(PSO1(I,3)) TO THE SOIL
C...WATER TENSION FOR THE I TH SOIL WATER LAYER
                    RAT(I)=PSO1(I,3)/TE
      IF(SMOS(I).LT.PSO1(I,4)*PSO1(I,5)*.009) RAT(I)=0.0
      ZR=ZR + RAT(I)

40200 CONTINUE
C...EVAPORATE WATER FROM THE DIFFERENT SOIL WATER LAYERS
      IF(ZR.LE.0.0)ZR=.01     $DO  40300  I=1,NLYA
40300 SMOS(I)=SMOS(I)-(RAT(I)/ZR)*PEVAS     $GO TO 40010
```

Equation 2.11 is used with the atmospheric simulation model because this equation needs all the parameters which are simulated stochastically. Equation 2.12 is used when observed daily rainfall and average daily temperature are used as the abiotic driving variables.

The bare soil evaporative water loss from soil water layers above 15 cm is assumed to be directly proportional to root density and inversely proportional to the soil water tension in the layer. The mathematical representation of this model is presented by the following equations:

$$PEVAS = \sum_{I=1}^{NLYA} E_A(I)$$

$$E_A(I) = PEVAS \cdot (RAT(I)/ZR) \quad \text{for } I = 1, 2, \ldots, NLYA$$

$$SMOS(I) = SMOS(I) - E_A(I) \quad \text{for } I = 1, 2, \ldots, NLYA$$

If $SMOS(I) < QZZ \cdot 0.9$, then $RAT(I) = 0.0$

where

$$ZR = \sum_{I=1}^{NLYA} RAT(I)$$

$RAT(I) = PS01(I,3)/TE$

NLYA = number of soil water layers in the A horizon (NLYA = 3).

$E_A(I)$ = evaporation water loss from the I^{th} soil water layer (cm).

TE = soil water tension of the I^{th} soil water layer.

PS01(I,3) = fraction or density of roots in each soil water layer.

QZZ = water content at the wilting point of the I^{th} soil water layer (cm).

```
C...CALCULATE THE TRANSPIRATION WATER LOSS(PEVAT)
C...--SITE SPECIFIC EQUATION---THE FUNCTIONAL RELATIONSHIP BETWEEN PEVAP AND PA,
C...PB,PC AND PD ARE SITE SPECIFIC EQUATIONS(VARY WITH THE SOIL TYPE)
      PA=ATANF(.6,18.7,20.,1.5,PEVAP)
      IF(PEVAP.GT..50) PA=16. + (PEVAP-.50)*18.
      IF(PA.GT.22.5) PA=22.5
      IF(PEVAP.GT..65) PB=.55
      IF(PEVAP.LE..65) PB=.55 -(.65-PEVAP)
      IF(PEVAP.LT..60) PB=.50
      IF(PEVAP.GE..65) PC=1.15
      IF(PEVAP.LT..65) PC=1.15 + (.65-PEVAP)
      IF(PEVAP.LE..60) PC=1.20
      IF(PEVAP.GT. .65) PD=.19
      IF(PEVAP.LE..65) PD=.13 +(PEVAP-.55)*.6
      IF(PEVAP.LT..55) PD=.13 + (.55-PEVAP)*.2
      IF(PEVAP.LT..45) PD=.15 + (.45-PEVAP)*.7
      IF(PEVAP.LT..35) PD=.22
C...CALCULATE THE VOLUMETRIC WATER CONTENT OF THE SOIL PROFILF(A AND B
C...HORIZONS)
      SMH=0.0   $DO  40082  I=1,NLYS
40082 SMH=SMH+ SMOS(I)     $PSM=SMH*100./DEPTH
      PEVA=ATANF(PA,PB,PC,PD,PSM)
      IF(PEVA.GT.1.) PEVA=1.  $IF(PEVA.LT.0.0) PEVA=0.0
C...CALCULATE THE LEAF AREA INDEX FOR LIVE ABOVEGROUND BIOMASS(PLA2)
      PLA2=(X(2)+X(3)+X(4)+X(5)+X(6))/150.0
      ZXZ=4.0*ALOG10(PLA2 + 1.)
      IF(ZXZ.GT.1.2) ZXZ=1.2
      IF(ZXZ.LF.0.0) ZXZ=.01
      PEVAT=PEVA*PEVAP*ZXZ
```

2.3.2.3 Transpiration model. This model estimates the transpiration water loss from seven soil water layers (see Fig. 2.2). The total transpiration water loss (PEVAT) is calculated using the relationship of PEVAT/PEVAP to the volumetric soil water content (0 to 75 cm) and potential evapotranspiration rate. The experimental data presented by Denmead and Shaw's (1962) article is used to determine this relationship for the average soil characteristics of the soil water layer from 0 to 75 cm (microwatershed no. 3, Pawnee National Grassland). The numerical representation of this relationship is presented in equation 2.13.

$$\text{PEVA} = \text{PEVAT/PEVAP} = \text{ATANF(PA, PB, PC, PD, PSM)} \qquad (2.13)$$

where

PEVAT = total transpiration water loss.

PSM = volumetric soil water content for the soil water layer from 0 to 75 cm (%).

$$\text{PA} = \begin{cases} \text{ATANF}(0.6,\ 18.7,\ 20.0,\ 1.5,\ \text{PEVAP}) & \text{if PEVAP} \le 0.50 \text{ cm/day} \\ 16.0 + (\text{PEVAP} - 0.50)18.0 & \text{if PEVAP} > 0.50 \end{cases}$$

If PA > 22.5, then PA = 22.5.

$$\text{PB} = \begin{cases} 0.50 & \text{if PEVAP} < 0.60 \\ 0.55 - (0.65 - \text{PEVAP}) & \text{if } 0.65 \ge \text{PEVAP} \ge 0.60 \\ 0.55 & \text{if PEVAP} > 0.65 \end{cases}$$

$$\text{PC} = \begin{cases} 1.20 & \text{if PEVAP} \le 0.60 \\ 1.15 + (0.65 - \text{PEVAP}) & \text{if } 0.65 > \text{PEVAP} > 0.60 \\ 1.15 & \text{if PEVAP} \ge 0.65 \end{cases}$$

```
C...EVAPORATE WATER FROM THE SOIL WATER LAYERS USING THE TRANSPIRATION
C...WATER LOSS METHOD
40005 IF(PEVAT.GT.PEVAP1) PEVAT=PEVAP1  $ZR=0.0  $DO  40012  I=1,NLYS
C...CALCULATE THE SOIL WATER TENSION(TE) IN BARS
C...---SITE SPECIFIC EQUATIONS--THE RELATIONSHIP OF THE SOIL WATER TENSION
C...TO THE VOLUMETRIC SOIL WATER CONTENT(Q) IS A FUNCTION OF SOIL TYPE
      Q=SMOS(I)*100./PSO1(I,5)    $IP=PSO1(I,1)  $TE=0.
C...CALCULATE TE FOR THE SOIL WATER LAYERS IN THE A HORIZON(IP=1)
      IF(IP.EQ.1.AND.Q.GE.PSO1(I,2))   TE=(60.-Q)*.3/(60.-PSO1(I,2))
      IF(IP.EQ.1.AND.Q.LT.PSO1(I,2)) TE=.3+(PSO1(I,2)-Q)*2.7/(PSO1(I,2)-
     111.5)
      IF(IP.EQ.1.AND.Q.LT.11.5) TE=3. + (11.5-Q)*3.40
      IF(IP.EQ.1.AND.Q.LT.8.0) TE=15. + (8.-Q)*20.
C...CALCULATE TE FOR THE SOIL WATER LAYERS IN THE B HORIZON(IP=2)
      IF(IP.EQ.2.AND.Q.GE.PSO1(I,2))TE=(60.-Q)*.3/(60.-PSO1(I,2))
      IF(IP.EQ.2.AND.Q.LT.PSO1(I,2))TE=.3+(PSO1(I,2)-Q)*2.7/(PSO1(I,2)-
     117.1)
      IF(IP.EQ.2.AND.Q.LT.17.1) TE=3. + (17.1-Q)*3.0
      IF(IP.EQ.2.AND.Q.LT.13.) TE=15.  + (13.-Q)*18.
      IF(TE.LE.0.0) TE=0.01
C...CALCULATE THE RATIO OF THE ROOT DENSITY(PSO1(I,3)) TO THE SOIL
C...WATER TENSION FOR THE I TH SOIL WATER LAYER
                  RAT(I)=PSO1(I,3)/TE
      IF(SMOS(I).LT.PSO1(I,4)*PSO1(I,5)*.009) RAT(I)=0.0
      ZR=ZR + RAT(I)
40012 CONTINUE
      IF(ZR.LE.0.0) ZR=.01
      PTZP=PEVAT
      IF(NDAY.EQ.1)  EVATT= EVAST=0.
       EVATT= EVATT + PEVAT/2.54
      DO  40013  I=1,NLYS
C...EVAPORATE WATER FROM THE I TH SOIL WATER LAYER
40013 SMOS(I)=SMOS(I) - (RAT(I)/ZR)*PEVAT
40010 CONTINUE
```

$$PD = \begin{cases} 0.22 & \text{if PEVAP} < 0.35 \\ 0.15 + (0.45 - \text{PEVAP})0.7 & \text{if } 0.35 \le \text{PEVAP} < 0.45 \\ 0.13 + (0.55 - \text{PEVAP})0.2 & \text{if } 0.45 \le \text{PEVAP} < 0.55 \\ 0.13 + (\text{PEVAP} - 0.55)0.6 & \text{if } 0.55 \le \text{PEVAP} \le 0.65 \\ 0.19 & \text{if PEVAP} > 0.65 \end{cases}$$

Monteith (1965) presents data indicating that the transpiration rate of a plant is directly proportional to the leaf area index. Equation 2.14 is determined from Monteith's data and is used to modify the predicted values of PEVA as a function of observed leaf area index of live aboveground biomass.

$$\text{PEVAT} = \text{PEVA} \cdot \text{PEVAP} \cdot 4.0 \cdot \log_{10}(\text{PLA2} + 1) \qquad (2.14)$$

where

PLA2 = SLIVE/150.0.

PLA2 = leaf area index of live aboveground biomass.

SLIVE = total live aboveground biomass [X(2)+X(3)+X(4)+X(5)+X(6)-g/m^2].

The water loss from each of the soil water layers is determined using a model that assumes that loss of water from a particular layer is directly proportional to the percentage of root biomass in the layer and is directly proportional to the soil water tension in the layer. The mathematical representation is presented in equations 2.15 to 2.17.

$$\text{PEVAT} = \sum_{I=1}^{\text{NLYS}} E_I \qquad (2.15)$$

$$E_I = \text{PEVAT} \cdot \text{RAT(I)}/\text{ZR} \qquad (2.16)$$

$$\text{SMOS(I)} = \text{SMOS(I)} - E_I \text{ for } I = 1, 2, \ldots, \text{NLYS} \qquad (2.17)$$

```
C                      ****************************************
C                      *      HEAT FLOW MODEL                 *
C                      ****************************************
      ZMOND=ZMOND + 1.   $IF(ZMOND.GT.30.) ZMOND=1.0
      NXZT=MON + 1   $IF(NXZT.GT.12) NXZT=1
      IF(MON.EQ.1.AND.NDAY.EQ.1) ZMOND=1.0
C...CALCULATE THE AVERAGE DAILY SOIL TEMPERATURE AT 180 CM(SAVTP(13))
      SAVTP(13)=SBOT(MON)+ (SBOT(NXZT )-SBOT(MON))*ZMOND/30.
      ABM=X(2)+X(3)+X(4)+X(5)+X(6)+X(20)+X(21)+X(22)+X(23)+X(24)+
     1X(25)+X(41)
C...CALCULATE THE AVERAGE DAILY CANOPY AIR TEMPERATURE(SAVTP(1))
      SAVTP(1)=PTEMP+ 12.*PEVAP*(1.-PTZP/PEVAP)*(1.-ABM/300.)
```

If SMOS(I) < QZZ·0.9, then RAT(I) = 0.0.

where

$$ZR = \sum_{I=1}^{NLYS} RAT(I)$$

RAT(I) = PS01(I,3)/TE

NLYS = total number of soil water layers (NLYS = 7).

E_I = evaporation water loss from the I^{th} soil water layer (cm/day).

PS01(I,3) = fraction or density of roots in each soil water layer.

QZZ = water content at the wilting point of the I^{th} soil water layer (cm).

TE = soil water tension for the I^{th} soil water layer (bars).

The application of the evaporation model at a particular site requires that the following parameters be specified for the site:

1. The function relationships for the PA, PB, PC, and PD in equations 2.10 and 2.13
2. The value of PEA and PTE in equation 2.12.

2.4 HEAT FLOW SUBMODEL

The heat flow submodel simulates the average air temperature in the plant canopy and the soil temperature for 12 points 15 cm apart in the soil profile. The average daily canopy air temperature (SAVTP(1)) is predicted as a function of the average daily air temperature (PTEMP), the potential evapotranspiration rate (PEVAP), the total aboveground biomass, and the ratio of actual evaporation rate (PTZP) to PEVAP (see line 8 of FORTRAN code on the facing page).

The soil temperatures are calculated as functions of the average air temperature in the canopy and the soil water by solving the Fourier heat conduction equation:

$$\frac{\partial T}{\partial t} = K \frac{\partial^2 T}{\partial z^2}$$

This model also simulates the average daytime air temperature and the total daily solar radiation (Langleys/day). The influence of PEVAP upon SAVTP(1) is based upon observed data at the Pawnee Site which indicates that the difference between average daily soil temperature at 1 inch and the air temperature increases with increasing values of the observed pan evaporation rate (see Fig. 2.7). The effect of the ratio of PTZP to PEVAP upon SAVTP(1) is based upon the concept that more solar energy is used in evaporating water as the ratio of PTZP to PEVAP is increased, leaving less energy to heat the soil and the air. The influence of vegetation upon SAVTP(1) is based upon a comparison of the average difference between 1 inch soil temperature and the air temperature observed at Pawnee and Osage Sites. This comparison shows that the average difference is -6°F at the Osage Site compared with +7°F at Pawnee Site. At the Osage Site the peak standing crop biomass is over 350 g/m^2, while the peak standing crop at the Pawnee Site is around 80 g/m^2.

	TDIF = 1	TDIF = 2	TDIF = 3	TDIF = 4	TDIF = 5	TDIF = 6	TDIF = 7
Frequency distribution with all the data	.034	.026	.099	.137	.185	.176	.343
Frequency distribution when PEVAP < .2 inches	.051	.042	.145	.179	.247	.222	.111
Frequency distribution when .40 inches ≥ PEVAP ≥ .2 inches	.011	0.0	.056	.123	.112	.159	.539
Frequency distribution when PEVAP > .40 inches	.029	.029	.029	0.0	.057	.314	.542

PEVAP = daily pan evaporation (inches).

TDIF = 1 if TDIF < -6°F
TDIF = 2 if -3°F > TDIF ≥ -6°F
TDIF = 3 if 0°F > TDIF ≥ -3°F
TDIF = 4 if 3°F > TDIF ≥ 0.0°F
TDIF = 5 if 6°F > TDIF ≥ 3.0°F
TDIF = 6 if 10°F > TDIF ≥ 6.0°F
TDIF = 7 if TDIF ≥ 10°F

Fig. 2.7. Frequency distributions for the difference between the average 1 inch soil temperature (TS) and the average daily air temperature (TA) at the Pawnee National Grassland (TDIF = TS - TA).

The soil temperature submodel determines the average daily soil temperature at 12 points in the soil profile (15 cm, 30 cm, ..., 180 cm). The model assumes that the average daily canopy air temperature is equivalent to the average daily temperature at the interface between the ground surface and the air, and this is used to drive the soil temperature. The idea of using the air temperature to determine soil temperature has been used by several authors (Langbein, 1949; Uriang and Baker, 1968; Bonham and Fye, 1970). This model specifies the soil temperature at the upper (0 cm) and lower (180 cm) interfaces and then solves for the soil temperature at the intervening layers (15 cm, 30 cm, ..., 180 cm) by using the one dimensional Fourier heat transfer equation. The mathematical representation of this model is presented in the following equations:

```
      SAVTP(13)=SBOT(MON)+(SBOT(MXZT)-SBOT(MON))*ZMOND/30.
C...CALCULATE THE SOIL TEMPERATURES AT THE DIFFERENT LEVELS IN THE SOIL
C...PROFILE(SAVTP(I),I=2,12)
C...---SITE SPECIFIC PARAMETER--FSS IS THE DENSITY OF THE SOIL(GM/CENTIMETER
C...CUBED)
      DO  40080  I=1,11   $SA1=.002  $SA2=.30    $FSS=1.82
C...CALCULATE THE SOIL CONDUCTIVITY(SA1) AND THE SPECIFIC HEAT CAPACITY(SA2)
C...FOR THE SOIL TEMPERATURE LAYERS
      AT=DT1=DT3=DT4=DT2=0.$DO  40081  K=1,NLYS
      SK=0.0     $AT=PSO1(K,5) + AT  $UPL=(I-1)*15.  $ULO=(I+1)*15.
      IF(AT.GT.UPL.AND.AT.LE.ULO) GO TO 40060
      IF(AT.GT.ULO.AND.DT1.LE.ULO) GO TO 40060    $GO TO 40081
40060 SMIS=SMOS(K)*100./PSO1(K,5)  $ PA=(SMIS-PSO1(K,4))/(PSO1(K,2)-PSO1
     1(K,4))
      IF( PA.LE..20) SK=.0015
      IF( PA     .GE..20.AND. PA     .LT..40) SK=.0018
      IF( PA     .GE..40.AND. PA     .LT..60) SK=.002
      IF( PA     .GE..60.AND. PA     .LT..80) SK=.0025
      IF( PA     .GE..80) SK=.003
      DT2=DT2+ SK*PSO1(K,5)        $DT3=DT3 + PSO1(K,5)
      SMIS=SMIS/100.    $DT4=DT4 + (SMIS+.18*(1.-SMIS))*PSO1(K,5)
40081 DT1=AT         $IF(DT3.LE.0.) GO TO 40066
      SA1=DT2/DT3  $SA2=DT4/DT3
40066 CONTINUE
      SKK=SA1*86400./( FSS*SA2*225.)
      SKK=SKK*.45
      K=I+ 1
C...DETERMINE THE DAILY CHANGE OF TEMPERATURE AT THE I TH POINT IN THE
C...SOIL PROFILE (HEAT(I-1))
      HEAT(I)=SKK*(SAVTP(K-1)-2.*SAVTP(K) + SAVTP(K+1))
      ZOF=ABS(HEAT(I))     $ZZT=HEAT(I)/ZOF
      IF(ZOF.GT.5.) HEAT(I)=5.*ZZT
      IF(I.GT.1) HEAT(I)=SKK*(SAVTP(K-1) + HEAT(I-1)*1.-2.*SAVTP(K) +
     1 SAVTP(K+1))
40080 CONTINUE
C...CALCULATE THE NEW AVERAGE DAILY SOIL TEMPERATURE AT THE I TH POINT IN
C...THE SOIL PROFILE
      DO  40091  I=2,12
40091 SAVTP(I)=SAVTP(I) + HEAT(I-1)
```

$$\frac{\partial T_S}{\partial t} = \frac{SA1}{FSS \cdot SA2} \cdot \frac{\partial^2 T_s}{\partial z^2} \quad \text{(Fourier heat conduction equation)} \qquad (2.18)$$

The finite difference scheme used to solve Equation 2.18 is

$$SAVTP(13) = SBOT(MON) + (SBOT(MON+1) - SBOT(MON))ZMOND/30.0$$

$$\frac{SAVTP(I) - SAVTP_1(I)}{\Delta t} = \frac{SA1}{SA2 \cdot FSS} \cdot \left(\frac{SAVTP(I-1) - 2.0 \cdot SAVTP_1(I) + SAVTP_1(I+1)}{\Delta z^2} \right)$$

$$SAVTP(I) = SAVTP_1(I) + \frac{SA1}{SA2 \cdot FSS} \cdot \frac{\Delta t}{\Delta z^2} \cdot (SAVTP(I-1) - 2.0 \cdot SAVTP_1(I) + SAVTP_1(I+1))$$

where

T_S = soil temperature at a particular point (°C).

SA1 = soil thermal conductivity ($cal \cdot cm^{-1} \cdot sec^{-1} \cdot °C^{-1}$).

SA2 = specific heat capacity of the soil ($cal \cdot g^{-1} \cdot °C^{-1}$).

FSS = density of the soil (1.82 g/cm^3).

SBOT(MON) = average daily soil temperature (°C) on the first day of a particular month (MON = 1, 2, 3, ..., 12).

ZMOND = day of the month (1, 2, 3, ..., 30).

SAVTP(I) = average daily soil temperature for the I^{th} point in the soil profile.

$SAVTP_1(I)$ = average daily soil temperature for the I^{th} point (I = 2-15 cm, 3-30 cm, ..., 13-180 cm) in the soil profile during the previous day.

t = time (sec).

Δt = time step (Δt = 86,400 sec or 1 day).

Δz = distance between the points where soil temperature is determined (Δz = 15 cm).

```
C...SOLAR INSOLATION CALCULATIONS.
      IF(NOBSD.EQ.2)CLP=CLD(MON)
      DELT=0.401426*SIN(6.283185*(NDAY-77)/365.0)
      H=ACOS(-TAN(PHI)*TAN(DELT))
      SU1  =596.*(H*SIN(PHI)*SIN(DELT)+COS(PHI)*COS(DELT)*SIN(H))
      SUN=SU1*(1.0-(.18+.0053*CLP))
      SOLA1 = SUN*.026
```

This finite difference scheme is designed specifically to run with a 1-day time step. SA1 and SA2 are determined as a function of the soil water content using the following equations:

$$SA1 = \begin{cases} 0.0015 & \text{if } PA < 0.20 \\ 0.0018 & \text{if } 0.40 > PA \geq 0.20 \\ 0.0020 & \text{if } 0.60 > PA \geq 0.40 \\ 0.0025 & \text{if } 0.80 > PA \geq 0.60 \\ 0.0030 & \text{if } PA \geq 0.80 \end{cases}$$

$$SA2 = SMIS + 0.18(1 - SMIS)$$

where

SMIS = ratio of the volume of soil water to the volume of the soil.

PA = ratio of the difference between observed soil water and soil water at the wilting point to the difference between soil water at field capacity and soil water at the wilting point.

The values of SA1 and SA2 used by the model are determined by averaging the values of SA1 and SA2 calculated for the 15-cm soil water layers which enter into the calculation of the soil temperature at particular points in the soil profile. The SA1 and SA2 are set equal to 0.002 and 0.30, respectively for the calculation of soil temperature at the points where soil water is not simulated by the model (I = 7, 8, 9, 10, 11, 12).

The daily solar radiation on days without cloud cover is determined as a function of time of year using the following equation (Sellers, 1965):

$$SU1 = \frac{1440.0}{3.1415} \cdot 5 \cdot T_{\gamma}(H \cdot \sin(PHI) \cdot \sin(DELT) + \cos(PHI) \cdot \cos(DELT) \cdot \sin H)$$

where

H = arccos[-tan(PHI)·tan(DELT)].

DELT = 0.401 sin[6.283(NDAY - 77.0)/365)].

SU1 = daily solar radiation (Langleys/day).

T_Y = transmission coefficient (0.640).

PHI = latitude (radians)--site-specific parameter.

H = half-day length (radians).

DELT = solar declination (radians).

NDAY = day of the year (1 to 365).

The influence of cloud cover upon solar radiation is modelled using the following equations (Haurwitz, 1941):

SUN = SU1 (1 - BB)

BB = R + 0.0053 CLP

where

SUN = net incoming daily solar radiation (Langleys/day).

R = reflectivity of the plant canopy (0.18).

CLP = average daily cloud cover (%).

When the average cloud cover (CLP) is not known, the long-term average monthly cloud is used as an estimate of CLP.

The solar radiation coming into the outer part of the atmosphere (SOLA1 in mm of water per day) is calculated using the following equation:

SOLA1 = SUN·0.026

The number of hours during the day (Y1) and the night (Y2) are calculated using the following equations:

```
  SB = TMAX - TMIN
PHFF = 3.1415/(Y1+4.)  $PHFFI = 1./PHFF
 TCD = SB*(-PHFFI*(COS(PHFF*Y1)-1.))/Y1 + TMIN
```

$$TP(1) = H/3.14159$$

$$TP(2) = 1 - TP(1)$$

$$Y1 = TP(1) \cdot 24.0$$

$$Y2 = TP(2) \cdot 24.0$$

where

TP(1) = fraction of the day when it is light.

TP(2) = fraction of the day when it is dark.

Y1 = number of daylight hours.

Y2 = number of nighttime hours.

The average air temperature during the daylight hours (TCD) is simulated by integrating over a truncated sine wave in which the minimum air temperatures occur at sunrise, and the maximum air temperatures occur at 2 PM (see the following equations).

$$TTMP(NHS) = (TMAX - TMIN) \cdot \sin\left[\frac{2\pi}{2.0(Y1 + 4.0)} \cdot NHS\right] + TMIN$$

$$TCD = \frac{(TMAX - TMIN)}{y1} \cdot \left[\frac{-(Y1 + 4.0)}{\pi} \left(\cos\left(\frac{\pi Y1}{Y1 + 4.0}\right)\right) - \cos(0.0))\right] + TMIN$$

where

TTMP(NHS) = air temperature at a particular hour (NHS) after sunrise (°C).

TMAX = maximum air temperature (°C).

TMIN = minimum air temperature (°C).

NHS = number of hours since sunrise (hr).

TCD = average daylight temperature (°C).

The input parameters needed for the application of this model to other sites are:

1. The density of the soil (FSS).
2. The mean soil temperature for the first day of the Ith month at 180 cm in the soil profile (SBOT(I)).
3. The average monthly cloud cover (CLP(I)) for the Ith month.
4. The latitude of the site (PHI).

2.5 OUTPUT

The output from the abiotic model is demonstrated by a 2-year time series of some of the abiotic parameters. Fig. 2.8 illustrates the yearly cumulative rainfall and interception water loss by litter and the standing crop vegetation. Fig. 2.9 illustrates the soil water from 0 to 5 cm and from 15 to 30 cm. Fig. 2.10 illustrates the yearly cumulative evaporative water loss by the bare soil evaporation and transpiration, and Fig. 2.11 illustrates the air temperature in the canopy and the soil temperature at 30 cm and 60 cm.

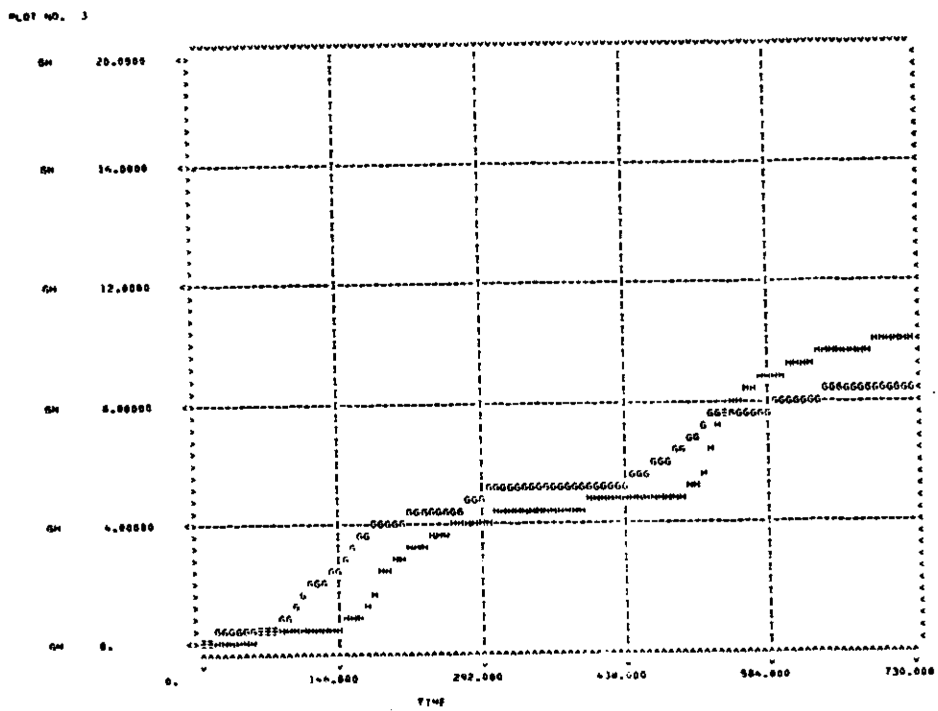

Fig. 2.10. Two-year time series of yearly cumulative evaporation water loss by bare soil evaporation (G) and transpiration (H).

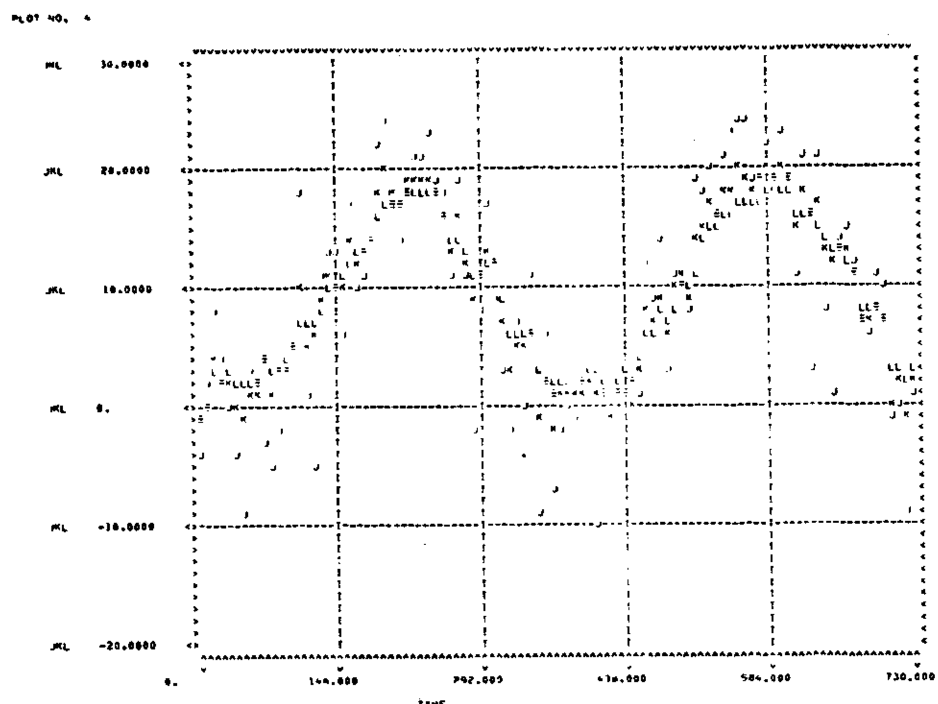

Fig. 2.11. Two-year time series of the air temperature in the canopy (J) and the soil temperature at 30 cm (K) and 60 cm (L).

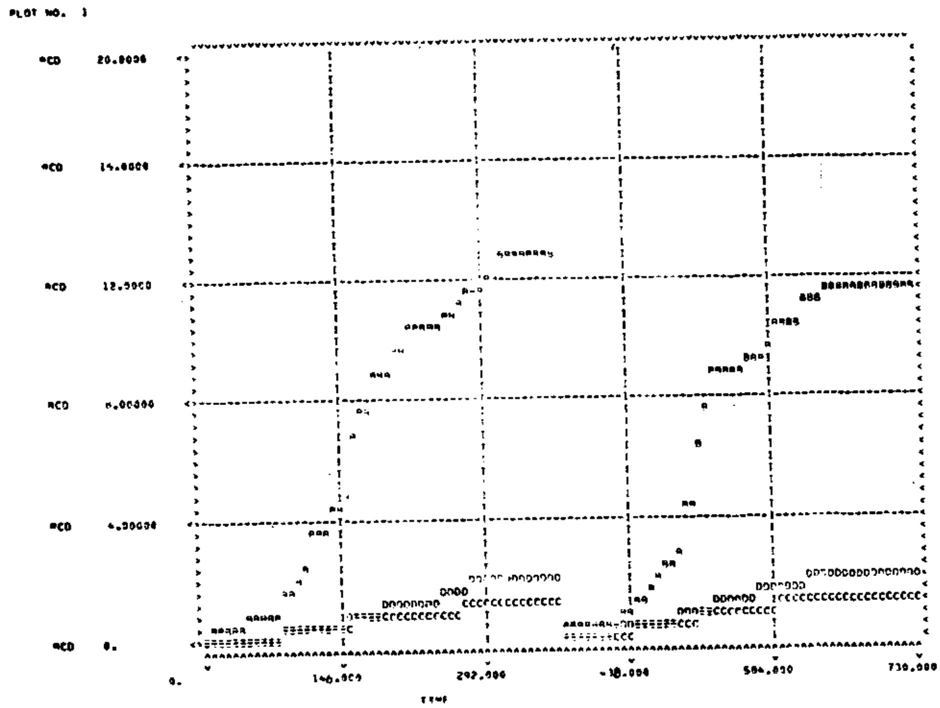

Fig. 2.8. Two-year time series of yearly cumulative rainfall (B) and interception water loss by litter (C) and standing crop vegetation (D).

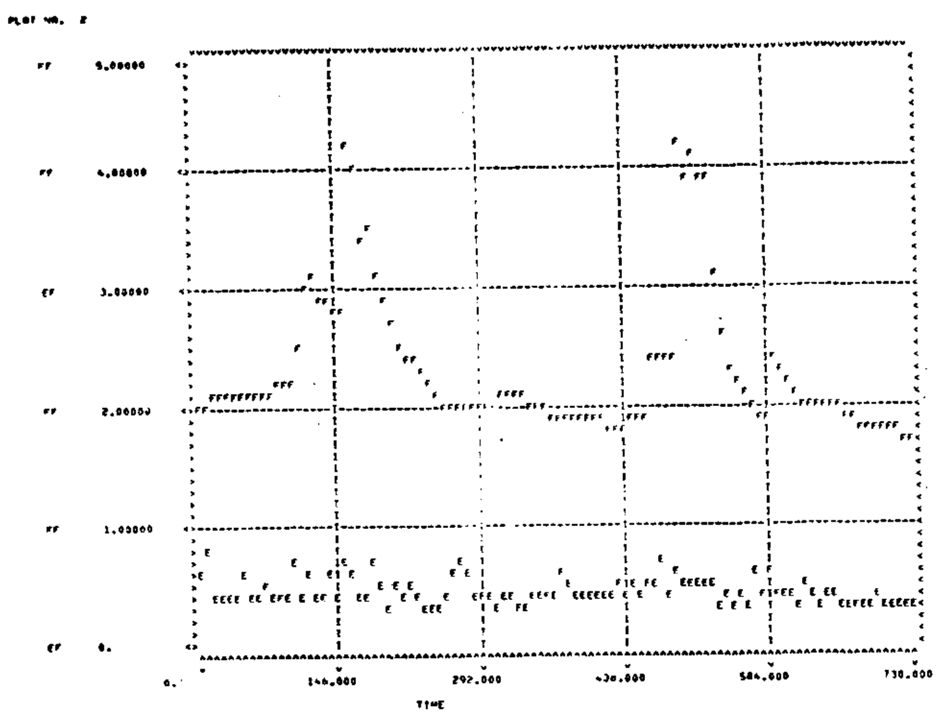

Fig. 2.9. Two-year time series of the soil water from 0 to 5 cm (E) and 15 to 30 cm (F).

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CHAPTER 3. PRODUCER SECTION

3.1 INTRODUCTION

The producer section of the ELM model simulates the biomass dynamics of the shoot systems, standing dead, live roots, dead roots, and litter (see Fig. 3.1). The producer section relies on information on rainfall, soil water, soil temperature, maximum and minimum air temperature, cloud cover, and insolation from the abiotic section. Information on the status of nitrogen and phosphorus is obtained from the nutrient section to determine nutrient stresses.

An important part of the producer section is the simulation of the phenological changes that occur during the growing season and dormant periods. The phenology calculations relate plant morphology and activity to the progression of climatic changes through the year rather than to the progression of chronological time.

Phenological progression, gross photosynthetic rates, respiration rates, shoot growth, and root growth are calculated in CYCL1, before the flows are calculated. The sequence of SIMCOMP activities is:

	START
Repeated for	CYCL1
each given	FLOWS
time step (Δt)	CYCL2
	FINIS

The results of these calculations, stored in common block variables, are available for use in the other model sections. For example, phenological information is used in the consumer model to determine digestibility of the forage.

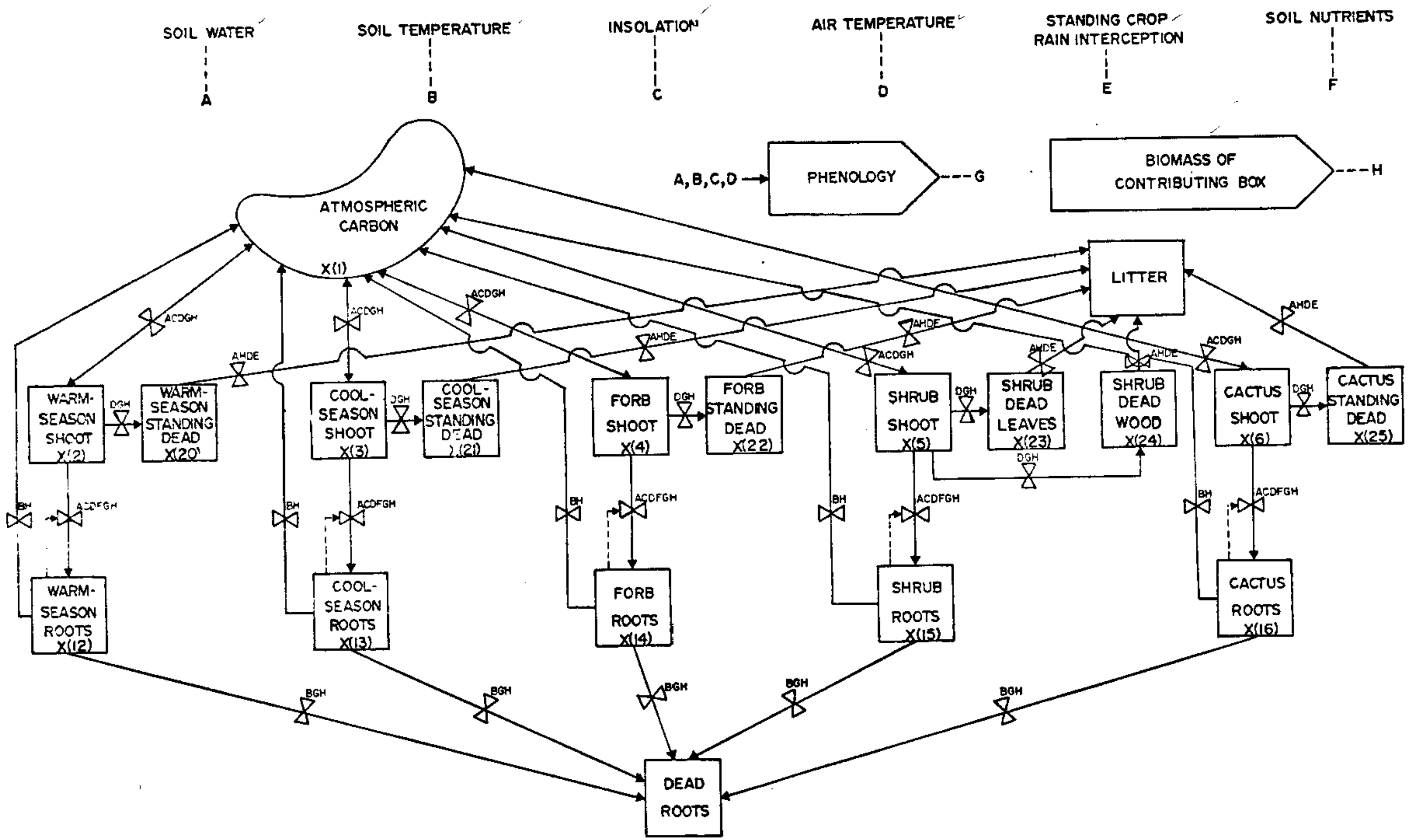

Fig. 3.1. Box and arrow diagram of the producer section.

The five species simulated are intended to represent the five major primary producer categories: Warm-season grasses, cool-season grasses, forbs, shrubs, and cacti. In the discussion of the producer and phenology sections, the simulated species will be identified by the subscript i as follows:

i = 1 *Bouteloua gracilis*--warm-season grass

i = 2 *Agropyron smithii*--cool-season grass

i = 3 *Sphaeralcea coccinea*--forb

i = 4 *Artemisia frigida*--shrub

i = 5 *Opuntia polyacantha*--cactus

Each of these five species had the greatest number of phenological observations (1971) in its respective vegetation class and thus was judged to be representative of its class. Another set of subscripts is used to designate the six standing dead categories.

m = 1 *Bouteloua* standing dead shoot system

m = 2 *Agropyron* standing dead shoot system

m = 3 *Sphaeralcea* standing dead shoot system

m = 4 *Artemisia* standing dead leaves

m = 5 *Artemisia* standing dead wood

m = 6 *Opuntia* standing dead shoot system

Many of the figures used in the producer section description are plots constructed by SIMCOMP during a typical 2-year run. With these plots, the general shape of the curve in the interval of values generated in the model is clearly evident, as well as the extreme values for the function.

3.2 PHENOLOGY SUBMODEL

A phenology submodel has been developed because organisms respond to climatic variables such as temperature and moisture as well as to indicators of chronological time such as photoperiod. A flowering time based on weather patterns rather than the day of the simulated year was the objective. The incorporation of phenological considerations improves the simulations by making plant developmental stages such as "flowering time" or "early vegetative" a function of climatic variability generated stochastically in the abiotic section of the model. Perturbations within the scope of the ELM model objectives, such as variations in rainfall, can more realistically be studied when plant development is determined by weather patterns instead of chronological time. It might be added that a representation of plant development is an aid in studying biomass dynamics.

The genetic component of the plant species simulated is considered by making plant development a function of environmental stresses. The producer section also considers genetic information by modelling the responses to weather; the phenology section extends the genetic consideration by modelling another aspect of plant activity, the change in morphology through a season. It is important to realize that the simulations in a biological model are actually simulations of the interactions between organisms' stores of genetic information and the environment impinging on those organisms. Hence, more accurate and, therefore, useful simulations can be determined by considering more of the content and variability of the genetic information of a modelled system.

Sixteen phenological stages are considered:

1. Pre-emergence growth/winter dormancy
2. First visible growth
3. First leaves fully expanded
4. Middle leaves fully visible
5. First leaves shed or senescent, middle leaves fully expanded
6. Late leaves fully expanded
7. Developing buds, middle-late vegetative
8. Mature buds/late vegetative
9. Buds and flowers
10. Buds, flowers, and green fruit
11. Buds, flowers, green fruit, and ripe fruit
12. Green fruit and ripe fruit
13. Ripe fruit and dispersing seeds
14. Flowering induced dormancy
15. Standing dead, Phase 1
16. Standing dead, Phase 2

(This space left blank intentionally.)

Dr. M. J. Trlica (personal communication) has suggested that low temperatures and high soil water content reset the phenological clock. Accordingly, dormancy induced by flowering (stage 14) is broken (returns to stage 1) when the 20-day running average of the product of maximum temperature and soil water deficit [SPTUR(i)] drops below a preset value [SP4(i)]. In the field and in growth chambers, a decrease in air temperature and/or a sudden increase in soil water often will break late season dormancy in species of *Clarkia* (Sauer, 1971).

The vegetative and early bud stages of phenology (phenological stages up to 7.0) are determined by a 20-day running average of the product of insolation, maximum daily air temperature, and soil water. Thus, a vegetative plant can regress to an earlier vegetative stage. It would seem that the onset of cooler, wetter conditions during the vegetative phases of development could result in an additional flush of vegetative growth and hence a reversion to an earlier phenological stage. The relationship between phenological stage PHEN(i) and the running average of the product of insolation, soil water, and maximum temperature [SRACR(i)] can be adjusted by changing the parameter SP2(i); an increase in this parameter will speed the rise to phenological stage 7.

The progression of the flowering stages to flowering induced dormancy is a function of the cumulative sum of the product of insolation, rain greater than 1.0 cm, and maximum temperature. (It should be noted here that the number of flowers produced and the quantity of seeds produced are not presently addressed in ELM; the simulated phenological stages of plant development are the most advanced stage in the "colony," not an indication of the number or biomass of, for example, seeds.) Cool cloudy days, indicative of a mild summer, possibly accompanied by rain, will prolong the flowering period, while hot clear days will truncate the flowering period. The length of the flowering period as a function of climate is open to question; future data and observations will increase the accuracy of this aspect of the phenology model. The rate at which phenology progresses through the flowering stages can be adjusted with SP5(i) and SP6(i), the midpoint and spread of the ATANX function (see Fig. 3.2). (See Chapter 7 for a description of the ATANX function.)

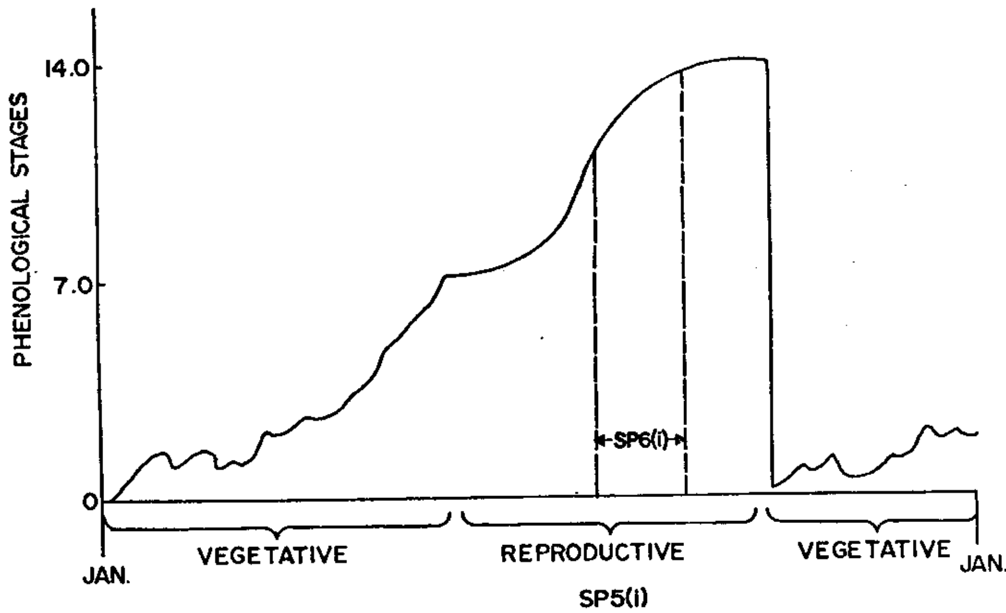

Fig. 3.2. Typical progression of phenology from vegetative through flowering stages, and back to vegetative stages, for a hypothetical plant species. Note the difference in vegetative and reproductive progressions.

The effect of phenology (EP(i) for i = 1, ..., 5) varies from 0.0 to 1.0, according to Fig. 3.3. The decrease after phenological stage 7 represents the decrease in plant activity due to flowering and winter weather conditions (Leopold, 1964, Chapter 12). During the winter when the plants revert to the earliest vegetative stages (PHEN(i) for i = 1 or 2), a soil temperature (average of the upper 60 cm) of less than a specific value [SP3(i)], will give an EP(i) of 0.0 and completely stop all photosynthetic and respiratory activity. Winter dormancy is thus simulated. The 60 cm depth of soil is used because dormant plants are almost totally subject to soil temperature, not air temperature, as the only live portions of the plants in winter are below ground. It is recognized that this is not true for cactus. However, using soil temperature of below surface layers has additional value in that it represents a weighted running average of air temperatures, which may have predictive value to the plants for indicating the onset of warming temperatures of spring.

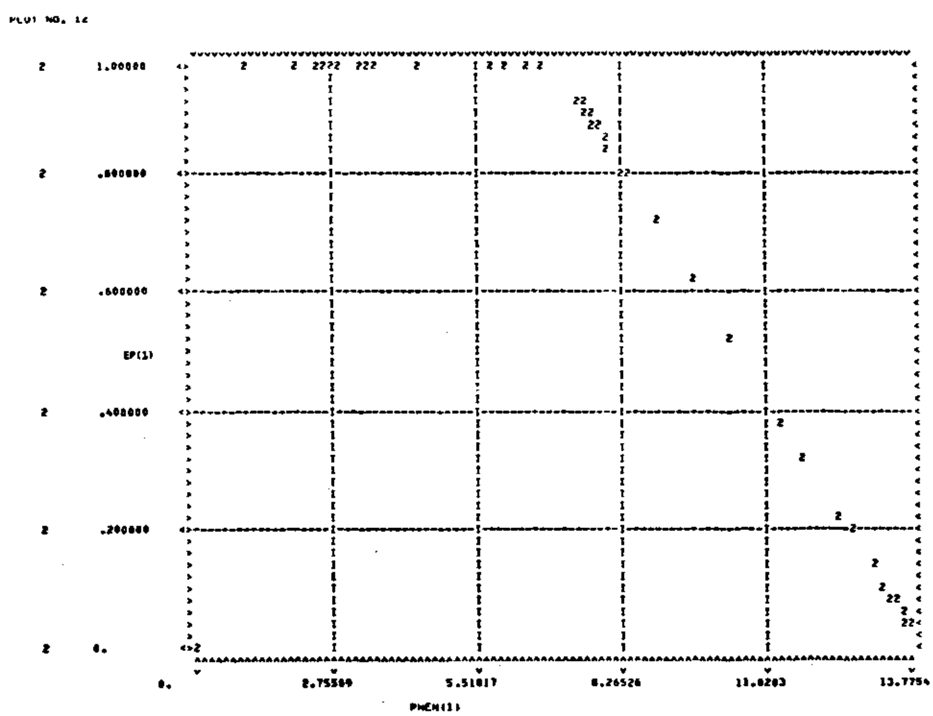

Fig. 3.3. Relationship between phenological stage and the effect of phenology (EP) on plant activity.

The insulating effect of snow cover on plant biomass is addressed in this model through the variable SP3(i). Snow cover is not simulated in the abiotic section. However, metabolic activity and even early vegetative growth may occur when a snow cover insulates plant biomass from very low day and/or night air temperatures. The variable SP3(i) can reflect the low temperature activity characteristics by setting it to some near or below freezing value. It should be noted that the photosynthetic rate vs. temperature (EAT, EATR) should also be changed to account for low temperature activity.

The effect of shallow warming of the soil on plant growth is addressed by using the weighted average soil temperature. By considering the upper 15 cm in three 5-cm increments, and the remaining soil down to 60 cm in three increments, the upper 15 cm has the same effect on the lower 45 cm. Thus, the soil with the most biomass and dormant shoots has the most effect on plant dormancy.

If flowering has been initiated during a growing season, but maturity is not obtained possibly because of inadequate soil water, flowers and fruits are considered aborted and the phenological cycle is reset to vegetative stages again when soil temperatures (upper 60 cm) decrease below the preset value SP3(i).

For the lack of a better name, the term phenology has also been used to describe the nutrient content of the standing dead categories used for forage in the consumer section, Chapter 4. APHEN(k) is set equal to PHEN(i) for the live phenologies where k = i = 1, ..., 5. Phenology of the standing dead categories is APHEN(k) where k = 6, ..., 11. The table in Fig. 3.4 gives the relationship between PHEN(i), APHEN(k), and the biomass categories.

APHEN(1)	= PHEN(1)	= Phenological index of	X(2)
(2)	(2)		X(3)
3	3		4
4	4		5
5	5		6
APHEN(6)	= Calculated phenological index of		X(20)
7			21
8			22
9			23
10			24
11			25

Fig. 3.4. Table showing relationships between aboveground biomass categories and phenological stages.

Nutrient loss from the standing dead categories is assumed to be related to leaching, a function of litter intercepted moisture (PILT1), and to microbial activity, a function of moisture (PILT1 and SMOS(1)) and temperature (STEMP). Thus the sum of the soil water in the top 5 cm of soil and litter intercepted moisture is multiplied by the average of the daily maximum and minimum temperatures, and this product is summed daily for each time step to obtain the cumulative sum WETDY(j) where j = 1, ..., 6. Temperature and moisture are multiplied together so that inadequate moisture or temperature will slow the accumulation of WETDY(j) and thereby APHEN. The cycle is reset by setting WETDY to 0.0 when the corresponding live shoot category is in early vegetative stages of PHEN(i) between 2 and 3.

Adjustments: The several parameters in the phenology model should be adjusted to reflect the characteristics of the particular producer species considered. SP2(i) determines the rate of vegetative progression. SP3(i) is the soil temperature (average of the upper 60 cm of soil) below which

EP(i) and PHEN(i) are set to zero and hence stop growth. SP4(i) is the value of cool temperature × soil water below which growth is reinitiated after flowering induced dormancy. SP5(i) and SP6(i) are the midpoint and spread, respectively, of the ATANX curve that determines the advance of the reproductive phenological stages. The above information, of course, is not readily available, and thus educated guesses must be made considering the local climatology and yearly growth cycle of the producer species considered.

The rate at which the standing dead phenologies progress can be adjusted by changing the site specific parameter APP(j) where APP(1) corresponds to APHEN(6). Initial values of APHEN and WETDY may also be changed, as well as the PHEN stages when WETDY is reset to 0.0.

3.3 PHOTOSYNTHESIS AND RESPIRATION OF THE SHOOT SYSTEM

Photosynthesis in the ELM model is represented as gross photosynthesis [CIN(i)] for the i^{th} plant group. Respiration [COUT(i)] is represented as the efflux of carbon for the whole simulated time step (DT). Net photosynthesis [CNET(i)] is the difference between gross photosynthesis and respiration. Validation of this representation of photosynthesis is essentially not possible because there is virtually no data on gross photosynthetic rates. Nevertheless, this representation is chosen so that the respiratory processes and photosynthetic processes can be independently affected by the several climatic factors that influence metabolic activity. Photosynthesis and respiration of the shoot system is calculated each time step in CYCL1, and the results are stored in COMMON block variables. It should be noted that, as of this version of the ELM model, no attempt has been made to account for acclimation; the effects of temperature and moisture on photosynthesis, for example, do not change with changing recent weather patterns. A more mechanistic approach would increase the optimum temperature for net photosynthesis following a period of higher than normal temperatures.

3.3.1 Air Temperature

The effect of air temperature on photosynthetic rate [EAT(i)] and respiratory rate [EATR(i)] for the i^{th} plant group is shown in Fig. 3.5 through 3.9. TCD, the average of the daytime temperatures, is plotted for a typical 1-year simulation in Fig. 3.10. The photosynthetic rate response to air temperature is represented as a sigmoid curve (Leopold, 1964). Respiration rate increases exponentially with rising air temperature (Leopold, 1964). At low temperatures photosynthetic rate is slightly greater than the respiratory rate. As temperature increases, photosynthetic rate increases faster than respiration rate until the optimum temperature for net photosynthesis is exceeded. At high temperatures, respiration rates are greater than photosynthetic rates, and a negative net photosynthesis occurs.

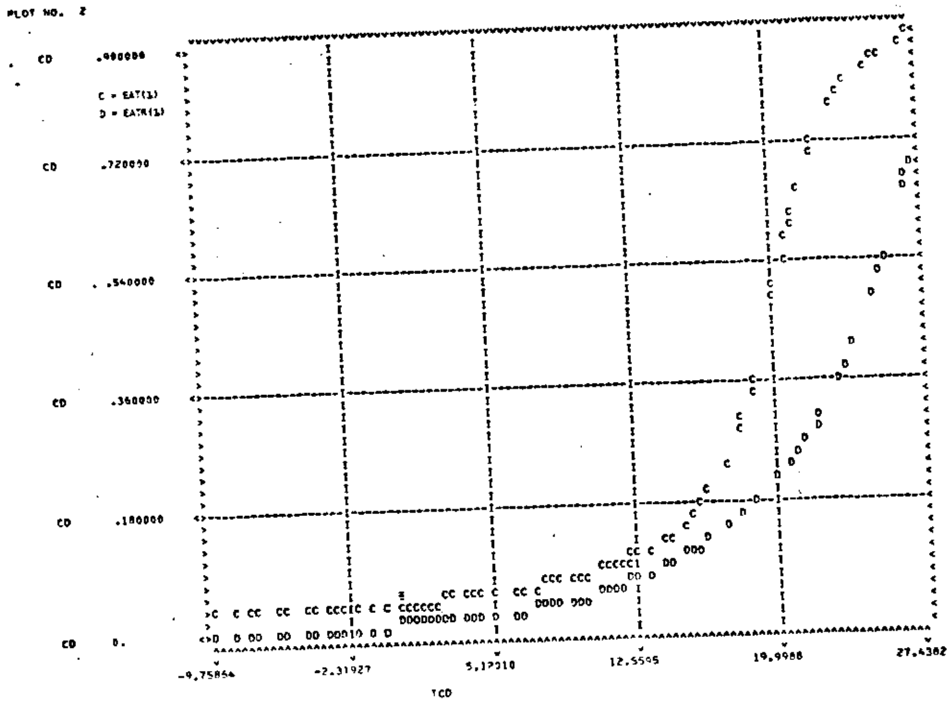

Fig. 3.5. Effects of air temperature on photosynthesis and respiration of *Bouteloua gracilis*: C = EAT(1), photosynthesis; D = EATR(1), respiration.

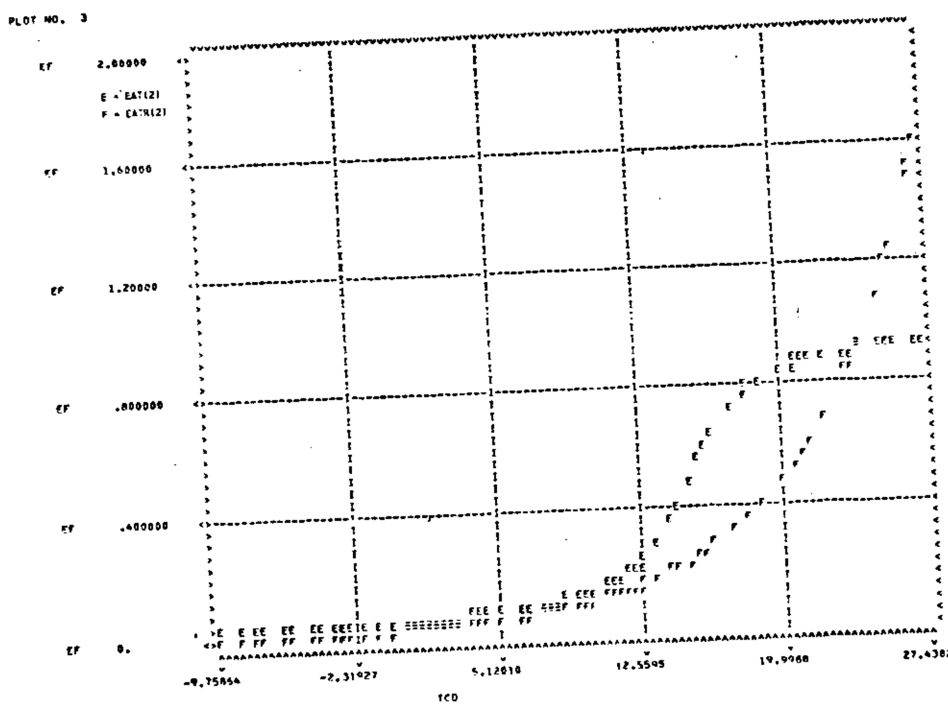

Fig. 3.6. Effect of air temperature on photosynthesis and respiration of *Agropyron smithii*: E = EAT(2), photosynthesis; F = EATR(2), respiration.

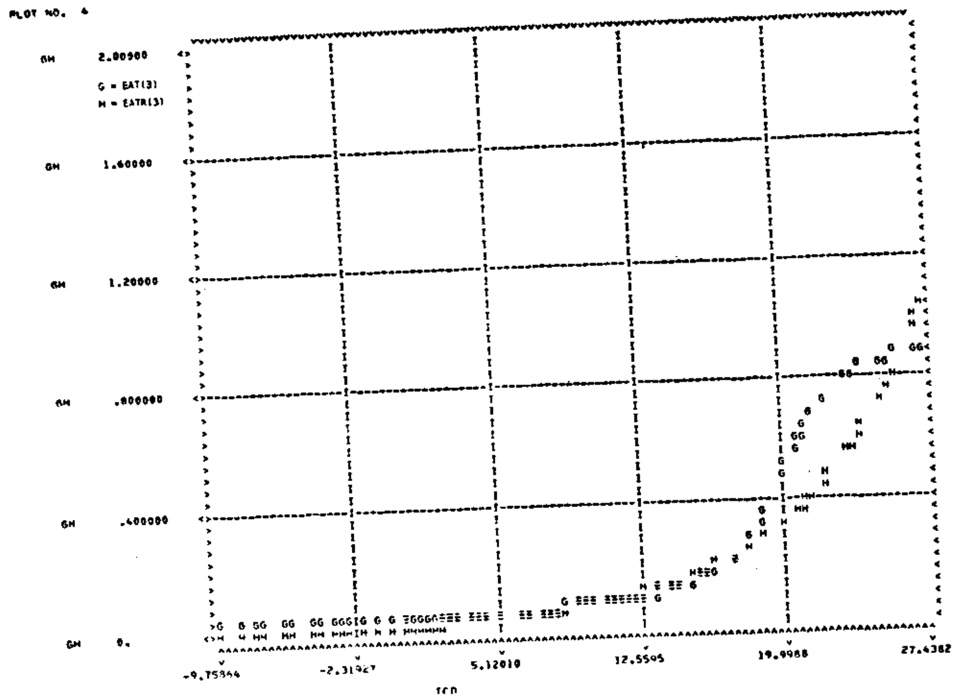

Fig. 3.7. Effect of air temperature on photosynthesis and respiration of *Sphaeralcea coccinea*: G = EAT(3), photosynthesis; H = EATR(3), respiration.

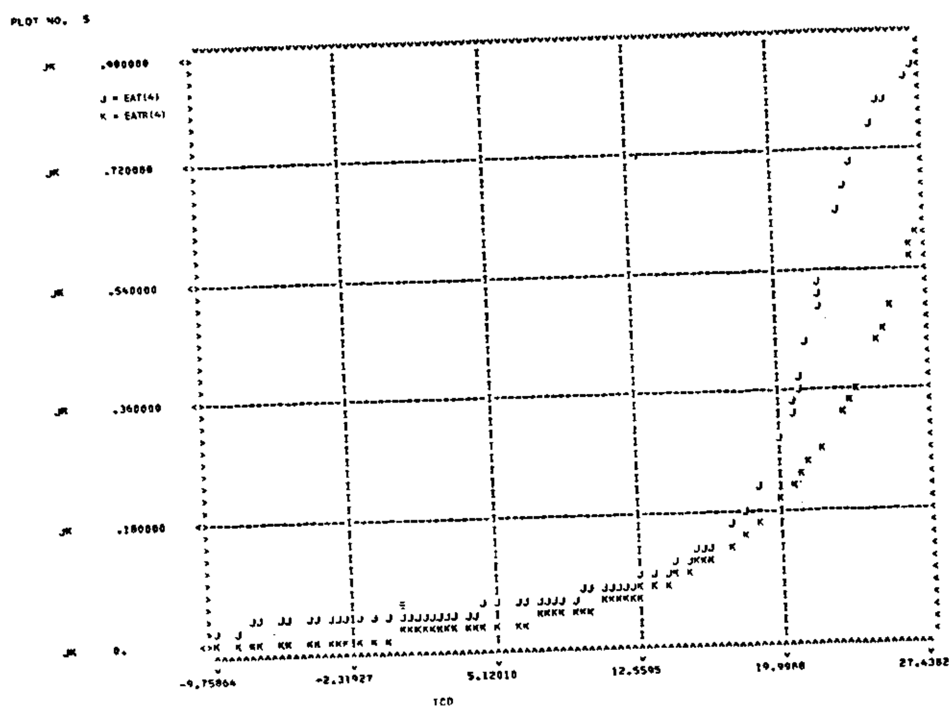

Fig. 3.8. Effect of air temperature on photosynthesis and respiration of *Artemisia frigida*: J = EAT(4), photosynthesis; K = EATR(4), respiration.

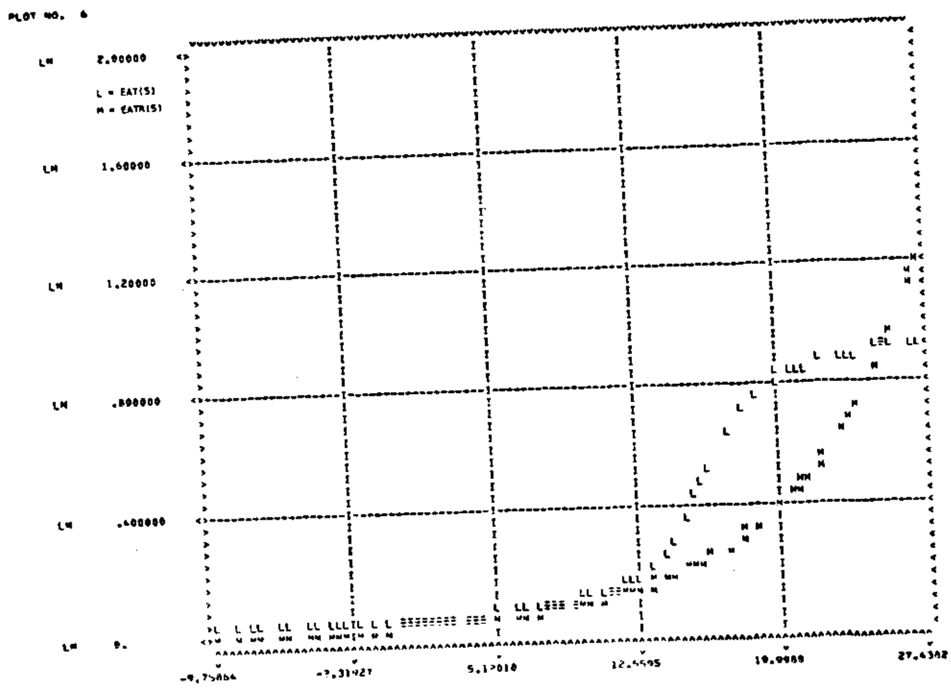

Fig. 3.9. Effect of air temperature on photosynthesis and respiration of *Opuntia polyacantha*: L = EAT(5), photosynthesis; M = EATR(5), respiration.

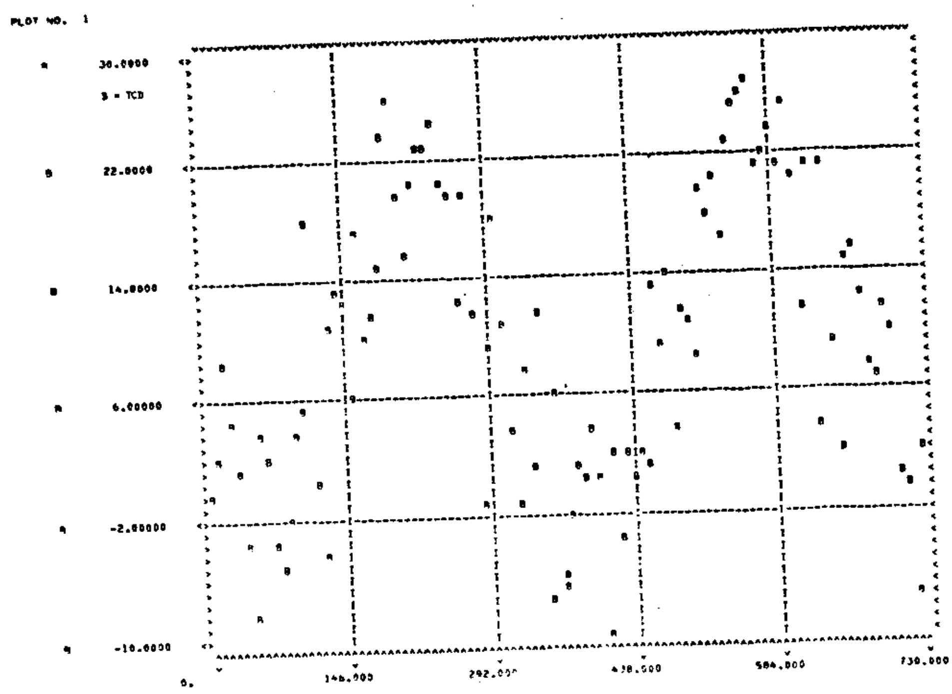

Fig. 3.10. Relationship between TCD (average daytime temperature in °C) and day of the year--a typical stochastic simulation.

```
      SUBROUTINE START
C...THE WEIGHTING FACTORS WF1(I) TO WF6(I) ARE SUMMED HERE FOR USE IN CYCL1.
      DO 53333 JIT = 1,5
      SASM(JIT)=WF1(JIT)+WF2(JIT)+WF3(JIT)+WF4(JIT)+WF5(JIT)+WF6(JIT)
      SMFC=(WF1(JIT)*SFC1(JIT)+WF2(JIT)*SFC2(JIT)+WF3(JIT)*SFC3(JIT)+
     1WF4(JIT)*SFC4(JIT)+WF5(JIT)*SFC5(JIT)+WF6(JIT)*SFC6(JIT))
     2/SASM(JIT)
      SMWP=(WF1(JIT)*SWP1(JIT)+WF2(JIT)*SWP2(JIT)+WF3(JIT)*SWP3(JIT)+
     1WF4(JIT)*SWP4(JIT)+WF5(JIT)*SWP5(JIT)+WF6(JIT)*SWP6(JIT))
     2/SASM(JIT)
      SM2(JIT)=(SMFC-SMWP)/2.0
      SMR2(JIT)=SM2(JIT)
      SM1(JIT)=SMFC-SM2(JIT)
      SMR1(JIT)=SM1(JIT)+(0.1*SM1(JIT))
53333 CONTINUE


C...WASM IS THE WEIGHTED AVERAGE SOIL MOISTURE, BASED ON ROOT/DEPTH
      WASM(JS)=(WF1(JS)*SMOS(1)+WF2(JS)*SMOS(2)+WF3(JS)*SMOS(3)+
     1WF4(JS)*SMOS(4)+WF5(JS)*SMOS(5)+WF6(JS)*SMOS(6))/SASM(JS)
C...ESM IS THE EFFECT OF SOIL MOISTURE ON PHOTOSYNTHESIS
      ESM(JS)=ATANX(SM1(JS),SM2(JS),WASM(JS))
C...ESMR IS THE EFFECT OF SOIL MOISTURE ON RESPIRATION
      ESMR(JS)=0.6*ATANX(SMR1(JS),SMR2(JS),WASM(JS))+.1
```

Adjustments: The sigmoid curve of EAT(i) can be adjusted by changing the values for the midpoint ST1(i) and spread ST2(i) of the ATANX function. TR1(i) and TR2(i) are the temperature response parameters for respiration. The exponential curve of EATR(i) can be made to rise faster with an increase in TR1(i). TR2(i) is the value of EATR(i) when temperature (TCD) is 0°C. These four parameters should be adjusted so that the curve EAT - EATR shows a peak at the optimum temperature (°C) for species i for net photosynthesis.

3.3.2 Soil Water

Photosynthetic and respiratory responses to soil water are based on a weighted average soil water [WASM(i)]. WASM(i) is the amount of soil water (in centimeters) of water in the top six soil strata (0-5, 6-10, 11-15, 16-30, 31-45, and 46-60 cm) weighted by the relative water absorbing surface of the roots in each layer. The latter value is derived from data on root biomass vs. depth (see Fig. 3.11).

Depth (cm)	Weighting Factor	Warm-Season Grass	Cool-Season Grass	Forb	Shrub	Cactus
0-5	WF1	3.	3.	2.	1.	5.
5-10	WF2	2.	2.	1.	1.	6.
10-15	WF3	1.	1.	1.	1.	5.
15-30	WF4	4.	2.	4.	3.	1.
30-45	WF5	1.	1.	2.	2.	1.
45-60	WF6	1.	1.	1.	1.	1.

Fig. 3.11. Values of weighting factors.

The effect of soil water on photosynthetic rate [ESM(i)] and respiration rate [ESMR(i)] for the i^{th} plant group are shown in Fig. 3.12 through 3.16. The response of photosynthesis to soil water is represented as a sigmoid curve with little change in rate at both high and low soil water levels. In the range of values between field capacity and the so called permanent wilting point, there is a rapid change in photosynthetic rate (Kozlowski, 1964; Meyer and Bðhming, 1960). Respiratory rate in the model is represented also as a sigmoid curve that lags the photosynthesis curve, but has a higher value at low soil water. The parameters in the ESM(i) and ESMR(i) functions are calculated in SUBROUTINE START and are a function of the weighting factors for the soil strata [WF1(i) to WF6(i)], field capacity of the six soil strata [SFC1(i) to SFC6(i)], and the wilting point of the soil strata [SWP1(i) to SWP6(i)]. The curves are currently adjusted so that at field capacity ESM(i) is approximately 0.9, and ESMR(i) is 0.6. At the wilting point ESM(i) is approximately 0.1, and ESMR(i) is 0.18.

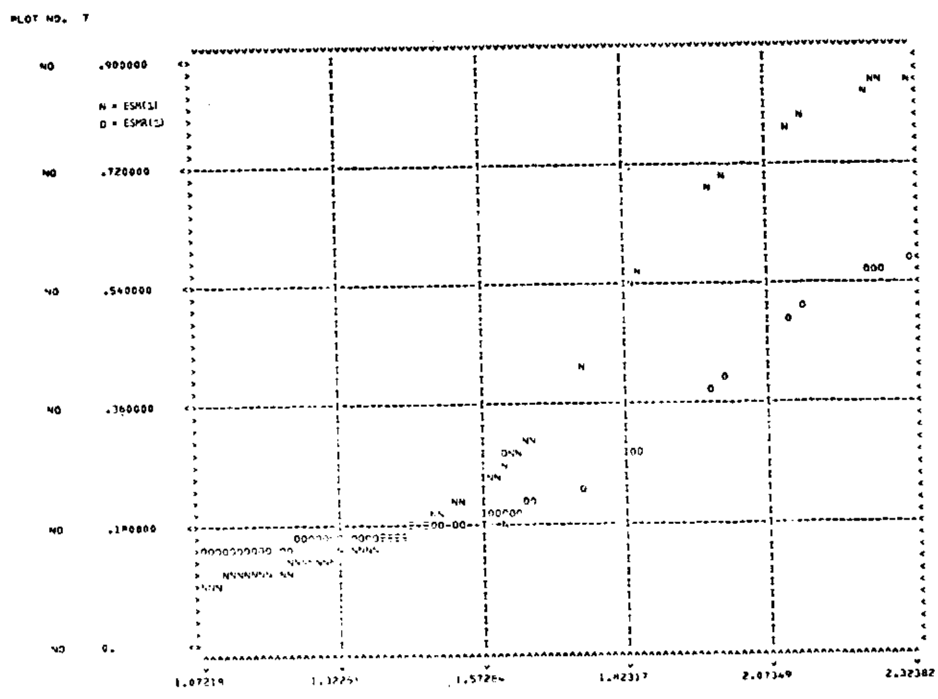

Fig. 3.12. Effect of soil water on photosynthesis and respiration of *Bouteloua gracilis*: N = ESM(1), photosynthesis; 0 = ESMR(1), respiration.

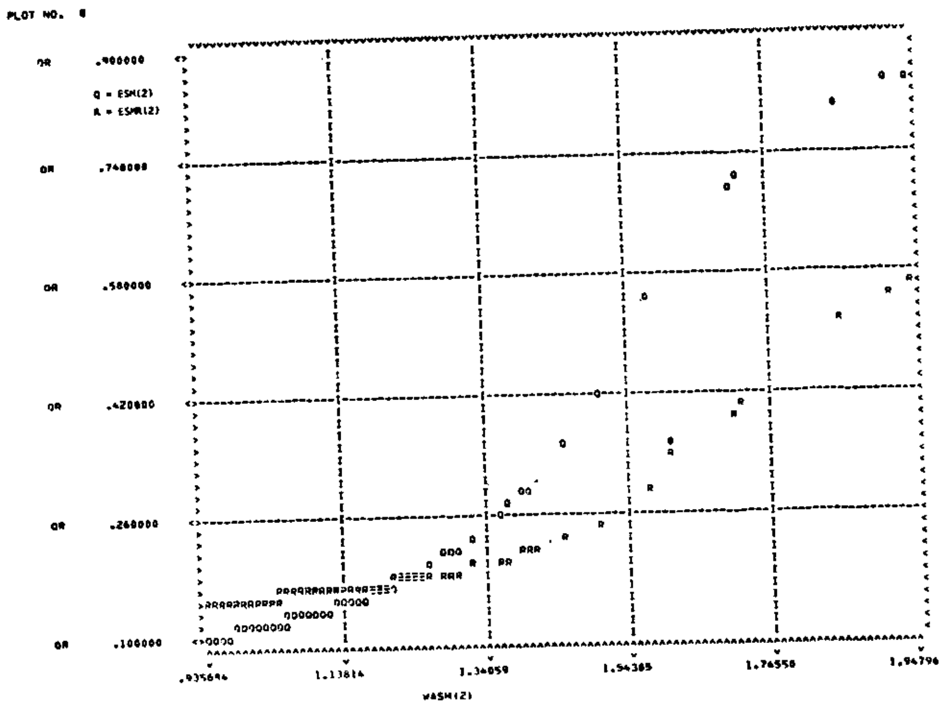

Fig. 3.13. Effect of soil water on photosynthesis and respiration of *Agropyron smithii*: Q = ESM(2), photosynthesis; R = ESMR(2) respiration.

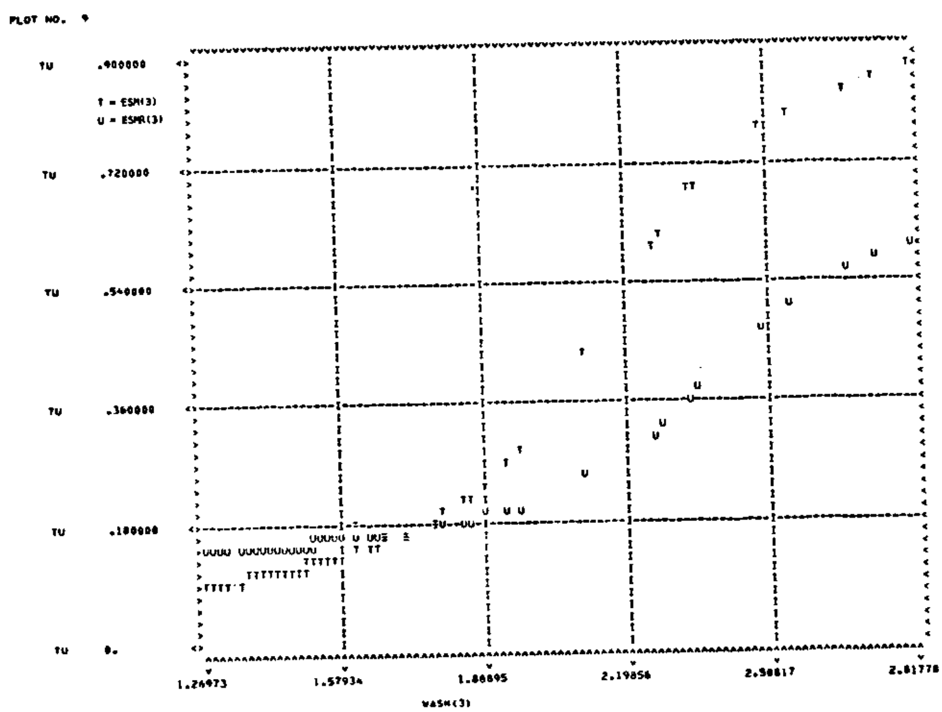

Fig. 3.14. Effect of soil water on photosynthesis and respiration of *Sphaeralcea coccinea*: T = ESM(3), photosynthesis; U = ESMR(3), respiration.

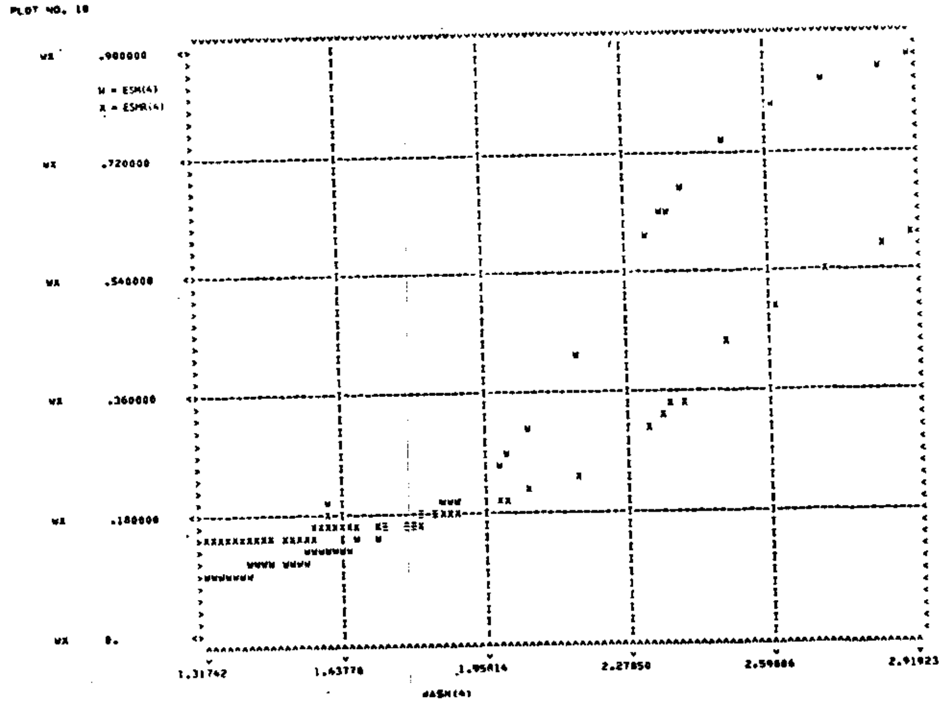

Fig. 3.15. Effect of soil water on photosynthesis and respiration of *Artemisia frigida*: W = ESM(4), photosynthesis; X = ESMR(4), respiration.

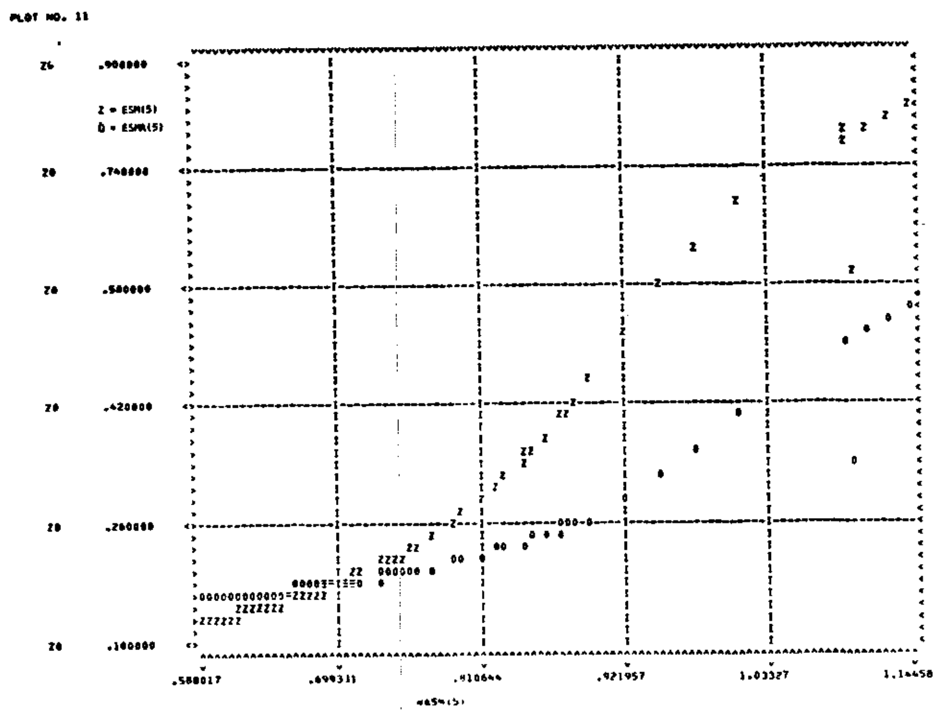

Fig. 3.16. Effect of soil water on photosynthesis and respiration of *Opuntia polyacantha*: Z = ESM(5), photosynthesis; 0 = ESMR(5), respiration.

```
      STEM=X(JS+1)
C...EBM IS THE EFFECT OF BIOMASS ON PHOTOSYNTHESIS
      EBM(JS)=SLA1(JS)*STEM-SLA2(JS)*STEM*STEM+SLA3(JS)
      IF(EBM(JS).LT.1.0)EBM(JS)=1.0
```

Adjustments: Changing the relative root densities in Fig. 3.11 will alter the response of a given plant group to rainfall, as only heavy or continued rain will wet the deeper soil layers. For example, increasing the values for all species in WF6(i) will make all species more responsive to soil water at the deepest soil layer considered in the producer section. Changing the field capacity and wilting point values for the different sites may be necessary. Also, some species of plants are able to utilize lower values of soil water than are other species; this can be accounted for by decreasing the wilting point value for the i^{th} species [SWP1(i) to SWP6(i)]. The units of SWF's and SWP's are centimeters water per centimeters soil profile.

3.3.3 Biomass

The effect of biomass on photosynthetic rate [EBM(i)] for the i^{th} plant group was introduced to account for the accumulation of non-photosynthetic tissue in larger plants. Plots of values for each plant group in a typical run are shown in Fig. 3.17 through 3.21. In young and small plants, nearly all of the shoot biomass is green and photosynthetically active leaf tissue. Larger plants have more woody tissue which is associated with structure and support of the green tissue and hence is not photosynthetically active biomass. Thus, a function that decreases with an increase in biomass is required to represent the effect of biomass on photosynthetic rate (Leopold, 1964; de Wit, Brouwer, and Penning de Vries, 1970).

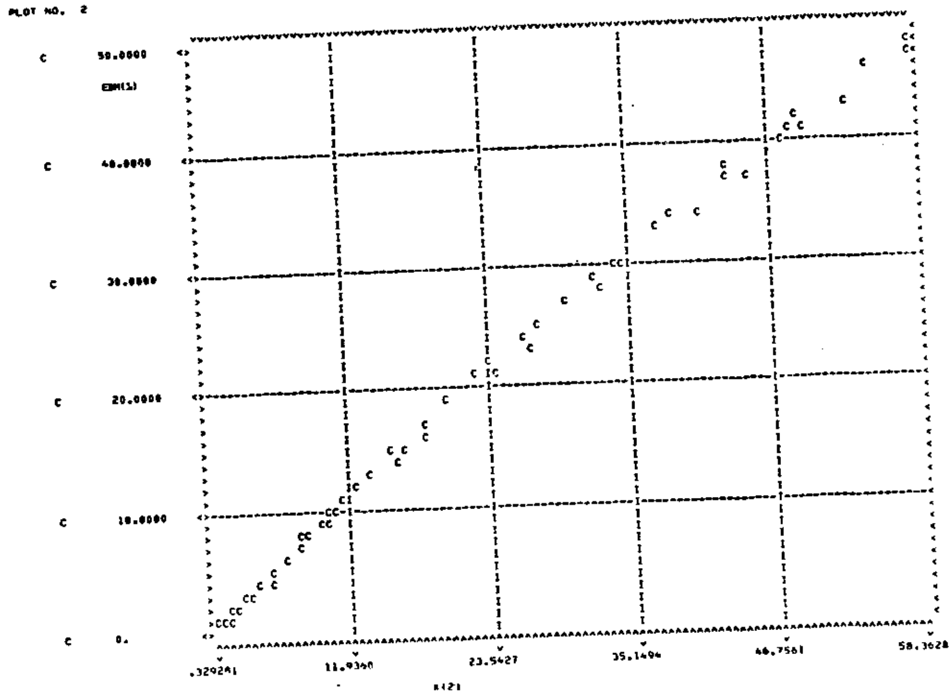

Fig. 3.17. The relationship between shoot biomass [X(2)] and the effect of biomass on photosynthesis of *Bouteloua gracilis*.

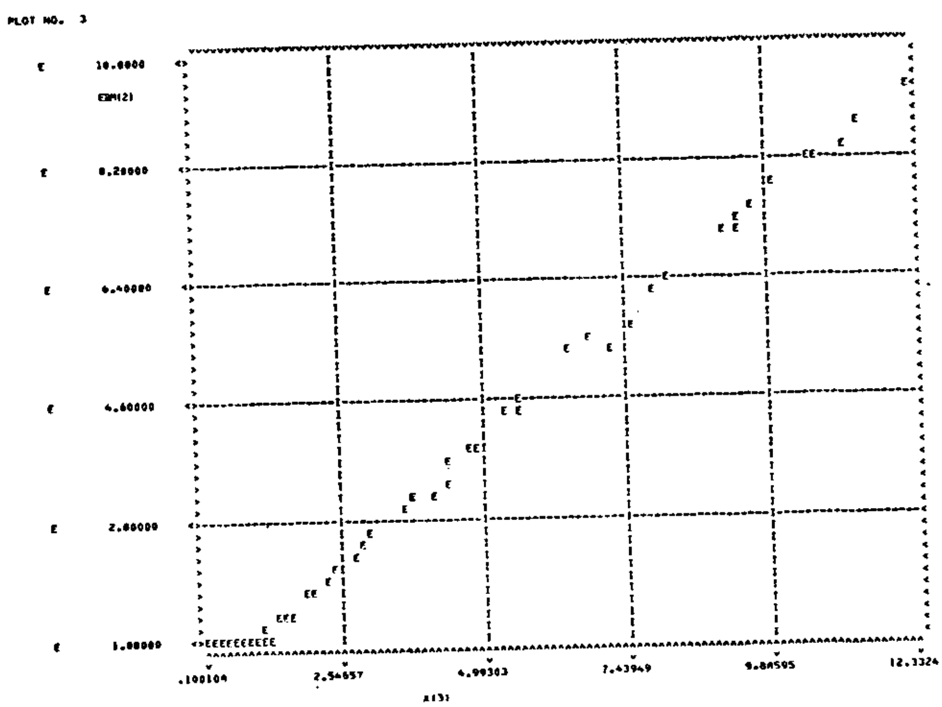

Fig. 3.18. The relationship between shoot biomass [X(3)] and the effect of biomass on photosynthesis of *Agropyron smithii*.

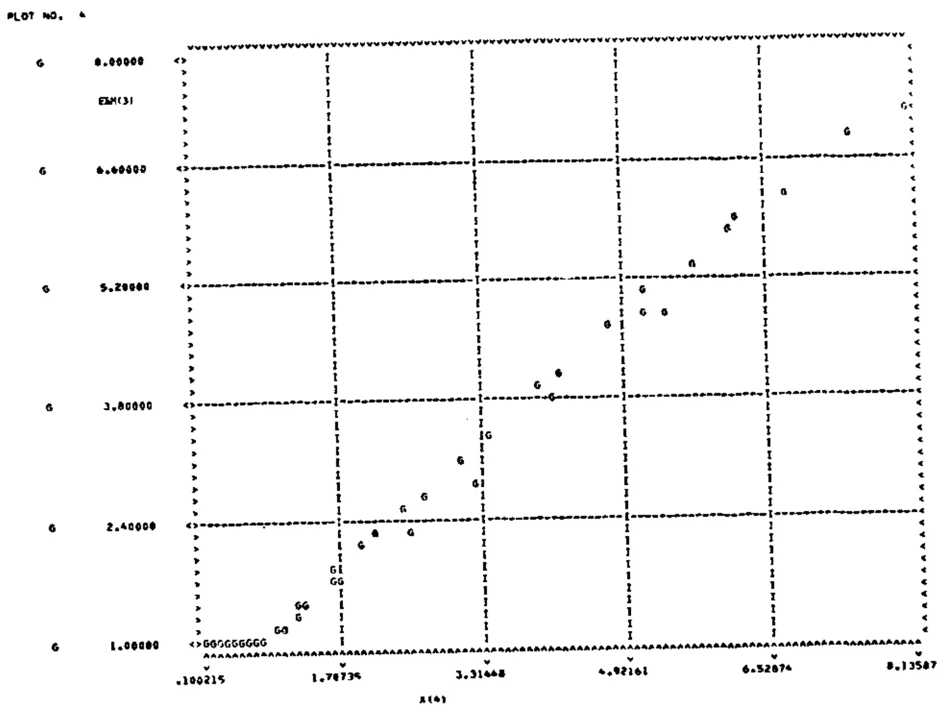

Fig. 3.19. Relationship between shoot biomass [X(4)] and the effect of biomass on photosynthesis of *Sphaeralcea coccinea.*

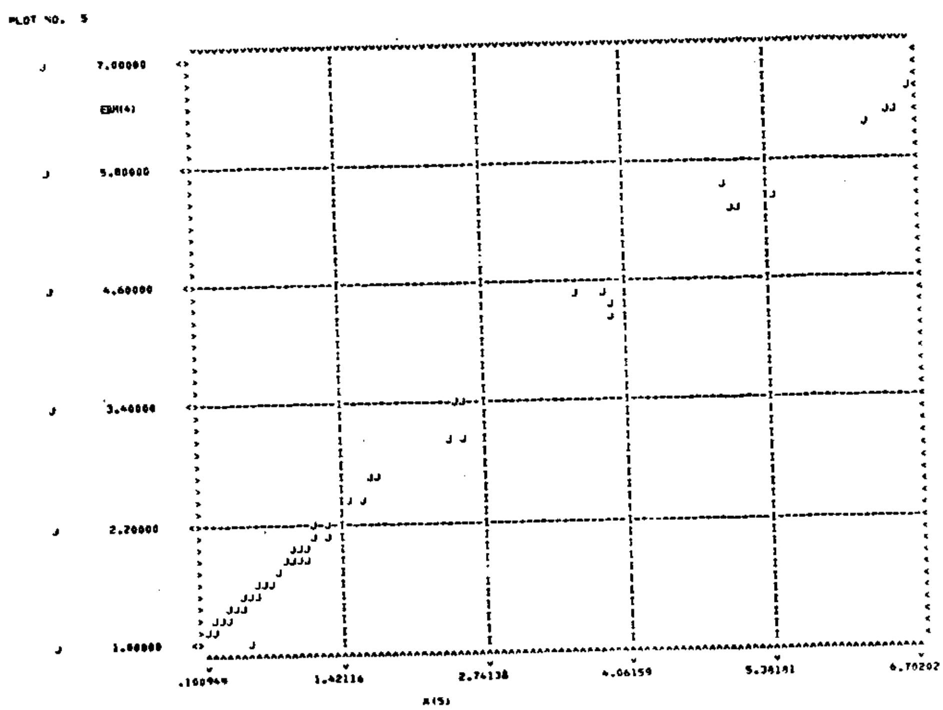

Fig. 3.20. Relationship between shoot biomass [X(5)] and the effect of biomass on photosynthesis of *Artemisia frigida.*

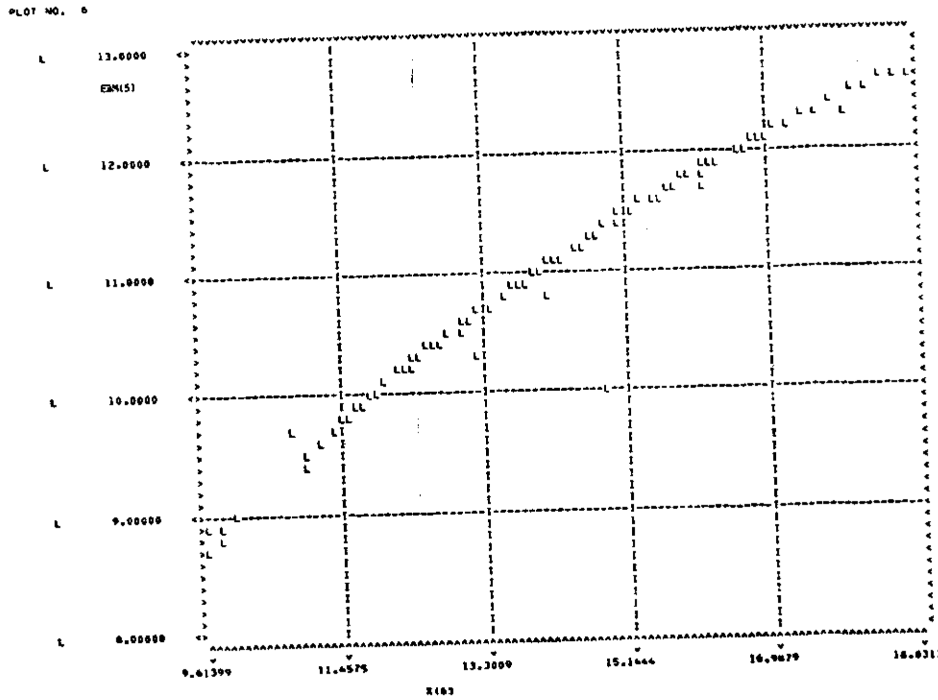

Fig. 3.21. Relationship between shoot biomass [X(6)] and the effect of biomass on photosynthesis of *Opuntia polyacantha*.

Respiration rate is affected by biomass directly. This assumes that all of the shoot biomass is live and therefore respiring tissue. However, if there is a significant accumulation of woody (dead) tissue, this assumption will not hold.

Adjustments: The shape of the parabola that describes the relationship between biomass and photosynthetic rate for the i^{th} plant group is determined by SLA1(i), SLA2(i), and SLA3(i) which correspond to a, b, and c, respectively, in $aX - bX^2 + c$.

3.3.4 Insolation

The effect of insolation (SUN) on photosynthetic rates is presently considered to be linear and equal among the five plant groups. Data provided

```
C...NUTRIENT STRESS CALCULATIONS FOR BOTH NITROGEN AND PHOSPHOROUS
      RDR=0.0
      TDR=0.0
      SNS=6.0*ATANX(.25,.4,X(60))*ATANX(.030,.05,X(70))

C...ENS IS THE EFFECT OF NUTRIENT STRESS
      ENS(JS)=SNS

C...ENS IN CRT INCREASES THE SHOOT/ROOT RATIO WITH HIGH N AND P
C...CONDITIONS, THEREBY INCREASING THE SHOOT BIOMASS AND THE
C...PHOTOSYNTHETIC RATE. HENCE, ENS IN CIN AND COUT ARE NOT NEEDED.
C...CRT IS CARBON MOVED TO THE ROOT SYSTEM
      CRT(JS)=TPRT(JS)*(6.0-ENS(JS))*CNET(JS)*STEM/(X(JS+11)*WASM(JS))
C...THIS IF CHECK SAYS ONLY DURING VEGETATIVE GROWTH IS THE ROOT-SHOOT
C...RATIO AFFECTED BY SOIL NUTRIENTS N AND P
      IF(PHEN(JS).GT.7.0)CRT(JS)=CRT(JS)/(6.0-ENS(JS))
```

by A. J. Dye (personal communication) show a nearly linear response; an increase in insolation in the visible region up to nearly full sunlight gives a linear increase in photosynthetic rate. Further research may enable plant group specific, nonlinear insolation functions to be incorporated.

Adjustments: There are no adjustments in the insolation factor.

3.3.5 Nutrients Nitrogen and Phosphorus

Soil solution pools of nitrogen and phosphorus control photosynthetic rates and shoot/root ratios through the variable ENS(i) for the i^{th} species. In the present version, no interspecific differences are considered in ENS. For both nitrogen and phosphorus, the relationship between plant response and soil solution pool size is a sigmoid curve, the ATANX function. The effect of nitrogen is multiplied by the effect of phosphorus so that if either element is limiting, growth will be restricted. This product is hypothesized to reach 6.0, a six-fold increase in growth rate under conditions of abundant moisture and fertilizer. The ENS(i) term does not appear in either the gross photosynthetic rate calculation or in the respiration calculation, but rather in the shoot/root ratios (see shoot growth section following). An increase in the N and P soil solution pools, in this formulation, increases the shoot/root ratio, thereby increasing the amount of photosynthesizing shoot biomass. Thus, photosynthetic rate is indirectly increased. The respiratory rate is similarly increased with high levels of N and P through the greater amount of shoot biomass. C. V. Cole (personal communication), among others, has suggested that N and P levels influence plant growth only during vegetative stages of growth. Accordingly, an IF check removes the influence of N and P levels [ENS(i)] when plant group i passes phenological stage 7.

```
C...CIN IS GROSS PHOTOSYNTHESIS
      CIN(JS)=PS(JS)*ESM(JS)*EAT(JS)*EP(JS)*SUN*EBM(JS)
C...COUT IS RESPIRATION
      COUT(JS)=RS(JS) * ESMR(JS) * EATR(JS) * EP(JS) * STEM
C...CNET IS NET PHOTOSYNTHESIS
      CNET(JS)=CIN(JS)-COUT(JS)
C...THIS IF-CHECK PUTS A MAXIMUM ON THE APPARENT PHOTOSYNTHETIC RATE
C...OTHERWISE. PS RATE RISES ABOVE A BIOLOGICALLY REASONABLE MAXIMUM OF
C...ABOUT 8GM/MSQ/DAY WITH 40GM OF BO-GR ON THAT MSQ OF GROUND.
      IF(CNET(JS)*DT.GT.SPSX*EBM(JS))CNET(JS)=SPSX*EBM(JS)/DT
```

```
      SHOT(JS)=CNET(JS)
      IF(STEM.LT.0.1)SHOT(JS)=CRT(JS)=0.0
54000 CONTINUE
```

```
                          FLOW=SHOT(1)
                          SPROD=SPROD+FLOW*DT
      (1-3).

                          FLOW=SHOT(2)
                          SPROD=SPROD+FLOW*DT
      (1-4).

                          FLOW=SHOT(3)
                          SPROD=SPROD+FLOW*DT
      (1-5).

                          FLOW=SHOT(4)
                          SPROD=SPROD+FLOW*DT
      (1-6).

                          FLOW=SHOT(5)
                          SPROD=SPROD+FLOW*DT
```

3.3.6 Net Photosynthesis Calculated

Gross photosynthetic rate is the multiplicative combination of the effects of air temperature, soil water, nutrient stress, biomass, insolation, phenology, and a basic photosynthetic rate with units of grams of carbon assimilated per gram of dry weight per square meter of soil surface per day. The other units are dimensionless so the units of PS(i) are the units of the flow ($g/m^2/day$). In a similar manner, respiratory rate is the result of the multiplication of the factors affecting respiration as discussed above. The multiplicative approach is employed so that if one factor is particularly inadequate, the entire function is decreased. This approach approximates the concept of limiting factors presented by Blackman (1965). Net photosynthetic rate is then calculated by simply subtracting the respiration rate from the photosynthetic rate. A maximum (SPSX • EBM(JS)) is set on the net photosynthetic rate so that biologically reasonable rates are not exceeded; the variable SPSX, a parameter, presently set to .2, can be varied per site as data indicate. At Pawnee A. J. Dye (personal communication) has estimated a maximum net photosynthetic rate of about 8 g C/m^2 soil/day at peak standing crop.

3.4 SHOOT GROWTH (1-2)(1-3)(1-4)(1-5)(1-6)

Shoot growth [SHOT(i)] in the i^{th} plant group is the difference between the carbon translocated to the root system [CRT(i)] and net photosynthesis [CNET(i)]. SHOT(i) can be negative if there is a negative net photosynthetic rate, in which case carbon will flow from root to shoot. This would appear to be a reasonable response as the root systems appear to be storage organs, except in the case of plant group 5, cactus.

Adjustments: None.

(2-12).

```
      F = CRT(1)
      IF(EP(1).GT.0.4317.AND.X(2).LT.1.0)F=-X(12)/(30000.*X(2))*X(90)
C...0.4317 CORRESPONDS TO A VALUE OF 11.0 FOR PHEN
      FLOW=F
      SCRT=SCRT+FLOW*DT
```

(3-13).

```
      F = CRT(2)
      IF(EP(2).GT.0.4317.AND.X(3).LT.1.0)F=-X(13)/(30000.*X(3))*X(90)
      FLOW=F
      SCRT=SCRT+FLOW*DT
```

(4-14).

```
      F = CRT(3)
      IF(EP(3).GT.0.4317.AND.X(4).LT.1.0)F=-X(14)/(30000.*X(4))*X(90)
      FLOW=F
      SCRT=SCRT+FLOW*DT
```

(5-15).

```
      F = CRT(4)
      IF(EP(4).GT.0.4317.AND.X(5).LT.1.0)F=-X(15)/(3000.0*X(5))*X(90)
      FLOW=F
      SCRT=SCRT+FLOW*DT
```

(6-16).

```
      F = CRT(5)
      FLOW=F
      SCRT=SCRT+FLOW*DT
```

3.5 SHOOT/ROOT RATIOS AND TRANSFERS

(2-12)(3-13)(4-14)(5-15)(6-16)

The flow rate of carbon from the shoot system is designed to account for the response of shoot/root ratios to net photosynthetic rate, soil water, N and P levels, shoot biomass, and root biomass. An increase in soil N and P, large net photosynthesis, or large root biomass decreases the transfer from shoots to roots. The shoot/root ratio is decreased by low soil water or small shoot biomass. If there is a negative net photosynthetic rate in the shoot system, material will be moved from the roots to the shoots. If early in the growing season or through heavy herbivory, shoot biomass is small and not setting fruit, carbon is again moved from the root system to the shoot system. There is no early season root to shoot transfer in the cactus group because the fleshy stems of this plant group are most likely the overwinter storage organs, not the roots.

Adjustments: The shoot/root ratio can be changed by altering TPRT(i) for plant group i; increasing this value will increase the shoot/root ratio. TRRT(i) is a linear parameter used in the computation of CRT(i), the amount of carbon moved to the root system. The rate at which carbon is moved to the shoot system is altered by changing the number in the denominator of the expression in the IF check in the flows.

(This space left blank intentionally.)

(2-20).

```
      F=X(2)*SDTH(1)*(ATANX(11.,4.0,PHEN(1)) + 0.5/EXP(0.1*TMAX))
      IF (X(2)-F.LT.0.1) F = 0.0
      TDR=TDR+F
      FLOW=F
```

(3-21).

```
      F=X(3)*SDTH(2)*(ATANX(9.0,4.0,PHEN(2)) + 0.5/EXP(0.1*TMAX))
      IF (X(3)-F.LT.0.1) F = 0.0
      TDR=TDR+F
      FLOW=F
```

(4-22).

```
      F=X(4)*SDTH(3)*(ATANX(9.0,4.0,PHEN(3)) + 0.5/EXP(0.1*TMAX))
      IF (X(4)-F.LT.0.1) F = 0.0
      TDR=TDR+F
      FLOW=F
```

(5-23).

```
      F=X(5)*SDTH(4)*(ATANX(9.0,4.0,PHEN(4)) + 0.5/EXP(0.1*TMAX))
      IF (X(5)-F.LT.0.1) F = 0.0
      TDR=TDR+F
      FLOW=F
```

(5-24).

```
      F=X(5)*SDTH(5)*(ATANX(9.0,4.0,PHEN(4)) + 0.5/EXP(0.1*TMAX))
      IF (X(5)-F.LE.1.0) F = 0.0
      TDR = TDR + F
      FLOW=F
```

(6-25).

```
      F=X(6)*SDTH(6)*(ATANX(9.0,4.0,PHEN(5)) + 0.5/EXP(0.1*TMAX))
      TDR=TDR+F
      FLOW=F
```

3.6 SHOOT BIOMASS TO STANDING DEAD

(2-20) (3-21) (4-22) (5-23) (5-24) (6-25)

The transfer of shoot biomass to standing dead biomass is a function of phenology, daily maximum air temperature, and shoot biomass. The ATANX function is used to obtain a rapid increase in transfer during the later reproductive stages of phenology, as leaf and stem senescence appear to progress more rapidly during the flowering processes. In *Clarkia* the rate of senescence of leaves on a vegetative plant is noticeably less than on a flowering plant, presumably because on the flowering plant the leaves are older (Sauer, 1971). The transfer to standing dead also increases exponentially with a decrease in maximum daytime temperature, a reflection of the effect of freezing temperatures on young grass (Sauer, personal observation, 1972). In the shrub category shoot biomass is transferred to both standing dead leaf and to standing dead wood so that these two different organs (leaves and wood) can be treated separately by the consumers and decomposers.

Adjustments: The parameter SDTH(m) for the m^{th} standing dead category can be changed to adjust the rate of transfer from live to standing dead biomass. Further adjustments can be made on the parameters in the ATANX function to alter the effect of phenology and on the exponential function to change the effects of low daytime temperatures.

(This space left blank intentionally.)

(12-42).

```
STEM=PHEN(1)
IF(STEM.LE.1.0) STEM=14.0
H12XX =  X(12) * RTDTH(1) * EXP(.115*STEM)     * 0.1
H1242 = 0.22 * H12XX
FLOW = H1242/DT
RDR = RDR + H12XX
```

(13-42).

```
STEM=PHEN(2)
IF(STEM.LE.1.0) STEM=14.0
H13XX =  X(13) * RTDTH(2) * EXP(.115*STEM)      * 0.1
H1342 = 0.22 * H13XX
FLOW = H1342/DT
RDR = RDR + H13XX
```

(14-42).

```
STEM=PHEN(3)
IF(STEM.LE.1.0) STEM=14.0
H14XX        = X(14) * RTDTH(3) * EXP(.115*STEM)     * 0.1
H1442 = 0.12 * H14XX
FLOW = H1442/DT
RDR = RDR + H14XX
```

(15-42).

```
STEM=PHEN(4)
IF(STEM.LE.1.0) STEM=14.0
H15XX =        X(15) * RTDTH(4) * EXP(.115*STEM)   * 0.1
H1542 = 0.11 * H15XX
FLOW = H1542/DT
 RDR = RDR + H15XX
```

(16-42).

```
STEM=PHEN(5)
IF(STEM.LE.1.0) STEM=14.0
H16XX  = X(16) * RTDTH(5) * EXP(.115*STEM)     * 0.1
H1642 = 0.20 * H16XX
FLOW = H1642/DT
RDR = RDR + H16XX
```

(12-1).

```
 F =RTRS(1)* X(90) * X(12)
FLOW=F
SRTRS=SRTRS+FLOW*DT
```

(13-1).

```
 F =RTRS(2)* X(90) * X(13)
FLOW=F
SRTRS=SRTRS+FLOW*DT
```

(14-1).

```
 F =RTRS(3)* X(90) * X(14)
FLOW=F
SRTRS=SRTRS+FLOW*DT
```

(15-1).

```
 F =RTRS(4)* X(90) * X(15)
FLOW=F
SRTRS=SRTRS+FLOW*DT
```

(16-1).

```
 F =RTRS(5)* X(90) * X(16)
FLOW=F
SRTRS=SRTRS+FLOW*DT
```

3.7 ROOT DEATH

(12-42)(13-42)(14-42)(15-42)(16-42)

The root death rate in the flows from the live root compartments to the belowground dead compartment is a function of root biomass, a constant RTDTH(i), and phenology. Root death is assumed, for lack of better data, to increase in an exponential manner with phenological advance during the growing season. Thus, there is more root death during dormancy and flowering than there is during vegetative stages. Live root biomass is included to account for the greater (presumed) transfer when there are more live roots per unit area of ground surface. These root dynamics, of course, apply only to perennial species. Annuals would lose all root biomass to the dead category each year.

Adjustments: The rate of root death can be changed by altering the initial values of live root biomass or the constant parameter RTDTH(i) for plant group i. The numbers in the exponential function may also be altered to obtain a different response to phenology.

3.8 ROOT RESPIRATION

(12-1)(13-1)(14-1)(15-1)(16-1)

Root respiration is a function of live root biomass, the average soil temperature in the top 60 cm, and a constant RTRS(i). Live root biomass is included because an increase in root biomass will produce an increase in respiratory carbon. Soil temperature is included to reflect the sensitivity of respiration rate to temperature.

Adjustments: The rate of root respiration can be changed by changing the constant RTRS(i).

(20-41).

```
      STEM = PISC1+SMOS(1)-.35
      IF(STEM.LT.0.0)STEM=0.0
      FLOW=STEM*STEMP*X(20)*SLOS(1)
      H2041 = FLOW*DT
```

(21-41).

```
      STEM = PISC1+SMOS(1)-.35
      IF(STEM.LT.0.0)STEM=0.0
      FLOW=STEM*STEMP*X(21)*SLOS(2)
      H2141 = FLOW*DT
```

(22-41).

```
      STEM = PISC1+SMOS(1)-.35
      IF(STEM.LT.0.0)STEM=0.0
      FLOW=STEM*STEMP*X(22)*SLOS(3)
      H2241 = FLOW*DT
```

(23-41).

```
      STEM = PISC1+SMOS(1)-.35
      IF(STEM.LT.0.0)STEM=0.0
      FLOW=STEM*STEMP*X(23)*SLOS(4)
      H2341 = FLOW*DT
```

(24-41).

```
      STEM = PISC1+SMOS(1)-.35
      IF(STEM.LT.0.0)STEM=0.0
      FLOW=STEM*STEMP*X(24)*SLOS(5)
      IF (X(24).LE.1.0) FLOW=0.0
      H2441 = FLOW*DT
```

(25-41).

```
      STEM = PISC1+SMOS(1)-.35
      IF(STEM.LT.0.0)STEM=0.0
      FLOW=STEM*STEMP*X(25)*SLOS(6)
      H2541 = FLOW*DT
```

(1-90).

```
      X(90) = (SAVTP(1)+SAVTP(2)+SAVTP(3)+SAVTP(4)+SAVTP(5))/5.0
      IF (X(90) .LT. 0.0) X(90) = 0.0
      FLOW=0.0
```

3.9 STANDING DEAD TO LITTER

(20-41)(21-41)(22-41)(23-41)(24-41)(25-41)

The rate at which standing dead biomass is transferred to the litter compartment is a function of moisture, temperature, standing dead biomass, and a rate constant SLOS(m). This set of flows is considered to reflect the decomposition rate of the bases of the stems and leaves so that these structures become detached from the plant body. The moisture content of the expression is the sum of the moisture content, greater than wilting point soil water content, of the upper 5 cm of soil and the rainfall intercepted by the standing crop. The temperature component is the average of daily maximum and minimum air temperatures, set to 0.0 if the average is below 0°C. Biomass is included to account for the presumably greater flow rates with greater standing dead biomasses.

Adjustments: The constant parameter SLOS(m) for the m^{th} category of standing dead can be altered to change the rate of loss of standing dead biomass.

3.10 SOIL TEMPERATURE FOR PRODUCER SECTION (1-90)

Soil temperatures used in the producer section are assigned to the state variable X(90). The average of the upper 60 cm of soil is used since this includes most of the roots.

Adjustments: None.

3.11 OUTPUT

The following plots are output from the run and listing of Chapter 9.

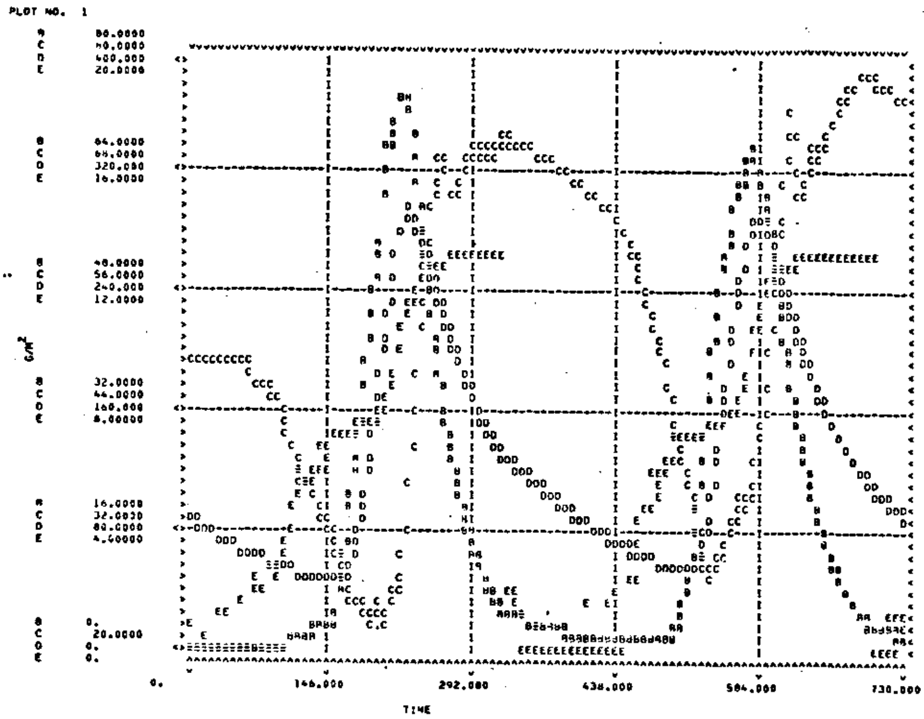

Fig. 3.22. *Bouteloua gracilis*: B = live shoot, X(2); C = standing dead, X(20); D = live roots, X(12); and E = phenology, PHEN(1).

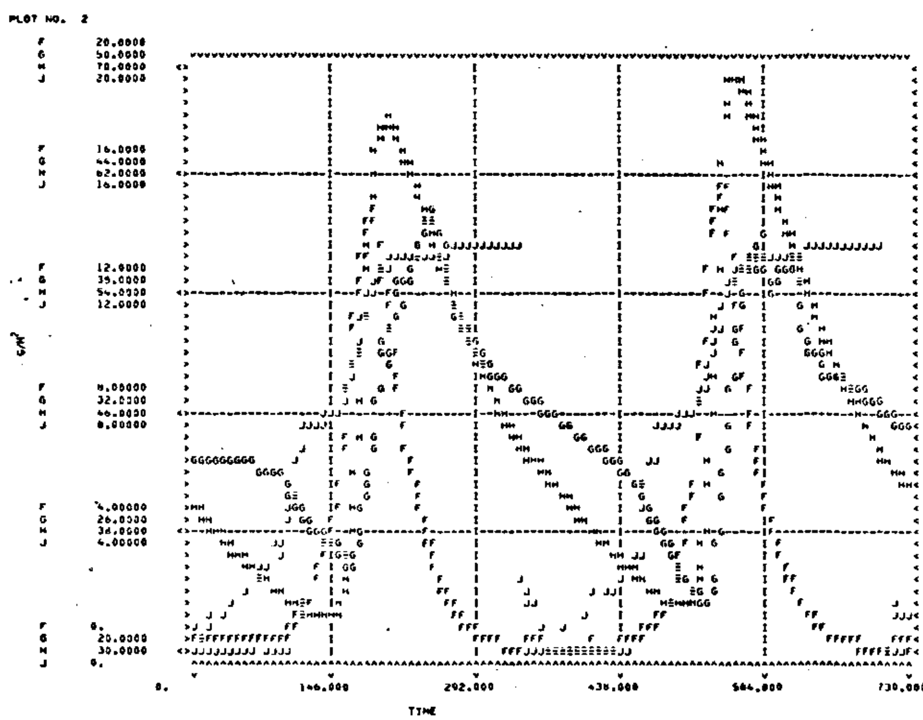

Fig. 3.23. *Agropyron smithii*: F = live shoot, X(3); G = standing dead, X(21); H = live roots, X(13); and J = phenology, PHEN(2).

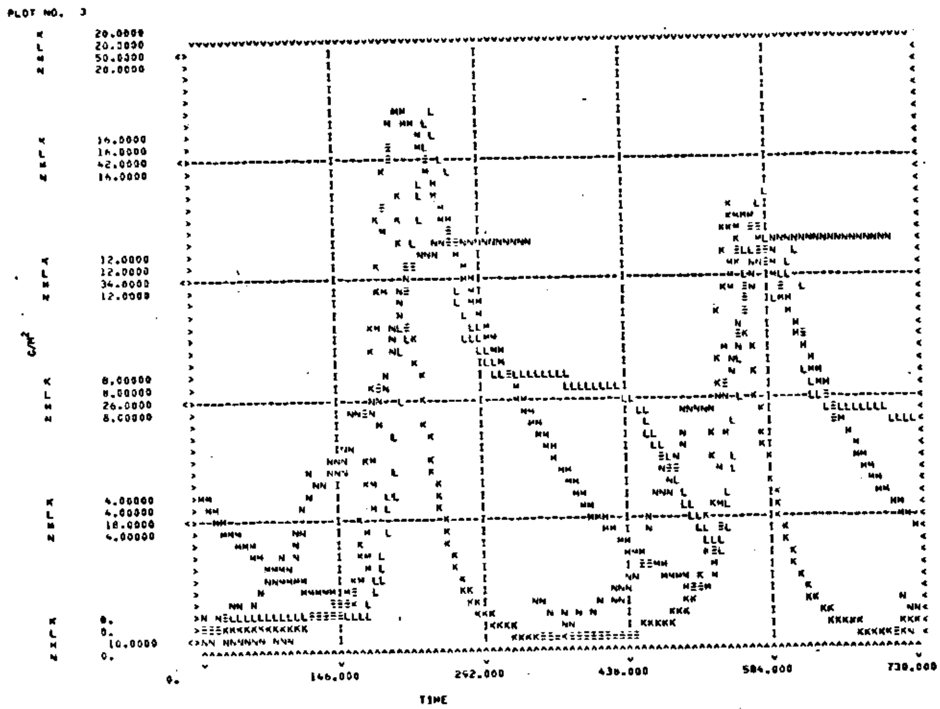

Fig. 3.24. *Sphaeralcea coccinea*: K = live shoot, X(4); L = standing dead, X(22); M = live roots, X(14); and N = phenology, PHEN(3).

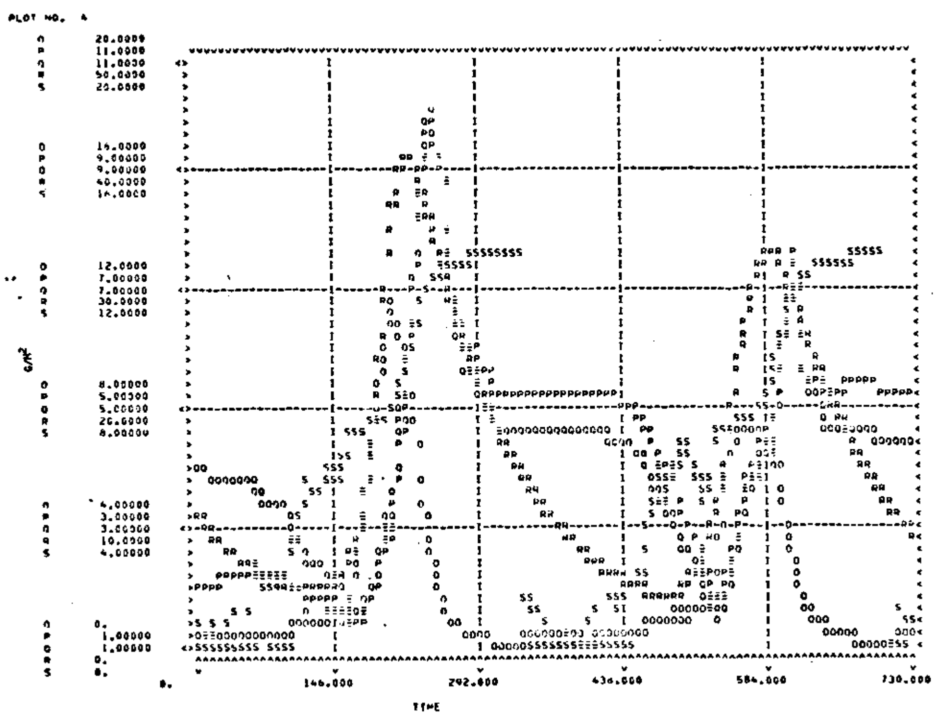

Fig. 3.25. *Aretmisia frigida*: O = live shoot, X(5); P = standing dead leaves, X(23); Q = standing dead wood, X(24); R = live roots, X(15); and S = phenology, PHEN(4).

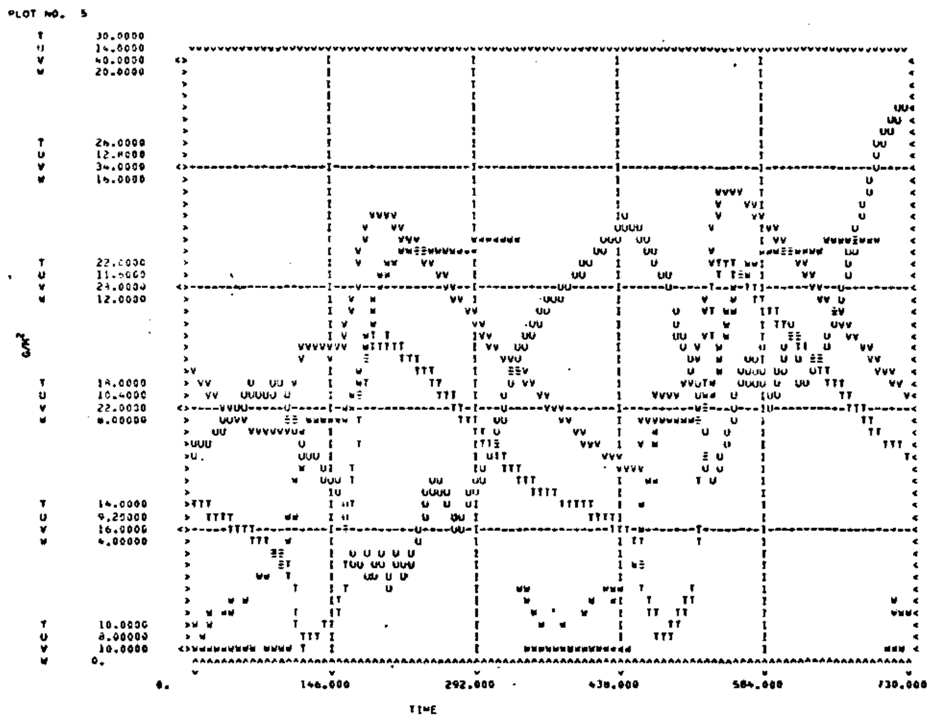

Fig. 3.26. *Opuntia polyacantha*: T = live shoot, X(6); U = standing dead, X(25); V = live roots, X(16); and W = phenology, PHEN(5).

3.12 LITERATURE CITED

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CHAPTER 4. MAMMALIAN CONSUMER SECTION

4.1 INTRODUCTION

This section (Fig. 4.1) is based on the idea that flows into and from an animal are primarily controlled by its metabolic rate and that, given the choice and opportunity, the animal will maintain an energy balance and rate of gain appropriate to its phenological stage. This basic control mechanism will be influenced by air temperature, animal total weight, wastes (gas, urine, feces), activity, accumulated hunger, maximum possible intake, herbage availability or accessibility, preference, and digestibility. To implement this concept all functions have been designed to produce a maximum contribution toward a peak energy balance. This will be represented by maximum weight gain within the natural range of variation for any given set of conditions.

The above factors influencing metabolism have mutual interactions. For example, the quantity, quality, and kind of herbage present influences intake; and, in turn, yesterday's intake influences today's herbage availability. This mutual interaction may be either as an information flow or as a flow of actual material. In the above example herbage influences intake via preference which is an information flow. What was actually eaten yesterday is a flow of material, and this reduces the amount of herbage available today.

Under stressed conditions the influence of these factors may be changed. For example, when the animal selects its diet, the energy needs are influenced by preference. Given high availability the organism will be highly selective; but when availability or accessibility is low, selection preference will become less important than total energy requirement.

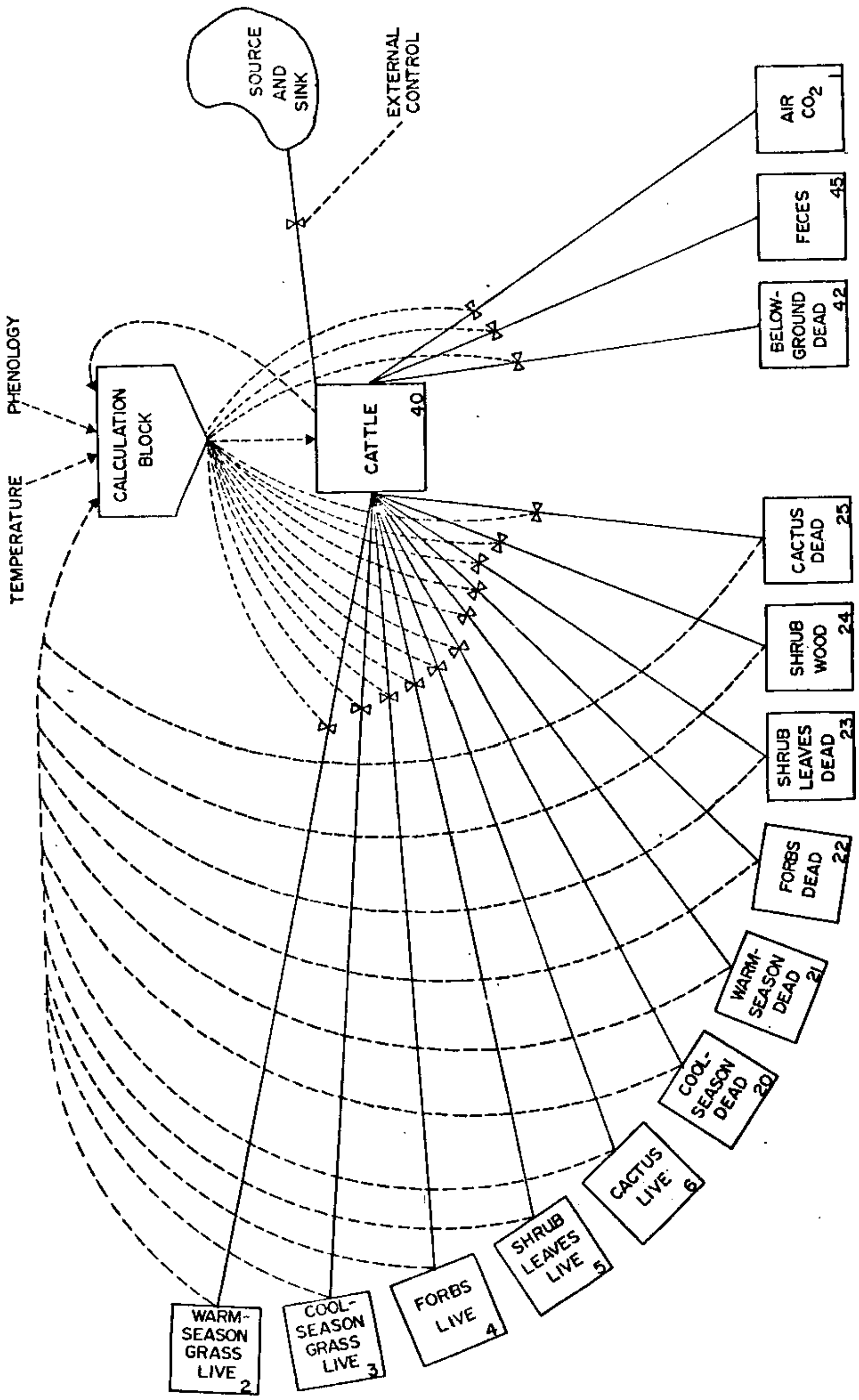

Fig. 4.1. Flows in the consumer section.

Fig. 4.1 illustrates the information flows (-----), material flows (———), and state variables involved. State variable X(40) is cattle biomass.

The calculation block in Fig. 4.1 contains all the calculations controlling flows in the consumer section. These calculations are located in the section of the model called SUBROUTINE CYCL1 and use all the information flows interactively to determine the material flows in the main program. The actual calculations consist of the last four sections as outlined in Fig. 4.2.

Initial calculation made only once:

GRAZING INTENSITY AND STARTING WEIGHT

Convert stocking rate, starting weight to g/m^2

1. DIGESTIBLE ENERGY REQUIREMENTS

Basal metabolism = $70W^{0.75}$

· Temperature effect

· Heat increment or calorigenic effect

· 2.0 (Multiplicative factor to determine total energy needs)

= Energy requirements

2. PREFERENCE TENDENCY

Available Food Biomass

· Digestibility

· Palatability index

= Preference set to decimal fraction

3. FOOD INTAKE

Energy Requirement

÷ 4 (kcal per gram food)

÷ Digestibility

· AFX · (intake increases as a function of degestibility)

+ Hunger

· Preference

= Food intake per category) Flows into X(40)

4. FOOD UTILIZATION

Total intake

- Feces
- Gas
- Urine
- Activity
- Metabolism

(Feces, Gas, Urine, Activity, Metabolism: Flows out of X(40))

= Gain

Fig. 4.2. Outline of consumer calculation block.

```
(2-40).
                              FLOW = FINT(1)
(3-40).
                              FLOW = FINT(2)
(4-40).
                              FLOW = FINT(3)
(5-40).
                              FLOW = FINT(4)
(6-40).
                              FLOW = FINT(5)
(20-40).
                              FLOW = FINT(6)
(21-40).
                              FLOW = FINT(7)
(22-40).
                              FLOW = FINT(8)
(23-40).
                              FLOW = FINT(9)
(24-40).
                              FLOW = FINT(10)
(25-40).
                              FLOW = FINT(11)

C         ***************************************************************
C         *                  CALCULATION BLOCK FOR STEER FLOWS           *
C         ***************************************************************
      IF(ATIM .EQ. 1.) 61160, 61161
61160 IF(TIME .LT. 119.) GO TO 66001
      IF(ABS(TIME-119.) .GT. .01) GO TO 53000
      X(40)=(ATWT*ANUM*453.59)/(ACRES*4047.0)
      GO TO 53000
61161 IF (NDAY.LT.120.OR.NDAY.GT.300) GO TO 66001
      IF (NDAY.EQ.120) GO TO 53001
      GO TO 53000
53001 IF (TIME .LT.365.0) GO TO 53002
      IF (TIME.LT. 730.0) GO TO 53003
      IF (TIME.LT. 1095.0) GO TO 53002
      IF (TIME.LT. 1460.0) GO TO 53003
      GO TO 53000
53002 X(40)=(ATWT1*ANUM1*453.59)/(ACRE1*4047.0)
      GO TO 53000
53003 X(40)=(ATWT2*ANUM2*453.59)/(ACRE2*4047.0)
53000 CONTINUE
```

4.2 CONSUMER INTAKE FLOWS

(2-40) (3-40) (4-40) (5-40) (6-40) (20-40) (21-40) (23-40) (24-40) (25-40)

4.2.1 Calculation Block for Steer Flows

The first set of calculations determines the amount of time the animals spend grazing (ATM) in that if ATIM = 1.0, the animals are initiated at the values for starting weight (ATWT) and number of animals (ANUM) per area (ACRES), and remain on the site from NDAY = 120 (time = 119) until the end of a 2-year run. If ATIM = 0.0, the model will respond to the grazing regime normally used on the Pawnee Site of a 180-day grazing period beginning NDAY = 120. Statement 53001 determines the grazing intensity for different years of simulation runs, as per values of ATWT1, ANUM1, ACRES1 or ATWT2, ANUM2, and ACRES2. The initial value for X(40) is then determined from the appropriate values. The block of code on the facing page describes a 4-year run with alternating light and heavy grazing.

```
C     ******************************************************************
C     *      CALCULATE ANIMALS DIGESTIBLE ENERGY REQUIREMENTS(DIGNR)       *
C...DETERMINE ANIMALS ENERGY NEEDS IN KCAL(AENK)
C
      ATWT=(X(40)*ACRES*4047.)/(ANUM*453.59)
      IF (ATWT.LT.0.0)ATWT=HUNGR=0.0
      ATWK=ATWT/2.2046
      AENK=70.*(ATWK**.75)
C
C...CALCULATE TEMP(SA) EFFECT INCLUDING HEAT INCREMENT(KLEIBER)
C
      IF(SA. GT. 13.0) 67723, 67724
67723 AHEAT=1.42
      GO TO 67725
67724 AHEAT=CLI(0.0,13.0,2.10,1.42,SA)
67725 CONTINUE
      IF(AHEAT.GT. 2.4) AHEAT = 2.4
C
C...DIGNR = DIGESTIBLE ENERGY REQUIRED PER SQUARE METER
      DIGNR=(AENK*AHEAT*2.*ANUM)/(ACRES*4047.)
```

4.2.2 Calculate Animal's Digestible Energy Requirements (DIGNR)

The second set of calculations determines the animal's energy needs in kcal as influenced by temperature and converted to digestible energy required per square meter.

The animal's energy needs in kcal (AENK) for basal metabolism are determined by the formula $70W^{0.75}$, where W is the animal's total weight in kilograms (Crampton and Lloyd, 1959; Maynard and Loosli, 1962). (In the code total weight in pounds is converted to kilograms.)

The influences of heat increment and temperature (AHEAT) on energy needs are based on a curve from Kleiber (1961) shown in Fig. 4.3. Since this curve is essentially two straight lines with a breaking point at approximately 13°C (critical temperature for fed animals), the calculated linear interpolation function is used to determine the increased effect as the temperature falls below 13°C. Above 13°C the value 1.42 was used to include the heat increment effect. AHEAT is computed from:

$$\text{AHEAT} = \text{CLI}\ (0.0,\ 13.0,\ 2.10,\ 1.42,\ \text{SA})$$

where

CLI = a function subroutine discussed in Chapter 7

SA = mean canopy temperature

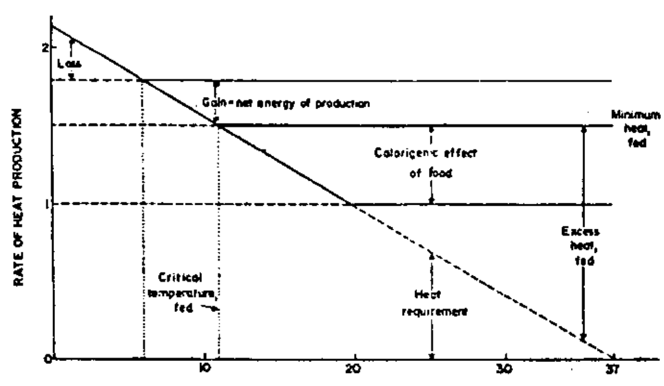

Fig. 4.3. Metabolic rate of fed animal vs. environmental temperature (from Kleiber, 1961, p. 274).

The final part of this section determines the total digestible energy required per square meter (DIGNR). This is determined by a multiplicative function with factors for basal metabolism (AFNK) and temperature and heat increment effect (AHEAT). This is then multiplied by 2.0 in order to obtain total energy needs from basal metabolism for herbivora (Crampton and Lloyd, 1959). The resulting value is then converted from a unit animal basis to grams per square meter.

Adjustments:

1. Some authors (e.g., Brody, 1945) prefer $70W^{0.73}$. This may also need changing for other consumers. The exponent has been shown to range from 0.64 for birds to 0.82 for rabbits (Brody, 1945, p. 371; Kleiber, 1961, p. 208).
2. The "critical temperature, fed" or breaking point of this curve (Fig. 4.3) is not the same for all consumers (see Scholander et al., 1950, Fig. 4.4). The graph used by Kleiber (Fig. 4.3) is more generalized and will probably be found appropriate except in extreme cases.
3. The multiplicative factor of 2.0 for herbivora might be replaced by 1.4 for omnivores and carnivores (Crampton and Lloyd, 1959).

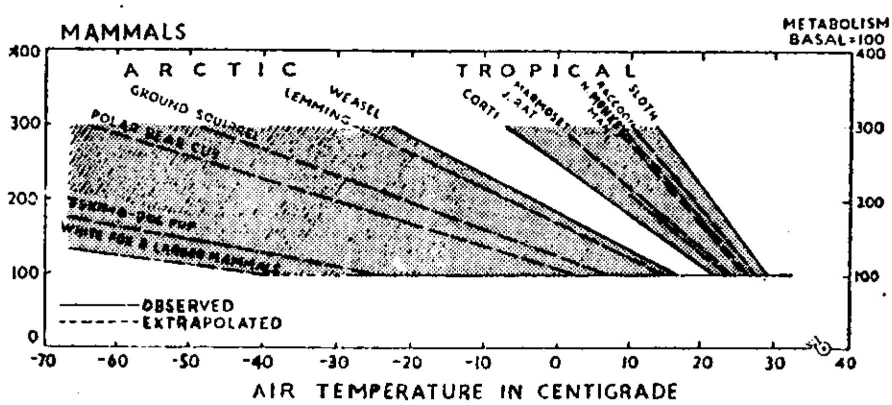

Fig. 4.4. Heat regulation and temperature sensitivity in Arctic and tropical mammals. Note that the fox needs only a small increase over its basal metabolic rate in order to be able to withstand the coldest recorded temperature (from Scholander et al., 1950).

```
C***********************************************************************
C          CALCULATIONS FOR ANIMALS PREFERENCE TENDENCY(APTC)
C
C...CALCULATE ACCESSIBLE FORAGE
C
      AX(1)=AMAX1(X(2)-5.0,0.0)
      AX(2)=AMAX1(X(3)-5.0,0.0)
      AX(3)=AMAX1(X(4)-5.0,0.0)
      AX(4)=AMAX1(X(5)-1.2,0.0)
      AX(5)=AMAX1(X(6)-24.0,0.0)
      AX(6)=AMAX1(X(20)-5.0,0.0)
      AX(7)=AMAX1(X(21)-5.0,0.0)
      AX(8)=AMAX1(X(22)-5.0,0.0)
      AX(9)=AMAX1(X(23)-1.0,0.0)
      AX(10)=AMAX1(X(24)-4.0,0.0)
      AX(11)=AMAX1(X(25)-20.0,0.0)
C
C...DETERMINE AMOUNT OF TOTAL AVAILABLE BIOMASS
      ATFB = 0.0
      DO 68808 I= 1,11
68808 ATFB = ATFB + AX(I)
C...DETERMINE IF ATFB IS ADEQUATE - IF NOT REMOVE COWS FOR SEASON
      IF(ATFB .LE. .0001) 68810, 68812
68810 ASTP=0.0
68812 CONTINUE
      IF(NDAY .EQ. 119.) ASTP = 1.0
      IF(ASTP .EQ. 0.0) GO TO 66001
```

4.2.3 Calculations for Animal's Preference Tendency (APTC)

The third set of calculations determines the animal's preference tendency for each food source based on the food's available biomass, digestibility, and the palatability index.

The food categories considered are live warm-season grasses [X(2)], live cool-season grasses [X(3)], live forbs [X(4)], live shrubs [X(5)], live cacti [X(6)], standing dead warm-season grasses [X(20)], standing dead cool-season grasses [X(21)], standing dead forbs [X(22)], standing dead shrub leaves [X(23)], standing shrub wood [X(24)], and standing dead cacti [X(25)].

Available biomass [AX(I)] is the aboveground biomass of each category (AMAXI[X(I)]) minus a minimum grazing level, with the provision that this shall not be less than zero:

$$AX(I) = AMAX1\left([X(I)] - \text{minimum grazing level, } 0.0\right)$$

where

AMAX1 is a FORTRAN IV system subroutine which takes the maximum of the floating point arguments and returns its floating point value.

The minimum grazing level for each category was chosen to leave a certain amount of aboveground biomass (average total of 20 g/m^2) unavailable for grazing (Bement, 1969; J. E. Ellis, personal communication).

The values for cacti are very high as the spines make this plant nearly inaccessible. R. W. Rice (personal communication) believes that cactus consumption by cattle is accidental.

Immediately following the determination of availability the amount of total available forage biomass (ATFB) is determined; and if it is less than 0.0001 g/m^2, the animals are removed for the season.

The phenological index (APHEN) is determined in the producer section. The digestibility curves used are based on nylon bag digestibilities obtained by Wallace (1969) and keyed to phenological stage (Free, 1969; R. H. Sauer, personal communication). They are shown in Fig. 4.5. The digestibility curves for phenophases 14-16 (standing dead) progress more rapidly than Wallace's data in an attempt to represent the effects of a low nutrient content which during the later stages is too low to support an animal's ruminal flora which, in turn, hampers the animal's utilization of the food (Rauzi, Painter, and Dobrenz, 1969; R. W. Rice, personal communication; K. B. Addison, personal communication).

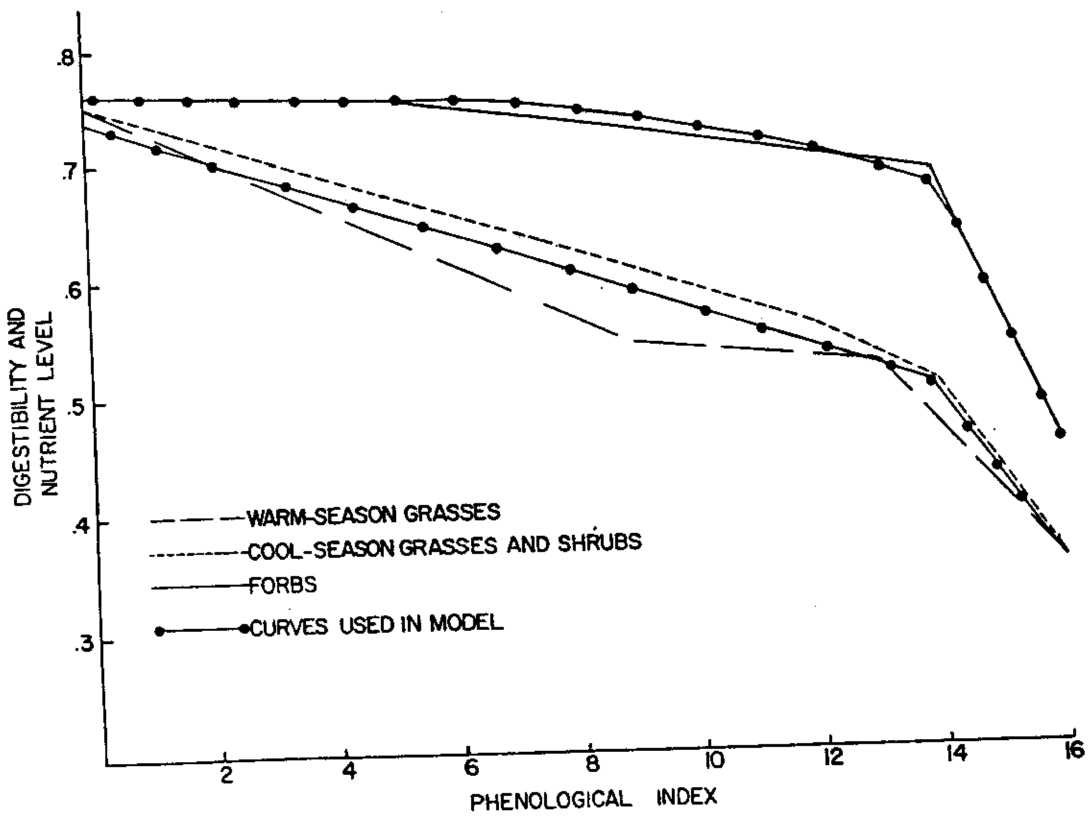

Fig. 4.5. Digestibility per phenological index.

```
C...DETERMINE DIGESTIBILITY OF FORAGE
      ADIG(1)=CLI(2.0,14.0,ADGVA,ADGVB,APHEN(1))
      ADIG(2)=CLI(2.0,14.0,ADGVA,ADGVB,APHEN(2))
      ADIG(3)=ATANF(17.0,0.4222,0.7157,-.2,APHEN(3))
      ADIG(4)=CLI(2.0,14.0,ADGVA,ADGVB,APHEN(4))
      ADIG(6)=CLI(14.0,16.0,ADGVB,ADGVC,APHEN(6))
      ADIG(7)=CLI(14.0,16.0,ADGVB,ADGVC,APHEN(7))
      ADIG(8)=CLI(14.0,16.0,ADGVB,ADGVF,APHEN(8))
      ADIG(9)=CLI(14.0,16.0,ADGVB,ADGVC,APHEN(9))
      DO 69810 I=1,11
      IF(ADIG(I) .GT. .80) ADIG(I) = .80
69810 IF(ADIG(I) .LT. .30) ADIG(I)=.30
C
C...CALCULATE AVERAGE DIGESTIBILITY (AVDIG)
      ADG = AQ = 0.0
      DO 69811 I=1,11
      ADG = ADG + (ADIG(I) * FINT(I))
      AQ = AQ + FINT(I)
69811 AVDIG = ADG/AQ
      IF(NDAY .EQ. 120) AVDIG = 0.6
```

```
C...DETERMINE APTC VALUES
C
      DO 60002 I=1,11
      APTC(I) = AX(I) * ADIG(I) * APAL(I)
60002 CONTINUE
C...SET APTC TO DECIMAL FRACTIONS
C
      SPTC=0.0
      DO 60003 I=1,11
60003 SPTC=SPTC+APTC(I)
      DO 60004 I=1,11
      APTC(I)=APTC(I)/SPTC

60004 CONTINUE
```

The weighted averaged digestibility of total daily food intake (AVDIG) is calculated by summing the products of individual food categories and digestibilities, and their previous day's intake, and then dividing by total daily intake.

$$AVDIG = \frac{\Sigma[FINT(I) \cdot ADIG(I)]}{\Sigma FINT(I)}$$

where

FINT(I) = desired forage intake

ADIG(I) = digestibility by food category

The palatability index for each food category [APAL(I)] is a relative index of food desirability. Values from diet content analysis (Vavra, 1972) are compared with relative availability [AX(I)] and adjusted in the light of field experience to determine a value for each category on a scale of from 0.0 to 1.0. Thus, live forbs and grasses have an APAL index of 1.0, while cacti have a value of .0002.

The animal's preference tendency [APTC(I)] is then calculated using these three items in the following formulation:

$$APTC(I) = AX(I) \cdot ADIG(I) \cdot APAL(I)$$

After the APTC values for each food category have been calculated, the values are proportionally reduced so that the sum of the APTC's equals 1.

Adjustments: The minimal grazing level is given in terms of plant biomass, but must be considered as biomass distribution. At the Pawnee Site there is approximately 20 g/m^2 left when animals have grazed to the minimum grazing height of approximately 20 mm. At other sites the herbage

```
C*****************************************************************
C...CALCULATIONS FOR FORAGE INTAKE
C...HUNGR= HUNGER CARRIED OVER FROM PREVIOUS DAY
      HUNGR=ERR+HUNG
      AHU= .01*X(40)
      IF(HUNGR .GT. AHU) HUNGR = AHU
      IF(HUNGR .LT. 0.0) HUNGR = 0.0
C...INTAKE INCREASES PROPORTIONALLY AS DIGESTABILITY INCREASES
      AFX = CLI(.60,.45,1.40,0.70,AVDIG)
C
C...CALCULATE FORAGE INTAKE RATE (AFIN)
C
      AFIN = ((DIGNR/4./AVDIG)* AFX)+ HUNGR
C
      AMFIN=.04 *X(40)
      IF(AFIN. GT. AMFIN)  AFIN=AMFIN
```

may be distributed differently which would result in different amounts of biomass being left below the minimum grazing height.

The digestibility curves are probably representative of their respective forage classes, but they may need to be changed if species composition changes. Adjustments to the digestibility curves, especially the lower levels, have a strong effect on gain.

APAL values may need to be adjusted depending upon species composition for the site being considered.

4.2.4 Calculations for Forage Intake

The fourth set of calculations determines the actual forage intake per category using information determined in the previous sets of calculations (DIGNR, AVDIG, APTC(I), ATWT) plus hunger as carried over from the previous day. This hunger interacts as follows:

Hunger from the previous day is found by adding the two variables ERR and HUNG. ERR is a value which represents the difference between desired forage intake (FINT) and available food (AX) if the available food was less than desired on the previous day. HUNG is a value which represents the difference between a maximum weight gain (2.25 lb.) and the gain realization the previous day. The reasoning and calculation of this are discussed in the section on determining weight gain in this chapter. The calculation of hunger (HUNGR) is a simple addition of HUNG + ERR, followed by two IF checks to keep hunger from becoming negative or from exceeding 1% of the animal's weight.

The amount of forage intake has been shown to increase as digestibility increases (see Fig. 4.6) (Church, 1971; Blaxter, Wainman, and Davidson, 1966; Hodgson and Wilkinson, 1968; R. W. Rice, personal communication). The average energy content of forage is taken to be 4 kcal/g. Total forage intake needed AFIN) is therefore obtained by dividing the energy needs in kilocalories by 4 to obtain the weight of forage needed to provide this energy. Division of this figure by average digestibility (AVDIG) ensures that due allowance is made for the indigestible fraction of forage and its nutrient content. This figure for intake is then multiplied by AFX which is the factor for increasing intake as digestibility increases (see Fig. 4.6 and 4.7). Finally HUNGR, representing unsatisfied hunger of the previous day, is added.

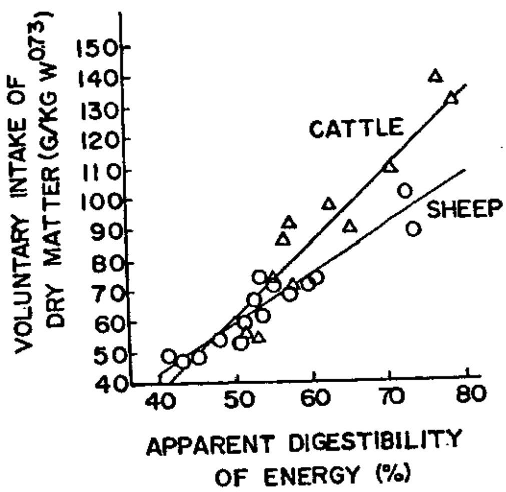

Fig. 4.6. The relation between apparent digestibility of energy of roughage or roughage mixtures and voluntary intake by sheep and cattle (from Blaxter et al., 1966).

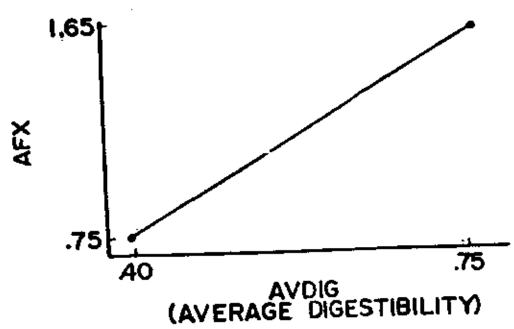

Fig. 4.7. ADVIG (average digestibility) (from Blaxter et al., 1966).

```
C...CALCULATE FORAGE DESIRED PER CATEGORY
      DO 60005 I=1,11
60005 FINT(I)= APTC(I) * AFIN
```

The calculated linear interpolation function (Fig. 7.4) is used to estimate the value of AFX which is then multiplied by forage intake to determine total intake desired (Fig. 4.7).

The calculation of total forage intake needed (AFIN) involves the above factors plus dividing DIGNR (energy needs) by 4 kcal. The literature values of energy content were all 4.0 or greater (Wallace and Denham, 1970; Cook, Stoddart, and Harris, 1954; Beck, 1969), thus the value 4.0 was chosen as a conservative estimate of the number of kilocalories per gram dry weight of forage.

The digestible energy required is divided by average digestibility to insure that intake includes fecal loss of nondigestible material.

An IF check then insures that AFIN does not exceed a maximum (TMAFN) of 4% of the animal's weight (K. B. Addison, personal communication).

The forage desired per plant category is determined by multiplying the preference tendency (APTC) by forage intake (AFIN).

(This space left blank intentionally.)

```
C
C...ARRANGE DESIRED FORAGE INTAKE IN ORDER OF PREFERENCE
      CALL GETS(FINT,INDX)
C
C...COMPARE FORAGE INTAKE / AVAILABILITY IN ORDER OF PREFERENCE--
C...FILL UNAVAILABLE CAT. FROM MORE PREFERRED AVAILABLE CAT.
      ERR=0.0
      DO 67704 I=1,11
      J=INDX(I)
      IF(FINT(J).GT.AX(J)) 67703,67704
67703 ERR=ERR+(FINT(J)-AX(J))
      FINT(J)=AX(J)
67704 CONTINUE
      IF(ERR. EQ. 0.0) GO TO 67709
      DO 67706 I=1,11
      J=INDX(I)
      IF(FINT(J).LT.AX(J)) 67705,67706
67705 FINT(J)=FINT(J)+ERR
      IF(FINT(J).LT.AX(J)) 67709,67708
67708 ERR=FINT(J)-AX(J)
      FINT(J)=AX(J)
67706 CONTINUE
      GO TO 67710
67709 CONTINUE
      ERR=0.0
67710 CONTINUE
```

Once the desired forage intake (FINT) per plant category has been determined, it is necessary to check this against the amount available (AX). Should the amount available be less than the amount desired for any category, the unfulfilled desire will then be filled from a more preferred category, if possible. Thus, subroutine GETSET is called to rank the FINT's in order of preference. These are then compared in order of preference against the appropriate AX's. Should there be any unfulfilled desired intake, the FINT's are changed to fill the desire from some more preferred category. Should there be insufficient amounts available to fill all FINT's, then the unfilled amount is carried to the next day as ERR, to be added to HUNG.

The FINT's represent the actual amount of material moved for their respective flows, and at this point they are carried to the main program for determination of these flows [e.g., (02-40) (F = FINT(1))]. The variable APERN is intake as percent of body weight. It is used to check the rate of intake and is an output variable.

Adjustments:

1. ERR. No adjustment is provided.

   HUNG. See section on determining weight gain or loss in this chapter. One may want to omit HUNG for other consumer types where weight gain is not as well known. This deletion will necessitate adjusting the AFX function.

2. An increase of intake with digestibility is not true for all animals. In rabbits, for example, the opposite is apparently true (A. Johanningsmeier, personal communication). For omnivores there is a shift in diet which is accounted for in the ADIG portion

(40-01).

```
FLOW = ARESP
```

(40-42).

```
FLOW = AURIN
H4042 = FLOW*DT
```

(40-45).

```
FLOW = AFECE
H4045 = FLOW*DT
```

of the APTC calculations, and in carnivores digestibility is relatively constant. Thus, for omnivores and carnivores AFX may be deleted.

3. The calorific value of the food will need to be changed for other consumers. For example, it is 4.0 to 4.5 for herbivores, 4.5 to 5.0 for an omnivore such as the grasshopper mouse, and 4.0 for carnivores. The proportion of seeds in the diet is the important factor here since seeds may have calorific values as high as 6 kcal/g (Kendeigh and West, 1965).

4. Maximum consumption as a percentage of body weight is quite variable depending on the animal species. There may be a relationship between maximum consumption and metabolic weight, but it has not been identified.

5. No adjustment is suggested for food utilization.

4.3 STEER METABOLISM (40-01)(40-42)(40-45)

The rate of loss or transfer of material via gas, urine, feces, activity, and respiration are calculated in this section. The final calculation of respiration is determined in the weight gain or loss section in this chapter. Many of the values and rates used in this section are based on Cook (1970).

(This space left blank intentionally.)

```
C
C...RINT=REAL FORAGE INTAKE
      RINT=AFIN-ERR
      APERN = RINT/X(40)


C...STEER METABOLISM
C
      GAS = .07 * RINT * AVDIG
      AURIN = .07 * RINT * AVDIG
      AFECE=RINT-(AVDIG*RINT)
C...ACTIVITY INCREASES WITH DECREASED FORAGE BIOMASS
      ATX=CLI(150.,0.0,0.0,6.,ATFB)
      IF(ATX .LE. 0.0)ATX=0.0
      IF(ATX .GT. 6.0) ATX = 6.0
      ACT  = .00015  * X(40) * (1.8 + ATX)
```

Food lost via gas, urine, and feces are all functions of real intake (RINT) and digestibility (AVDIG). Gas and urine losses are each considered to be 7% of the digestible intake, while fecal material is the nondigestible intake.

Food utilized in activity is a function of distance traveled and animal weight (Van Dyne and Van Horn, 1965). Other activities such as chewing, lying down, getting up, etc., not considered herein, are probably of lesser importance. Distance traveled increases from a minimal distance as food biomass decreases. The minimal distance is here considered to be 1.8 km, and the food biomass-travel relationship (ATX) is determined from the linear relationship shown in Fig. 4.8.

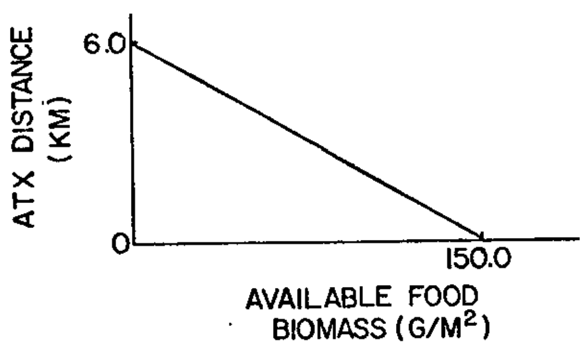

Fig. 4.8. Available food biomass.

The distance traveled is, thus, a sum of 1.8 and ATX. Average distance simulated for spring and summer are very nearly the same as those given by Cook (1970).

The amount of energy required per unit activity (ACT) is dependent upon body weight and slope of terrain. Brody (1945) suggests that range cattle use 33 to 35 kcal of net energy per 100 lb. of live weight for walking a mile in the process of grazing on rather level terrain. Information presented by

Blaxter (1962) suggests that it requires about 0.1 kcal to move 100 lb. of live weight 1 ft vertically. Data from Clapperton (1964) agree with these calculations rather closely. Thus, if a 100-lb. animal walked a mile ascending a 2% slope, the required kilocalories would be calculated as follows: (2) · (5,280 ft per mile/100) · (0.1 kcal) + 33 kcal = 43.6 kcal (Cook, 1970). Since animals generally move down a slope in a gentle manner by traversing the incline on a slight angle of descent or by zigzagging down steep terrain, it was believed practical to treat the energy required to descend as distance traveled increased. For example, 43.6 kcal/100 lb. live weight per mile of travel corresponds to .0006 kcal/g live weight/km. This divided by 4 kcal/g of food equals .00015 g food used in travel per gram live weight per kilometer.

Respiratory loss is a function of basal metabolism as influenced by temperature, activity, and gain or loss of weight. To determine the food used in respiration the digestible energy required (DIGNR), calculated above, is divided by 8 (4 kcal/g of food multiplied by 2, the factor used to determine total needs from basal metabolism). The remaining portion of material allocated to respiration is a function of gain or loss in weight.

Adjustments:

1. Feces and urine calculations are apparently about the same for most consumers. The actual water content of small desert mammal urine is lower, but the energy content is about the same. The percent used for gas is appropriate for herbivores, but should be close to zero for omnivores and carnivores.
2. Activity in cattle is primarily spent in travel. In smaller mammals activity is a more general function, and adjustments for

```
C*************************************************************
C          DETERMINE GAIN(AGAIN) AND CARRYOVER HUNGER(HUNG)
C
      IF(ATWT .LT. 600.) 68977, 68978
68977 AZT = 2.25
      GO TO 68979
68978 AZT = 1.75
68979 CONTINUE
      HUNG = 0.0
      ATGAN = (AZT * 453.59 * ANUM * 1.945)/(ACRES * 4047.)
      ADUM = RINT - AFECE- AURIN - ACT  - GAS - (DIGNR/8.)
      IF(ADUM .GT. 0.0) 68980, 68981
68980 AGAIN = ((ADUM/1.945)* ACRES * 4047.)/(ANUM * 453.59)
      ARESP=(DIGNR/8.)+GAS+ACT +ADUM-(ADUM/1.945)
      HUNG = ATGAN - ADUM
      GO TO 68982
68981 ARESP=(DIGNR/8.)+GAS+ACT -(ADUM/3.)
      AGAIN = ((ADUM*.66666) * ACRES * 4047.)/(ANUM * 453.59)
      HUNG = ABS(ADUM) + ATGAN
68982 CONTINUE
      IF(ADUM .GT. ATGAN) HUNG = 0.0
C
      GO TO 67712
66001 DO 60001 I=1,11
60001 FINT(I)=0.0
      ATWT = 486.
      AGAIN = 0.0
      AURIN=AFECE=ARESP=0.0
67712 CONTINUE
```

seasonal changes may be necessary. Because the multiplier ATX is a function of available food biomass, this scale may need to be readjusted where aboveground biomass is distributed differently from that at the Pawnee Site.

3. No adjustment is suggested for respiration.

4.3.1 Determine Weight Gain (AGAIN) and Accumulated Hunger (HUNG) (40-01)

To determine the gain or loss of weight, real intake is partitioned as nondigestible material: lost as feces (AFECE) and nonmetabolizable material and lost as gas (GAS) and urine (AURIN) and metabolizable material. The metabolizable material is used first to satisfy maintenance, and the remainder is then available for conversion to new animal tissue. Should maintenance exceed metabolizable intake, then respiration includes the metabolism of weight loss.

To determine if there is a gain or loss of weight, the variable ADUM is calculated as follows:

$$ADUM = RINT - AFECE - AURIN - GAS - ACT - (DIGNR/8.0)$$

where

RINT = real intake

If ADUM is positive, it is divided by 1.945 to obtain the animal's real weight gain. The value 1.945 is derived from the figures: 7.78 kcal is needed to gain 1 g of weight, and 1 g of forage yields 4 kcal of energy (G. M. Van Dyne, personal communication). The material lost in this conversion is added to respiration to give a total respiration value (ARESP):

$$ARESP = (DIGNR/8.0) + GAS + ACT + ADUM - (ADUM/1.945)$$

The amount of gain (AGAIN) per animal in pounds is

$$AGAIN = ((ADUM/1.945) \cdot ACRES \cdot 4047.0)/(ANUM \cdot 453.59)$$

where

ANUM = number of animals

Should ADUM become negative, this indicates a loss in weight. To determine the real loss, the weight loss must be converted from its base of 4 kcal/g of food to 6 kcal/g animal (G. M. Van Dyne, personal communication). The energy differential is thus compensated by subtracting one-third of the apparent loss to obtain the real weight loss. The amount of loss (-AGAIN if AGAIN < 0.0) per animal in pounds is obtained as shown:

$$ARESP = (DIGNR/8.0) + GAS + ACT - (ADUM/3.0)$$

$$AGAIN = ((ADUM \cdot 0.6666) \cdot ACRES \cdot 4047.0)/(ANUM \cdot 453.59)$$

The role of hunger is also considered in this portion of the model. It was reasoned that within the limits of maximum intake (0.04 · body weight), the animal's hunger would not be satisfied until an excess intake above maintenance requirements occurred. The smaller this excess, the more quickly the animal will become hungry and resume feeding. Young animals (less than 600 lb.) will utilize the intake more quickly than more adult animals (over 600 lb.) because of their greater activity and growth rate. For any given time period, then, the amount of hunger to be carried to the next period would be the difference between the real excess food available for gain and the amount of excess food necessary to keep the animal from getting hungry in that time period. Because this excess food is used as gain, it was decided to identify a feasible daily rate of gain (AZT) and calculate hunger from this. The rates chosen were 2.25 lb./day in young animals (less than 600 lb.) and 1.75 lb./day in older animals. AZT is converted to grams per square meter and is stored in the variable ATGAN.

If ADUM is positive, ADUM is subtracted from ATGAN, and the difference is carried to the next day as HUNG. Should ADUM be negative, ATGAN is added to ADUM to equal HUNG. Should ADUM exceed ATGAN, HUNG equals 0.

At this point AURIN, ARESP, and AFECE represent the actual amount of material moved for their respective flows and are carried to the main program for determination of these flows [e.g., (40-01) (F = ARESP)].

Adjustments:

1. The value used for converting excess food to weight gain is variable depending on energy content of food (i.e., herbivores 7.78/4.0 = 1.95; omnivores 7.78/4.7 = 1.66; granivores 7.78/5.0 = 1.56.
2. The energy involved in weight loss is likely to be uniform for mammals. Thus, probably no adjustment will be needed.
3. The rate of gain (AZT) may require adjustment at other sites.

4.4 OUTPUT

The following graphs are samples of output from this section of the model. The phenology curves [APHEN(1-11)] are shown because of their important influence on preference (APTC) and digestibility. AVDIG (average digestibility of ingested food) influences forage intake [FINT(I)] and gas, urine, and fecal losses. ATWT (animal total weight in pounds) and

AGAIN (amount of gain or loss per animal) are shown as they represent the final results of this section.

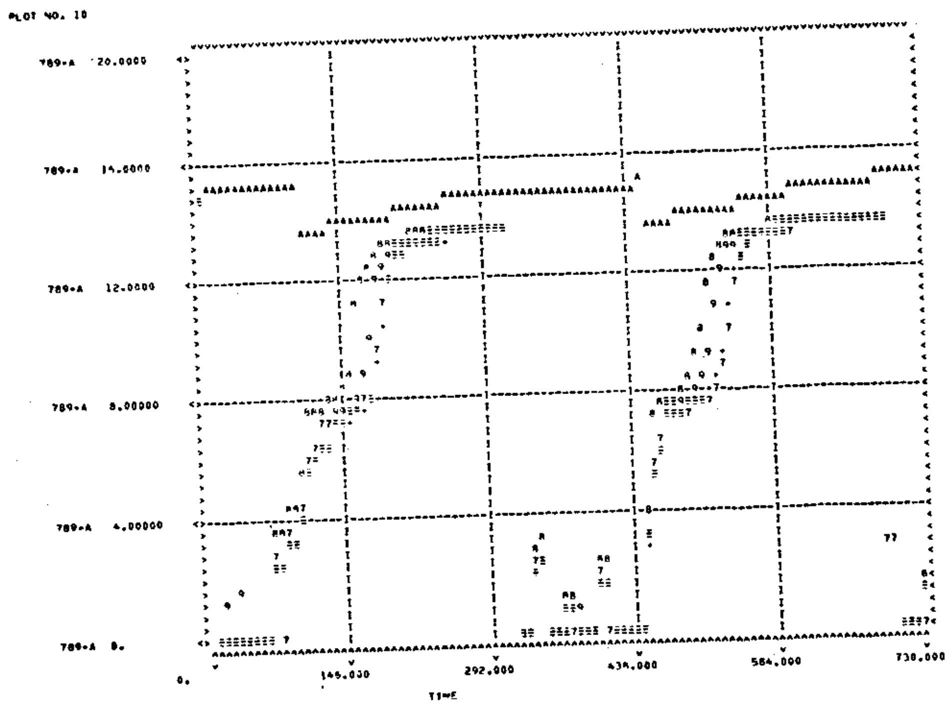

Fig. 4.9. Phenological index for aboveground live for 2 years.

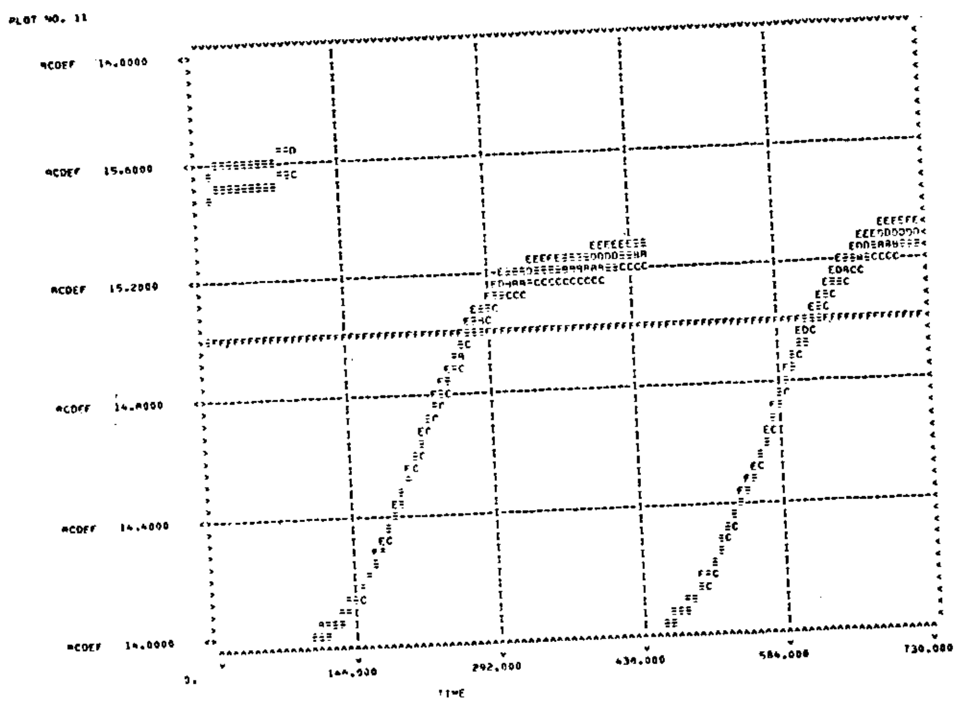

Fig. 4.10. Phenological index for aboveground standing dead for 2 years.

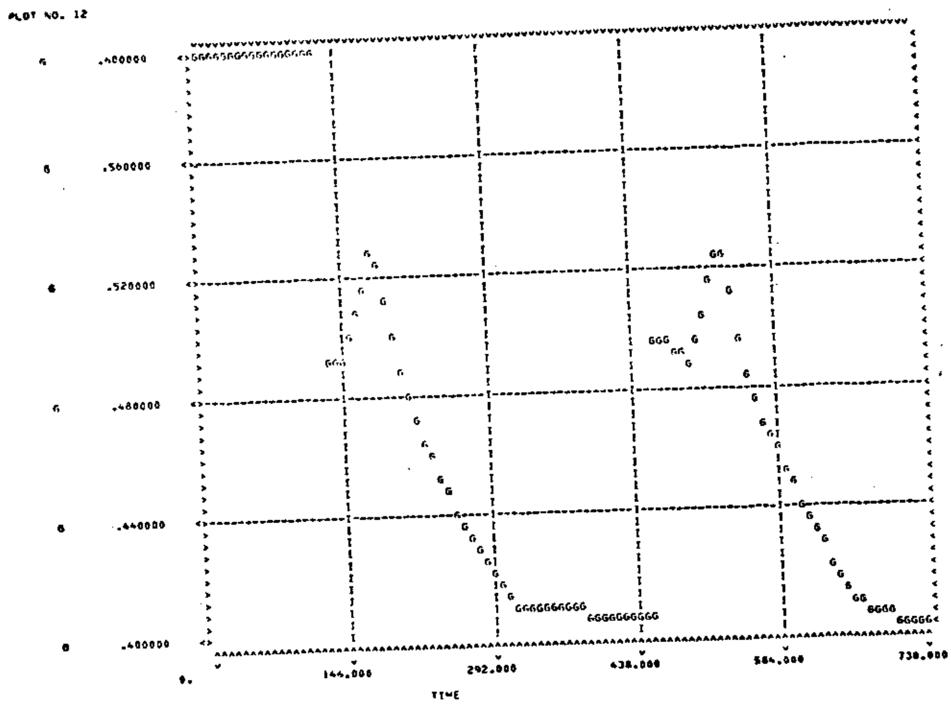

Fig. 4.11. Average digestibility of intake for 2 years.

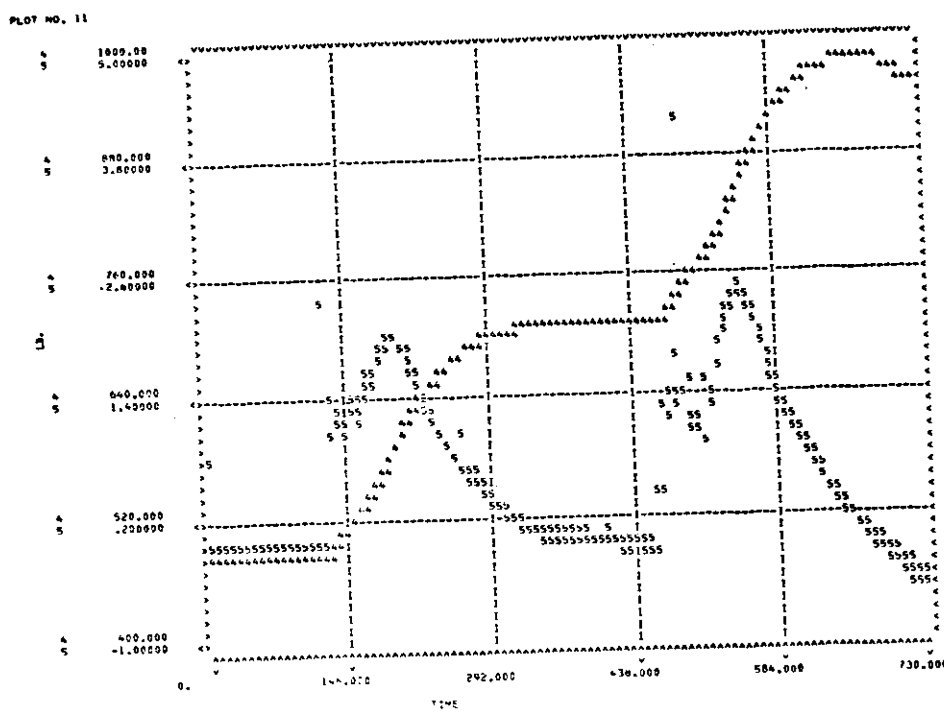

Fig. 4.12. Animal total weight (4) and ratio of gain in pounds (5) for a full 2 years.

4.5 LITERATURE CITED

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CHAPTER 5. DECOMPOSER SECTION

5.1 INTRODUCTION

In this section of ELM decomposition is represented by the flow of material from the litter, feces, and belowground dead compartments to the microbe compartments (see Fig. 5.1). These flows are controlled by the temperature and moisture in the various layers and by the initial nitrogen content of the material. Microbial biomass increases through the assimilation of a fixed proportion of decomposed material and decreases through respiration, the rate of which depends on temperature. Respiration is represented in Fig. 5.1 by the flows from microbes to atmospheric carbon dioxide.

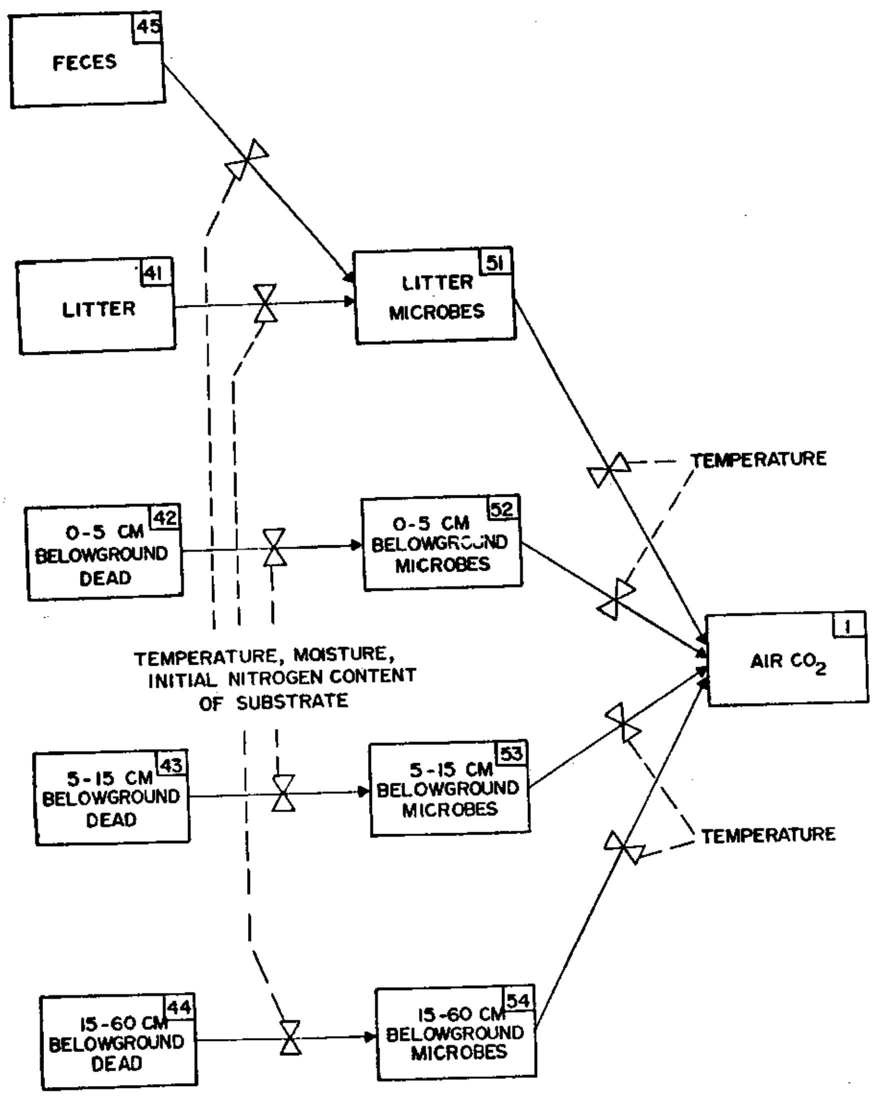

Fig. 5.1. The decomposer submodel.

5.2 THE EFFECT OF NITROGEN

Minderman (1968) pointed out that the course of decomposition of a complex material cannot, in general, be represented by an exponential function, but that perhaps individual components of the material might show exponential decay. This suggestion has been incorporated into ELM as follows. Materials to be decomposed are considered to consist of two components:

1. "hard" or slowly decomposing substances, such as cellulose and lignin, and
2. "soft" or rapidly decomposing substances, such as proteins and simple sugars.

The hard components of all plant materials are assumed to decompose at the same rate, and similarly for soft substances. The proportion of either hard or soft material decomposing per unit time in a given layer is taken as the product of three factors: a function of moisture (see section on "The Effect of Moisture"), a function of temperature (see section on "The Effect of Temperature"), and a rate coefficient which is greater in the case of soft material. Thus, the model corresponds, under constant conditions, to exponential decay at different rates for the hard and the soft components. The utility of this approach was tested by an analysis of data (Pinck, Allison and Sherman, 1950) on decomposition of various plant materials at constant temperature and moisture. The initial carbon/nitrogen ratio (C/N) and lignin content of the materials were given along with the amount present after 1½, 4, and 12 months. The following model was applied to this data.

$$A(t) = So \cdot e^{-ks \cdot t} + (1 - So)e^{-kh \cdot t} + \text{error} \qquad (5.1)$$

where

$A(t)$ = proportion of material remaining after t days

t = time in days

So = proportion of soft component at time $t=0$

e = base of natural logarithms

ks = rate constant for the soft component

kh = rate constant for the hard component

The method of least-squares was used to estimate the three parameters So, ks, and kh. Regression analysis revealed that the estimates of So, but not of kh or ks, are significantly related to C/N and to lignin content. Inclusion of lignin content and C/N simultaneously in a regression does not explain significantly more variability than either variable alone. The following expression is employed to predict So from C/N (transformed to $\sqrt[3]{N/C}$).

$$So = 1.348 \sqrt[3]{N/C} - 0.0216 \qquad (5.2)$$

$$R^2 = .85,\ P < .001.$$

Thus, if we are given the nitrogen content of a material, we can, by predicting a single parameter (So), explain to a considerable degree the time course of its decomposition under constant conditions.

The nitrogen content of plant material can be predicted from its phenological stage (see Chapter 3, Producer Section). These predictions are based on the data of Wallace (1969) and are given in Fig. 5.2.

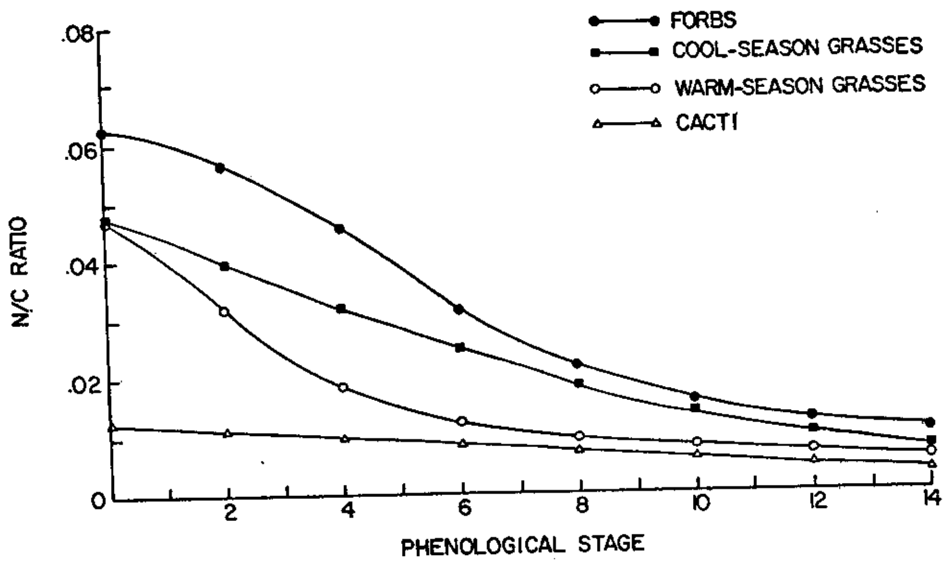

Fig. 5.2. The relationship between phenological stage and the nitrogen to carbon ratio.

Floate (1970) measured the rates of decomposition of four plant materials and of the feces of sheep fed the materials. The above model (equation 5.1) has been applied to his data to obtain estimates of So, kh, and ks. For the plant materials, the relationships among the three parameters and $\sqrt[3]{N/C}$ are the same as discussed above for the data of Pinck et al. (1950); that is, only So is significantly related to $\sqrt[3]{N/C}$, and So accounts for much of the variation in the dynamics of decomposition. For feces, however, none of the three parameters are significantly related to $\sqrt[3]{N/C}$ or to each other. The estimates of So are less variable for feces (0.06 to 0.12) than for the plant material (0.13 to 0.46), so a value of 0.08 for So for cattle feces has been assumed. The ks and kh parameters are about half as great for feces as for the plant materials, so feces must be treated separately from litter in the model. Since the assimilation efficiency of grasshoppers is less than that of cattle, grasshopper feces probably decompose more readily than cattle feces. Therefore, grasshopper feces are assumed to be 50% soft.

Implementation of the hard-soft distinction is made with variables for the proportion of soft material in the various compartments. These subscripted variables are designated as HSK(J) where K is a one- or two-digit number and J is a one-digit number. HSK(J) gives the proportion of soft material in compartment K+J. For example, HS1(1) is the proportion of soft in compartment 2. Similarly, HS11(3) refers to compartment 14, HS19(4) to 23, and HS40(5) to 45.

The amount of material flowing into compartments 41 to 45 is calculated in the producer and consumer sections. Variables for the amount of material flowing into compartments 41 to 45 from various sources are designated HWXYZ (the flow from compartment WX to YZ). For example, H1242 is the amount flowing per day (Δt) from compartment 12 to 42. The producer section does not divide belowground live material into depth layers, so the total flow from belowground live to belowground dead must be apportioned among the three belowground dead compartments. This is done by creating variables (HKJXX) representing the total flow from compartment KJ to the belowground dead compartments. For example, H12XX is the total flow per day from compartment 12 to the belowground dead compartments. The flows from compartments 12 to 16 to compartments 42 to 44 are divided as in Fig. 5.3 (numbers from R. H. Sauer, personal communication). These variables appear in the coding for the producer and consumer flows.

```
C...COMPUTE NITROGEN TO CARBON RATIO FROM PHENOLOGICAL STAGE
C...AND SOFT COMPONENT FROM N/C FOR INPUTS TO LITTER FROM
C...ABOVEGROUND LIVE COMPARTMENTS
      HS1(1)= ATANF(1.5,0.035691,0.069032,-0.12,PHEN(1))
      HS1(2) = ATANF(3.0,0.03591,0.09663,-0.04,PHEN(2))
      HS1(3) = ATANF(5.0,0.03878,0.07268,-0.1,PHEN(3))
      HS1(4) = ATANF(5.0,0.03878,0.07268,-0.1,PHEN(4))
      HS1(5) = 0.0123 - 0.000664 * PHEN(5)
      DO 20074 K = 1,5
20074 HS1(K) = -0.0216 + 1.348 * HS1(K) ** 0.333
```

Belowground Live Compartment	Proportion of Total Flow Going to Compartments		
	42	43	44
12 Warm-season grasses	.22	.45	.33
13 Cool-season grasses	.22	.45	.33
14 Forbs	.12	.24	.64
15 Shrubs	.11	.22	.67
16 Cacti	.20	.42	.38

Fig. 5.3. The proportions of the flows from belowground live compartments going to the belowground dead compartments.

Each flow to compartments 41 to 45 must be divided into a hard and soft component. For flows from compartments 2 to 6 (aboveground live), the N/C ratio is predicted from phenological stage (see Fig. 5.2) and the proportion of soft from N/C (see equation 5.2). In the model arc tangent functions are employed to represent the curves of Fig. 5.2. Flows from compartments 20 to 25 (standing dead) are assumed to consist of 21% soft for warm-season and cool-season grasses, 25% soft for forbs and shrub leaves, 0.0% for wood, and 17% for cacti. Roots are assumed to be 10% soft for forbs, shrubs, and cacti. Cattle feces are assumed to be 8% soft, and grasshopper feces 50% soft.

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```
C...CALCULATE THE LOSSES OF THE HARD AND SOFT COMPONENTS FROM THE
C...BELOWGROUND DEAD AND LITTER COMPARTMENTS
      DO 20064 K=1,4
      K1 = 40 + K
      HSO40(K) = X(K1) * HETMP(K) * HMOIS(K) * HS40(K) * HKSP
20064 HHO40(K) = X(K1) * HETMP(K) * HMOIS(K) * (1.0 - HS40(K))*HKHP
      HSO40(5) = X(45) * HETMP(1) * HMOIS(1) * HS40(5) * HKSF
      HHO40(5) = X(45) * HETMP(1) * HMOIS(1) * (1.0 - HS40(5)) * HKHF
C...CALCULATE THE GAINS OF HARD AND SOFT MATERIALS TO THE LITTER AND BELOWGROUND
C...DEAD COMPARTMENTS
      HSI40(1) = H0241*HS1(1) + H0341*HS1(2) + H0441*HS1(3)
     1 + H0541*HS1(4) + H0641*HS1(5) + H2041*HS19(1)+H2141*HS19(2)
     1 + H2241*HS19(3) + H2341*HS19(4) + H2441*HS19(5) + H2541*HS19(6)
     2 + H3541 * 0.5
      HHI40(1) = H0241 + H0341 + H0441 + H0541 + H0641 + H2041 + H2141
     1 + H2241 + H2341 + H2441 + H2541 - HSI40(1)  + H3541
      HSI40(2) = H1242*HS11(1) + H1342*HS11(2) + H1442*HS11(3)
     1 + H1542*HS11(4) + H1642*HS11(5)   + H4042
      HHI40(2) = H1242 + H1342 + H1442 + H1542 + H1642 - HSI40(2)+H4042
      HSI40(3) = H1243*HS11(1) + H1343*HS11(2) + H1443*HS11(3)
     1 + H1543*HS11(4) + H1643*HS11(5)
      HHI40(3) = H1243 + H1343 + H1443 + H1543 + H1643 - HSI40(3)
      HSI40(4) = H1244*HS11(1) + H1344*HS11(2) + H1444*HS11(3)
     1 + H1544*HS11(4) + H1644*HS11(5)
      HHI40(4) = H1244 + H1344 + H1444 + H1544 + H1644 - HSI40(4)
      HSI40(5) = 0.08 * H4045        + 0.5*H3545
      HHI40(5) = 0.92 * H4045  + 0.5*H3545
```

Each time the state variables are updated, the proportion of soft in each of compartments 41 to 45 must be updated according to the flows of hard and soft material into and out of the compartments. Variables for these flows are of the form HXY40(K). Here X = S for the soft component, and X = H for the hard component. Y = Ø (Ø = letter O and 0 = zero) for flows out of the compartment, and Y = I for flows into the compartment. K takes a value of 1 to 5 for compartments 41 to 45. Thus HSØ40(3) is the flow per unit time of soft material out of compartment 43. These variables are assigned values near the end of subroutine CYCL1. The flows out correspond to the amount of decomposition and are calculated as the product of the amount of material in the compartment, the proportion hard or soft, the temperature factor, the moisture factor, and a constant (the value of which depends on whether the calculation is for the hard or soft component and whether it is for feces or for plant material). The flows into compartments 41 to 45 are merely the sums of flows calculated in the producer and consumer sections. Of course, these flows are split into a hard and soft component as discussed above.

The proportion of soft material in compartments 41 to 45 is updated in each cycle according to the following scheme. The proportion of soft material in a compartment at time $t+\Delta t$ equals the amount of soft material at time $t+\Delta t$ divided by the total in the compartment at time $t+\Delta t$. The amount of soft material at time $t+\Delta t$ is the amount at time t plus the amount of soft material flowing in between t and $t+\Delta t$ and minus the amount of soft material flowing out during that interval. The amount of soft material at time t is the proportion soft at time t multiplied by the total at time t. The total at time t is the total at time $t+\Delta t$ minus the flows in (between

```
      SUBROUTINE CYCL2
C...UPDATE THE PROPORTION SOFT MATERIAL ACCORDING TO THE FLOWS
C...INTO AND OUT OF THE LITTER AND BELOWGROUND DEAD COMPARTMENTS
      HSI40(2) = HSI40(2) + H4142
      HSO40(1) = HSO40(1) + H4142
      DO 20066 K=1,5
      K2 = 40 + K
      IF(X(K2).EQ.0.0)20066,20067
20067 HS40(K)=((HSI40(K)-HSO40(K))*DT+HS40(K)*(X(K2)+(-HSI40(K)-
     1HHI40(K)+HSO40(K)+HHO40(K))*DT))/X(K2)

20066 CONTINUE

C...CALCULATE THE LOSSES OF THE HARD AND SOFT COMPONENTS FROM THE
C...BELOWGROUND DEAD AND LITTER COMPARTMENTS
      DO 20064 K=1,4
      K1 = 40 + K
      HSO40(K) = X(K1) * HETMP(K) * HMOIS(K) * HS40(K) * HKSP
20064 HHO40(K) = X(K1) * HETMP(K) * HMOIS(K) * (1.0 - HS40(K))*HKHP
      HSO40(5) = X(45) * HETMP(1) * HMOIS(1) * HS40(5) * HKSF
      HHO40(5) = X(45) * HETMP(1) * HMOIS(1) * (1.0 - HS40(5)) * HKHF
```

times t and t+Δt) of hard and soft materials and plus the flows out of hard and soft materials during the interval. These relations are encoded in subroutine CYCL2. Note that in CYCL2 the state variables have been updated, but the flows for the next time interval have not yet been computed, so X(K2) corresponds to the total amount present at time t+Δt in the discussion above. HS40(K) on the right-hand side of the statement is the proportion soft at time t, and HS40(K) on the left-hand side is the proportion soft at time t+Δt. The variables for the flows of hard and soft components into and out of compartments 41 to 45 are appropriate for the time interval t to t+Δt. The above calculation is performed for each of the state variables 41 to 45.

5.3 THE EFFECT OF MOISTURE

The effect of moisture on the rate of decomposition enters as a multiplicative factor in the calculation of the amount of material flowing from the substrate compartments (41 to 45) to the microbe compartments (51 to 54).

The form of the moisture factor (HMØIS) as a function of the percentage (by volume) of water in the soil is derived from the data of Bhaumik and Clark (1947). They give peak rates of CO_2 evolution at six different moisture tensions for five different soils. The peak rate of CO_2 evolution, plotted against water tension, gives very similar curves for all but a very sandy soil. Averaging the data points for the four least sandy soils and normalizing to make the peak rate equal to one gives the curve in Fig. 5.4. Moisture tension is given in terms of the fourth root of bars. This arbitrary transformation was made to facilitate graphical representation. HMØIS is set to zero at 1.97 (= $\sqrt[4]{15}$) on the assumption that decomposition ceases near the wilting point, which is taken as -15 bars.

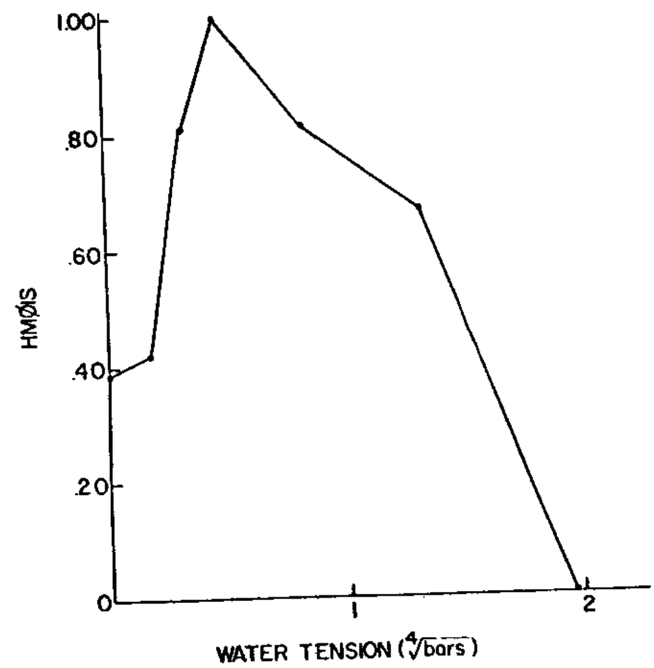

Fig. 5.4 The relationship between water tension and the moisture factor (HMØIS).

The water content of the soil is given here as an amount, not a water tension. To apply the model to a given soil, a moisture release curve is used in conjunction with Fig. 5.4 to find the relationships between the percentage water in the soil and HMØIS (the moisture factor). Applying the moisture release curve for the Ascalon sandy loam of the Pawnee Site (Van Haveren and Galbraith, 1971) results in the relationship between HMØIS and percentage water given in Fig. 5.5.

```
      SUBROUTINE CYCL1
C...CALCULATE THE EFFECT OF MOISTURE ON THE RATE OF DECOMPOSITION
      HMOI(2) = SMOS(1) / 5.
      HMOI(3) = (SMOS(2) + SMOS(3)) / 10.
      DO 20002 K = 2,3
      HMO = HMOI(K)
      IF(HMO.LT.0.064)20000,20001
20000 HMOIS(K) = 0.0
      GO TO 20002
20001 IF(HMO.LT.0.10)20003,20004
20003 HMOIS(K) = -1.191 + 18.61 * HMO
      GO TO 20002
20004 IF(HMO.LT.0.28)20005,20006
20005 HMOIS(K) = 0.488 + 1.83 * HMO
      GO TO 20002
20006 IF(HMO.LT.0.45)20040,20041
20040 HMOIS(K) = 1.0
      GO TO 20002
20041 HMOIS(K) = 2.3725 - 3.05 * HMO
20002 CONTINUE
      HMOIS(1) = HMOIS(2)
      HMO = (SMOS(4) + SMOS(5) + SMOS(6)) / 45.
      IF(HMO.LT.0.093)20042,20044
20042 HMOIS(4) = 0.0
      GO TO 20046
20044 IF(HMO.LT.0.129)20048,20050
20048 HMOIS(4) = -1.7308 + 18.61111 * HMO
      GO TO 20046
20050 IF(HMO.LT.0.32)20052,20054
20052 HMOIS(4)=.447 + 1.73 * HMO
      GO TO 20046
20054 IF(HMO.LT.0.45)20056,20058
20056 HMOIS(4) = 1.0
      GO TO 20046
20058 HMOIS(4) = 2.37 - 3.05 * HMO
20046 CONTINUE
```

Note that HMØIS is a subscripted variable (see facing page). The variable with subscript 1 controls the flows from compartments 41 and 45 to 51, that with subscript 2 controls the flow from 42 to 52, that with subscript 3 controls the flow from 43 to 53, and that with subscript 4 controls the flow from 44 to 54. The coding for the HMØIS factors represents a series of straight-line equations corresponding to Fig. 5.5. HMØIS(4) is related to soil water by a different function than HMØIS(2) and HMØIS(3) because the moisture release curves are different for soil from different depths (Van Haveren and Galbraith, 1971).

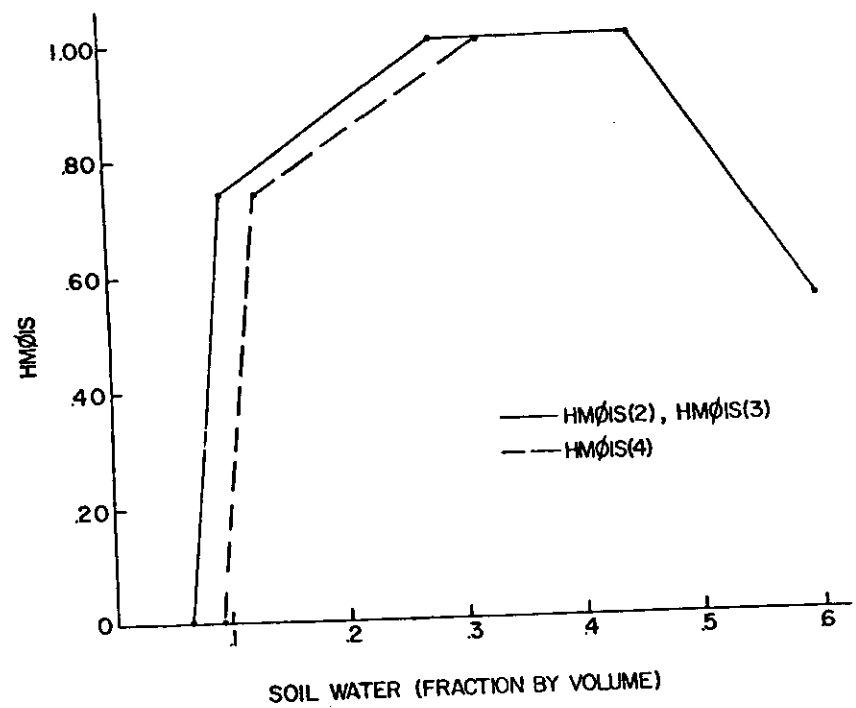

Fig. 5.5. The relationship between soil water and the effect of moisture (HMØIS).

Algebraically, the moisture functions are as follows. For HMØIS(2) and HMØIS(3):

$$HM\emptyset IS = \begin{cases} 0.0 & \text{if } HM\emptyset < 0.064 \\ -1.19 + 18.6\cdot HM\emptyset & \text{if } 0.064 \le HM\emptyset < 0.10 \\ 0.488 + 1.83\cdot HM\emptyset & \text{if } 0.10 \le HM\emptyset < 0.28 \\ 1.0 & \text{if } 0.28 \le HM\emptyset < 0.45 \\ 2.37 - 3.05\cdot HM\emptyset & \text{if } 0.45 \le HM\emptyset \end{cases}$$

where

HMØ = proportion of water by volume in the 0 to 5 cm soil layer for HMØIS(2) and the 5 to 15 cm soil layer for HMØIS(3)

For HMØIS(4):

$$HM\emptyset IS = \begin{cases} 0.0 & \text{if } HM\emptyset < 0.093 \\ -1.73 + 18.6\cdot HM\emptyset & \text{if } 0.093 \le HM\emptyset < 0.13 \\ 0.447 + 1.73\cdot HM\emptyset & \text{if } 0.13 \le HM\emptyset < 0.32 \\ 1.0 & \text{if } 0.32 \le HM\emptyset < 0.45 \\ 2.37 - 3.05\cdot HM\emptyset & \text{if } 0.45 \le HM\emptyset \end{cases}$$

where

HMØ = water content of the 15 to 60 cm layer

HMØIS(1) is set equal to HMØIS(2); that is, it is assumed that the decomposition rate of litter depends on the moisture of the top soil layer.

5.4 THE EFFECT OF TEMPERATURE

The effect of temperature (HETMP) on the rate of decomposition enters as a multiplicative factor in the calculation of the amount of material flowing from the substrate compartments (41 to 45) to the microbe compartments (51 to 54).

```
      FUNCTION HEFT(HT)
C...CALCULATES THE EFFECT OF TEMPERATURE ON THE RATE OF DECOMPOSITION
      IF(HT.LE.40.0.AND.HT.GT.0.0)20014,20016
20014 HEFT = EXP(-5.9132 + 0.31887*HT - 0.004357*HT*HT)
      GO TO 20015
20016 IF(HT.LE.0.0.OR.HT.GE.45.)20017,20018
20017 HEFT = 0.0
      GO TO 20015
20018 HEFT = 9.0 - HT/5.0
20015 RETURN
      END
```

HETMP is related to the temperature in degrees centigrade (HT) by

$$HETMP = e^{(-5.9 + 0.32\ HT - 0.0044\ HT^2)} \qquad (5.4)$$

This curve (Fig. 5.6) is similar to the one reported by Kucera and Kirkham (1971) for CO_2 evolution in a grassland soil, but predicts a lower rate near 10°C and a higher rate near 30°C. The form of the temperature function employed here was chosen to improve the fit of the model to field experiments performed by Clark (1970, and personal communication) on the decomposition of hay in a grassland soil.

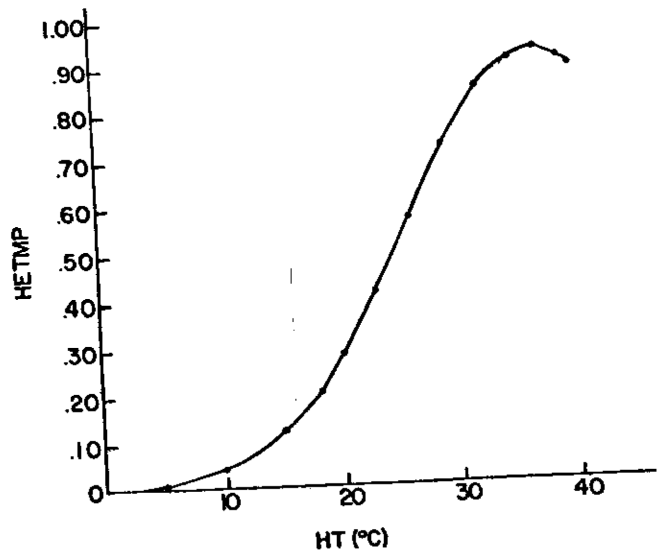

Fig. 5.6. The relationship between temperature (HT) and the effect of temperature (HETMP).

Function HEFT embodies the relationship of Fig. 5.6 and equation 5.4. HETMP is a subscripted variable, there being a temperature factor for the litter layer and for each soil layer. The abiotic section herein provides estimates of the maximum, mean, and minimum canopy temperature (TMAX, SA, and TMIN) and of mean temperature in the soil at 15-cm depth increments. By

```
C...CALCULATE THE EFFECT OF TEMPERATURE ON THE RATE OF DECOMPOSITION
      HETMP(1) = HEFT(TMAX)/4. + HEFT(SA)/2. + HEFT(TMIN)/4.
      HETMP(2) = HEFT(TMAX - SB/4.)/4. + HEFT(SA)/2.
     1 + HEFT(TMIN + SB/4.)/4.
      HETMP(3) = HEFT(SAVTP(2))
      HETMP(4) = HEFT(SAVTP(3))
```

```
C...LEACHING IS REPRESENTED BY THE FLOW OF SOFT MATERIAL FROM THE LITTER TO
C...THE BELOWGROUND DEAD.  A 2.5 CM RAIN IN A DAY WILL LEACH THE MAXIMUM AMOUNT-
C...10 PCT.

        IF(RAIN.GT.2.5)20100,20101
20100 FLOW = 0.1 * X(41) * HS40(1)
      GO TO 20102
20101 FLOW = 0.1 * X(41) * HS40(1) * RAIN / 2.5
20102 H4142 = FLOW*DT
```

assuming that the temperature of litter and feces is equal to canopy temperature and that the temperature is at its maximum one-fourth of the day, at average one-half of the day, and at minimum one-fourth of the day, a weighted average of the effect of temperature (HETMP(1)) is calculated. A similar weighted average for the 0 to 5 cm layer is based on the observation (Whitman, 1969, Fig. 1) that at 5 cm, the daily range in temperature is about half the range in the canopy (SB). Since daily temperature variation decreases with depth, the effect of temperature in the 5 to 15 and the 15 to 60 cm soil layers may be predicted from the mean temperature at 15 cm and at 30 cm (SAVTP(2) and SAVTP(3), respectively).

5.5 LEACHING (41-42)

Leaching of material from litter is represented by the flow of the soft component of compartment 41 (litter) to compartment 42 (belowground dead, 0 to 5 cm). It is assumed that a rainfall of 2.5 cm or more in a day will leach 10% of the soft component. A lighter rain will leach out proportionately less material (see Fig. 5.7).

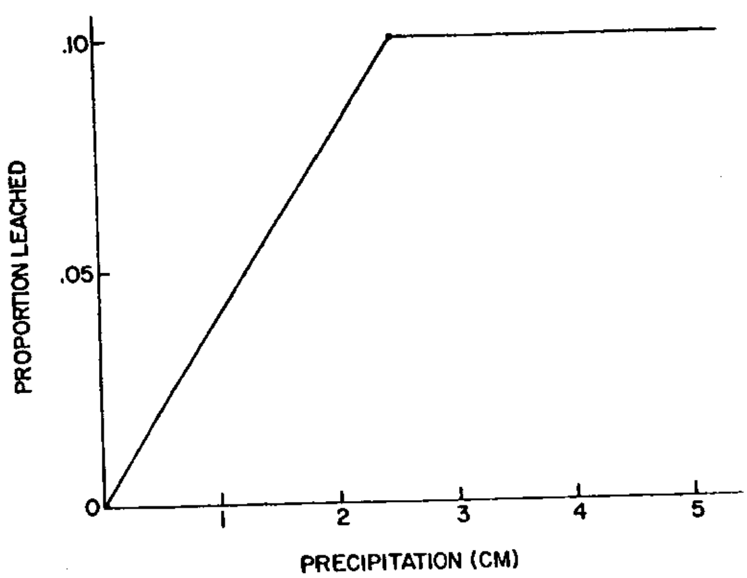

Fig. 5.7. The proportion of the soft component of litter leached by precipitation.

```
C...MAINTENANCE ENERGY REQUIREMENT (GRAMS SUBSTRATE PER DAY)
C...IS A FUNCTION OF TEMPERATURE
      HMER(1) = (HMAIN (TMAX+273.)/4. + HMAIN (SA+273.)/2.
     1 + HMAIN (TMIN+273.)/4.) * X(51)
      HMER(2) = (HMAIN (TMAX+273. - SB/4.)/4. + HMAIN (SA+273.)/2.
     1 + HMAIN (TMIN+273.+ SB/4.)/4.) * X(52)
      HMER(3) = HMAIN (SAVTP(2) + 273. ) * X(53)
      HMER(4) = HMAIN (SAVTP(3) + 273. ) * X(54)
```

(41-51).

```
                    FLOW =   HSO40(1) + HHO40(1)
```

(42-52).

```
                    FLOW = HSO40(2) + HHO40(2)
```

(43-53).

```
                    FLOW = HSO40(3) + HHO40(3)
```

(44-54).

```
                    FLOW = HSO40(4) + HHO40(4)
```

(45-51).

```
                    FLOW = HHO40(5) + HSO40(5)
```

```
      FUNCTION HMAIN(HT)
C...CALCULATES THE EFFECT OF TEMPERATURE ON THE MAINTENANCE ENERGY REQUIREMENT
C...OF MICROBES
      HMAIN  = 2.51 * EXP(-10000./HT + 32.24)
      RETURN
      END
```

5.6 MAINTENANCE ENERGY REQUIREMENT OF MICROBES

Microbial biomass increases through the assimilation of decomposing material and decreases through the requirement of energy for maintenance. It is assumed that when the availability of material for growth exceeds the maintenance energy requirement (MER), microbes conform to the generalization (Odum, 1971) that ecological growth efficiencies often equal 20%; that is, 20% of decomposed material is converted into microbes and 80% into CO_2.

MER is assumed to depend on temperature according to the Arrhenius equation. Marr, Nilson, and Clark (1963) found that the MER of *Escherichia coli* has a temperature characteristic of about 20 kcal/mole. Therefore MER and the absolute temperature (T) are related by

$$MER = k \cdot e^{-10,000/T}$$

where k is a constant. Schulze and Lipe (1964) give the MER of *E. coli* at 30°C as 1.32 g glucose/g cell weight per day, from which k may be found to equal 2.51×10^{14}. Thus,

$$MER = 2.51 \cdot e^{32.24 - 10,000/T} \tag{5.5}$$

The units of the MER in equation 5.5 are grams substrate per gram microbes per day. Function HMAIN calculates the MER as a function of absolute temperature (equation 5.5). The MER's of the litter microbes and 0 to 5 cm soil layer microbes are functions of the maximum, mean, and minimum temperatures in the canopy and at the 5-cm soil level; these are predicted as discussed above for the calculation of the effect of temperature on decomposition rate. The MER's of the 5 to 15 cm and the 15 to 60 cm

(51-1).

```
      HIN = HS040(1) + HH040(1)    + HH040(5) + HS040(5)
      IF(HMER(1).GT.HIN)20080,20082
20082 FLOW =HECEF* HIN
      GO TO 20108
20080 HCHNG = HMER(1) - HIN
      HMAXLOS = HMAXL * X(51)
      IF(HCHNG.GT.HMAXLOS)20104,20106
20104 FLOW = HMAXLOS  + HIN
      GO TO 20108
20106 FLOW = HMER(1)
20108 H5101 = FLOW*DT
```

(52-1).

```
      HIN = HS040(2) + HH040(2)
      IF(HMER(2).GT.HIN)20083,20084
20084 FLOW =HECEF* HIN
      GO TO 20114
20083 HCHNG = HMER(2) - HIN
      HMAXLOS = HMAXL * X(52)
      IF(HCHNG.GT.HMAXLOS)20110,20112
20110 FLOW = HMAXLOS  + HIN
      GO TO 20114
20112 FLOW = HMER(2)
20114 H5201 = FLOW*DT
```

(53-1).

```
      HIN = HS040(3) + HH040(3)
      IF(HMER(3).GT.HIN)20086,20087
20087 FLOW =HECEF* HIN
      GO TO 20120
20086 HCHNG = HMER(3) - HIN
      HMAXLOS = HMAXL * X(53)
      IF(HCHNG.GT.HMAXLOS)20116,20118
20116 FLOW = HMAXLOS   + HIN
      GO TO 20120
20118 FLOW = HMER(3)
20120 H5301 = FLOW*DT
```

(54-1).

```
      HIN = HS040(4) + HH040(4)
      IF(HMER(4).GT.HIN)20089,20090
20090 FLOW =HECEF* HIN
      GO TO 20126
20089 HCHNG = HMER(4) - HIN
      HMAXLOS = HMAXL * X(54)
      IF (HCHNG.GT.HMAXLOS)20122,20124
20122 FLOW = HMAXLOS   + HIN
      GO TO 20126
20124 FLOW = HMER(4)
20126 H5401 = FLOW*DT
```

layer microbes are functions of the average temperature at 15 and 30 cm, respectively. Equation 5.5 gives the MER on a per gram basis. This must be multiplied by the total biomass to find the total MER.

Clark and Paul (1970) pointed out that the rate of energy fixation in grasslands may be insufficient to maintain the observed standing crop of microbes, if published estimates of the MER are accepted. Apparently, many of the microbes present at a given time are inactive. In ELM when the MER exceeds the influx of material from decomposing substrates, the microbial biomass decreases, but the decrease is not allowed to exceed .0001 Δt of the microbial biomass per Δt. This restriction involves the assumption that microbes become inactive under conditions poor for growth.

5.7 ADAPTING THE MODEL TO OTHER GRASSLAND SITES

Many of the relationships in the decomposer section were tailored specifically for the Pawnee (Intensive) Site. Only in the case of the effect of soil water on the rate of decomposition (HMØIS) are the required alterations obvious. A moisture release curve (by layers) for the soil of the site in question is used in conjunction with Fig. 5.4 to obtain a graph of HMØIS against soil water by volume (as in Fig. 5.5). The application of the model to decomposition experiments done at the site would facilitate the identification of the required alterations, particularly in the HMØIS factor. This is accomplished by setting the initial value of the appropriate state variable (litter for surface experiments, belowground dead for burials) equal to that used in the experiment. All flows to the litter or belowground dead compartment should be to a dummy state variable in order to avoid continuous input (decomposition experiments generally consist of a single input at time zero). The climatological variables observed during the course of the experiment should be used to drive the model. The initial value of the proportion soft depends on the material buried and is calculated as above. Departures of the model output from the observed data are then examined along with plots of the temperature, moisture, HETMP, and HMØIS appropriate to the experiment. This procedure may suggest alterations required in the relationship between soil water and HMØIS and between temperature and HETMP. For example, if the experimental data suggest that decomposition ceases when soil water falls below 10%, HMØIS can be made to equal zero under these circumstances.

Site-specific soil factors such as organic matter content probably affect the rate of decomposition. For this reason, the rate constants for the hard and soft components of plant materials (HKHP and HKSP) and feces (HKHF and HKSF) may require change. However, the ratios among these variables should probably remain unaltered.

The assumptions on the ecological efficiency of microbes and on their respiratory rate under various conditions are candidates for alteration, but it is not obvious how site-specific factors should determine the direction of the change.

Data will probably not be available to make site-specific relationships between N/C and phenological stage or between the soft component (So) and $\sqrt[3]{N/C}$. But note that the above two relationships are based on limited data and certainly can be refined. A computer program for applying the decomposition model of equation 5.1 to decomposition experiments is available.

The assumption about the division of belowground live (and dead) among soil layers (Fig. 5.3) can probably be adjusted to fit data for particular sites.

5.8 OUTPUT

The following graphs are output from the decomposer section. They were generated during the run reported in Chapter 9.

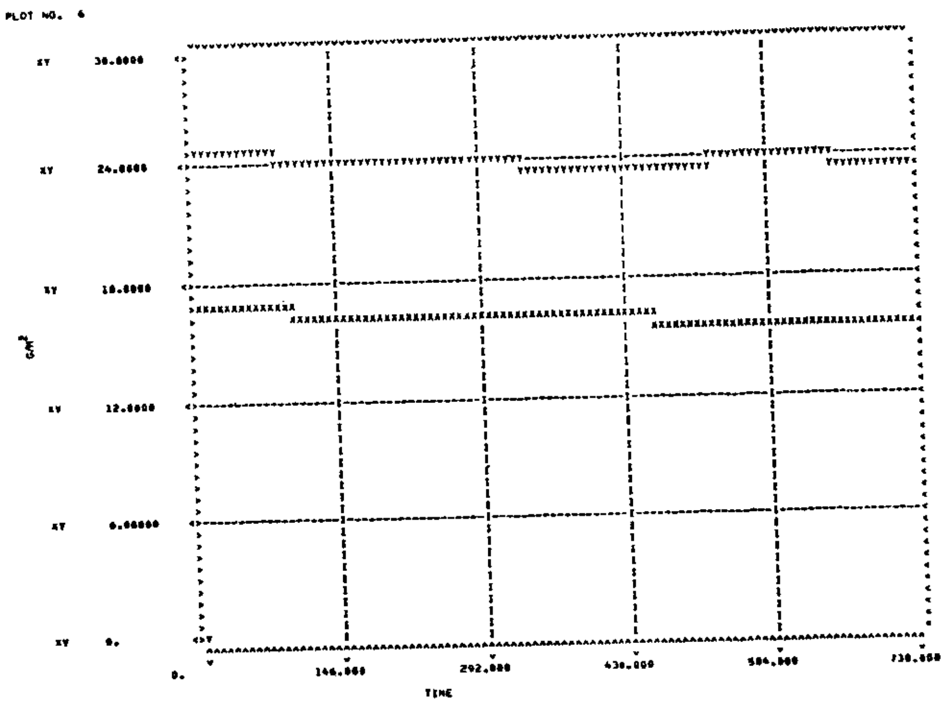

Fig. 5.8. X = biomass of litter layer microbes [X(51)] and
Y = biomass of microbes [X(51) + X(52) + X(53) + X(54)].

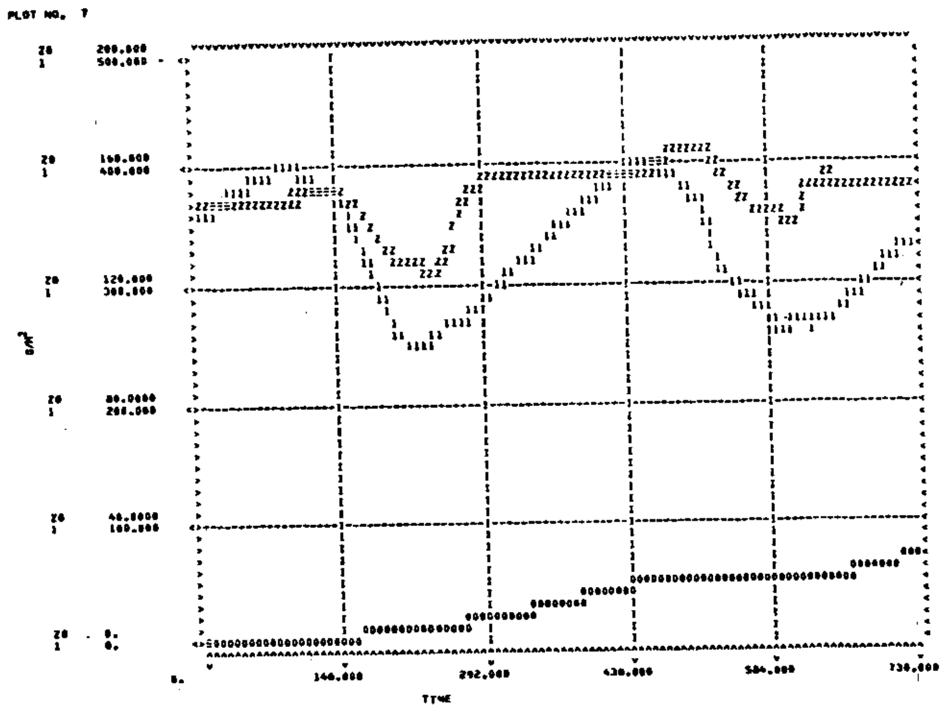

Fig. 5.9. Z = litter [X(41)], 0 = feces [X(45)], and
1 = belowground dead [X(42) + X(43) + X(44)].

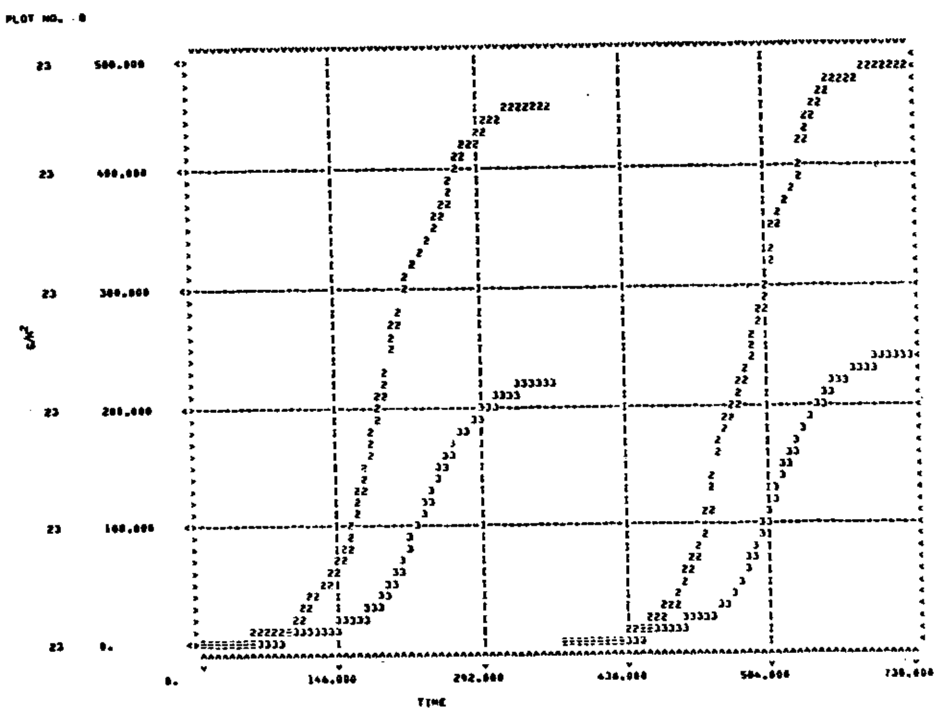

Fig. 5.10. 2 = cumulative carbon dioxide from microbes and
3 = cumulative carbon dioxide from roots.

5.9 LITERATURE CITED

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CHAPTER 6. NUTRIENT SECTION

6.1 INTRODUCTION

There are two nutrient submodels in this section of the current model. These are shown diagrammatically in Fig. 6.1 and 6.2. For simplicity, Fig. 6.1 (Nitrogen) and 6.2 (Phosphorus) show the same components as being represented in the cycles of these two nutrients. However, the similar components in the two submodels are given different state variable numbers as a modelling expedience. Also, the roles of the several components may be quite different from the phosphorus model to the nitrogen model.

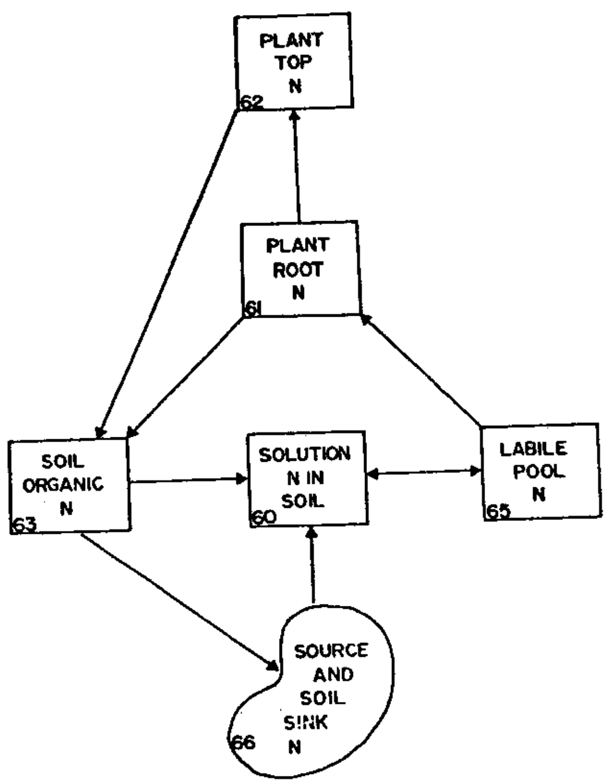

Fig. 6.1 Nitrogen submodel.

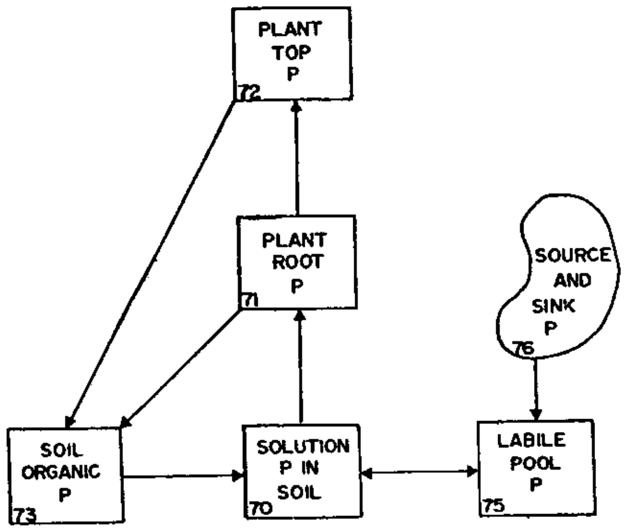

Fig. 6.2. Phosphorus submodel.

There are several fundamental points that need to be made concerning these models. First of all, these are submodels as parts of an overall systems model. It is not expected that they are to stand on their own. Rather, they are derived and incorporated solely as we deem necessary for the achievement of the overall modelling objectives. It is recognized that these cycles have been greatly simplified as they are represented in Fig. 6.1 and 6.2. However, it is believed that the simplified submodels are suitable for the objectives specified earlier. Secondly, although we have attempted to make the nutrient submodels "mechanistic," lack of information regarding the operational mechanisms, particularly with respect to the interaction of the nutrient and biotic components of the system, has resulted in incorporation of a number of empirical data into these segments of the model. It is in these interactions between the biotic components and the nutrient sections that we are perhaps as near the frontier of biological knowledge of the ecosystem dynamics as in any of the portions of the model. This is, of course, reflected in the modelling activity.

In each of these submodels the solution pool is the one which is available to the plant. This pool is generally quite small and must be replenished rapidly if it is not to become depleted. For each submodel the source of replenishment on a long-term basis is the soil organic material. On a short-term basis, however, the equilibrium between the labile pool and the solution pool serves as an immediate source of nutrient. The nutrients are translocated upwards in the plant as a function of the relative biomass of the roots and tops as well as the amount of nutrient present. From both the root and top material the nutrients are cycled back into the soil organic matter via the death process. Some of the aboveground material is cropped by herbivores and later returns to the soil organic matter. The release of nutrients from the soil organic pool is the decomposition process. This process is difficult to study and is represented here in a largely empirical way.

6.2 NITROGEN SUBMODEL

The state variables represented in the nitrogen submodel are the following:

X(60) = solution nitrogen in the soil (g/m^2)

X(61) = nitrogen in the plant roots (g/m^2)

X(62) = nitrogen in the plant tops (g/m^2)

X(63) = soil organic nitrogen (g/m^2)

X(64) = nitrogen present in herbivores (g/m^2)

X(65) = labile pool of nitrogen (g/m^2)

X(66) = atmospheric source and soil sink for nitrogen (g/m^2)

(60-65).

```
THETA=X(98)/60.0
F    = (X(60)-X(65)*P6560/P6065*THETA)/DT
FLOW=F
```

The following initial values are used in this model:

FNSR = 0.0624 = starvation level of nitrogen for the plant represented as the ratio of plant nitrogen to plant biomass

FNCIP = 0.03 = ratio of nitrogen to plant biomass maintained in the living plant tissue

P6065 = 100.0 = transfer coefficient from X(60) to X(65)

P6560 = 1.0 = transfer coefficient from X(65) to X(60)

P6360 = .0002 = transfer coefficient from X(63) to X(60)

X(62) = FNCIP · Aboveground Biomass

X(61) = FNCIP · Belowground Plant Biomass

The reader is cautioned that this nitrogen model is very preliminary. It is patterned after the phosphorus model, presented later, with only small changes to reflect the different pool sizes and flow dynamics. Work is currently underway to markedly improve this section of the model.

6.2.1 Movement of Nitrogen Between the Solution Pool and the Labile Pool (60-65)

This flow is essentially an equilibrium between the concentration of nitrogen in the soil solution and the labile nitrogen in the soil. Therefore, the flow can occur in either direction, i.e., from X(60) to X(65) or from X(65) to X(60), depending on the relative amounts in the two pools. The flow is a function of the average amount of soil water in the top 60 cm of soil and the concentration in the solution and labile pools.

Adjustments: The transfer coefficients (P6065 and P6560) may have to be adjusted for soil type.

(61-62).

```
      F=0.0
      TEMP=X(2)+X(3)+X(4)+X(5)+X(6)
      F1=X(62)/TEMP
      IF (F1 .GT. FNCIP) 70004, 70005
70005 F=(FNCIP-F1)/DT*TEMP
70004 CONTINUE
      FLOW=F
```

(61-63).

```
      F=FNNIP*RDR
      FLOW=F
```

(62-63).

```
      F=FNCIP*TDR
      FLOW=F
```

6.2.2 Movement of Nitrogen from the Plant Roots to the Plant Tops (61-62)

The flow of nitrogen from the plant roots to the plant tops is simply designed to maintain a constant concentration of nitrogen in the plant tops (FNCIP = 0.01). If the ratio of nitrogen in the tops to total plant top biomass falls below FNCIP, the flow makes up the difference between them. If the ratio is equal to or greater than FNCIP, no flow takes place.

6.2.3 Movement of Nitrogen from the Plant Roots to the Soil Organic Matter (61-63)

The loss of nitrogen from the roots to the soil organic nitrogen is a function of the nitrogen content in the roots (FNCIP) times the root death rate (RDR). It is assumed that each of the plant groups has the same nitrogen content. The root death rate factor is computed by summing the individual death rates for each of the plant groups. For more details on root death rates refer to flows (12-42), (13-42), (14-42), (15-42), and (16-42) in the Producer Section (page 98).

6.2.4 Movement of Nitrogen from the Plant Tops to the Soil Organic Matter (62-63)

The flow from plant tops to soil organic nitrogen is essentially the same as flow (61-63). The flow is equal to the concentration of nitrogen in the plant tops (FNCIP) multiplied by the plant top death rate (TDR). Again, it is assumed that each plant group has the same nitrogen content. The death rate is calculated by summing the top death rates over all of the plant groups. TDR's are explained in flows (2-20), (3-21), (4-22), (5-23), (5-24), and (6-25) in the Producer Section (page 96). Notice that the

(63-60).

```
F=P6360*X(63) * G(X(90)) * SF(X(98))
SMOGG = SMOGG + F*DT
FLOW=F
```

nitrogen in the plant tops is released directly into the soil organic pool on plant death and that no nitrogen is bound up in the standing dead and litter. Most certainly the submodel would be more realistically represented by cycling the nitrogen through the standing dead and litter categories.

6.2.5 Movement of Nitrogen from the Soil Organic Matter to the Solution Pool (63-60)

The release of soil organic nitrogen to the available pool of solution nitrogen is closely tied to the decomposition of belowground material. This flow depends on the amount of soil organic nitrogen [X(63)], soil temperature [X(90)], and soil water [X(98)]. The relationship of the G function with soil temperature is an exponential one where the function G(X(90)) can vary from 0.04 to about 3.5 as X(90) goes from 0°C to 30°C (Fig. 6.3).

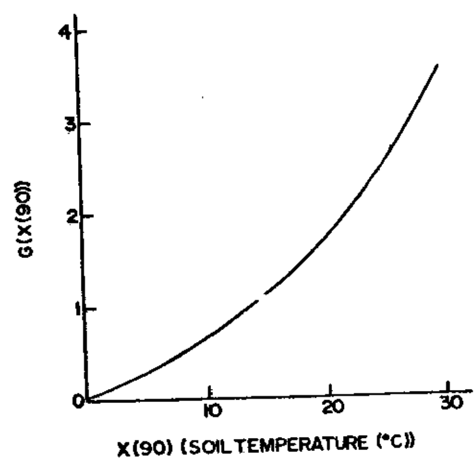

Fig. 6.3. Relationship of the movement of nitrogen from the soil organic matter to the solution pool to soil temperature.

X(90) is the average soil temperature from the surface to a depth of 60 cm. The relationship of the SF function to X(98) can take on values for SF(X(98)) ranging from 0.0 to 2.0 as soil water goes from 0.0 to 15.0 cm of water in

(63-66).

```
 F = 0.1/365.
FLOW=F
```

the top 60 cm of soil. The curve of this function is sigmoid in shape such that soil water greater than 15.0 cm of water causes little increase in the flow. Likewise, soil water less than 7.0 cm causes little additional decrease (Fig. 6.4).

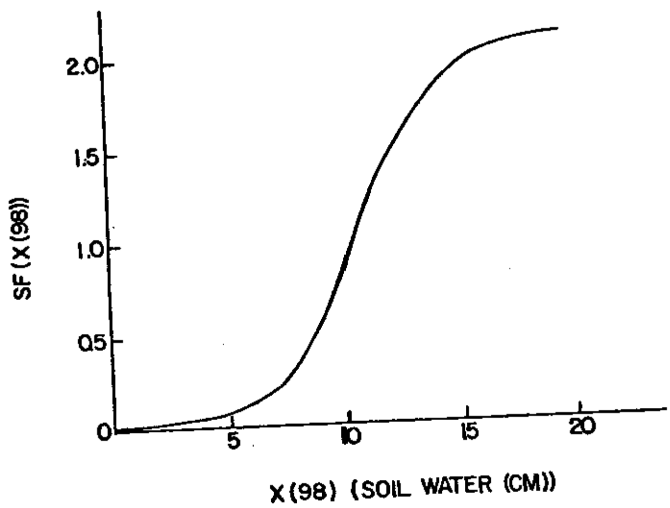

Fig. 6.4. Relationship of the movement of nitrogen from the soil organic matter to the solution pool to soil water.

Adjustment: The transfer coefficient (P6360) may have to be adjusted for soil type.

6.2.6 Movement of Nitrogen from the Soil Organic Matter to the Soil Sink (63-66)

The flow of soil organic nitrogen to the soil sink is included to account for the removal of NO_2 and NO_3 from the system by denitrifying bacteria.

(65-61).

```
       TEMP = X(12)+X(13)+X(14)+X(15)+X(16)
       PC = X(60)/X(98)
       RU=(.27E-5/(1.+1.43/PC)+.6E-6/(1.+.084/PC))
       THETA=X(98)/60.0
       IF(THETA.LE..09)50002,50003
 50002 RPU=0.0
       GO TO 50004
 50003 IF(THETA.GE..28)50005,50006
 50005 RPU=1.0
       GO TO 50004
 50006 RPU = 5.37 * THETA - .505
 50004 CONTINUE
       FLOW = RU*RPU*TEMP
```

6.2.7 Movement of Nitrogen from the Labile Pool by the Live Roots (65-61)

The purpose of having a flow from the labile pool to the plant roots is to eliminate the problem of high turnover rate in the solution pool. In other words, because the amount of nitrogen in the solution pool is small and the uptake rate high, occasionally the uptake by the roots will be greater than the amount available to it in a given time step. The reason there will not be enough nitrogen present, in terms of the implementation within the framework of the model, is that the time increment for the running model is usually 1 day. The adjustment of the nitrogen level only once each day, then, may not be enough to keep up with the demand. The problem of having a negative value in X(60) (solution nitrogen in the soil) is eliminated by allowing nitrogen to flow directly from the labile pool.

The flow is directly related to the rate of uptake (RU), the relative nitrogen uptake (RNU), and the live root biomass (TEMP). The rate of uptake is determined by the concentration of nitrogen in the soil solution (PC). As the nitrogen concentration increases, the rate of uptake increases as shown in Fig. 6.5. Actually the amount of nitrogen in soil solution is directly related to the soil water so the fraction X(60)/X(98) remains fairly constant. Therefore, as soil water increases, so does the nutrient uptake.

(66-60).

```
        F=.4/40.0* RAIN
       IF (RAIN .GT. 5.0) GO TO 70000
       GO TO 70001
70000  F = (RAIN - 5.0) * 0.004 - F
70001  CONTINUE
       FLOW=F
```

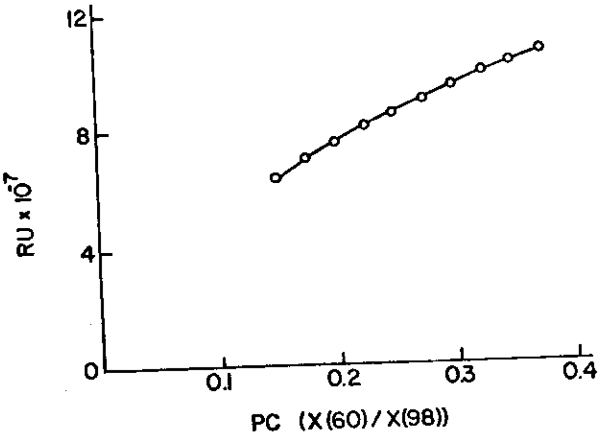

Fig. 6.5. Relationship of the rate of uptake to the concentration of nitrogen in the soil solution.

The relative nitrogen uptake varies linearly from 0.0 to 1.0 as a function of the volumetric water content (THETA) which varies from 0.09 to 0.28 (these values were determined by C. V. Cole from Watanabe, Olsen, and Danielson, 1960).

Adjustment: The THETA values in the IF checks will have to be adjusted to suit the soil type. Those used are for Apishapa soil.

Note that the rate of uptake (RU) will not vary with soil type (Watanabe et al., 1960).

6.2.8 Movement of Atmospheric Nitrogen to Soil Solution Nitrogen (66-60)

The flow of nitrogen in the atmosphere to solution nitrogen in the soil resulting from fixation by lightning is related directly to the amount of daily rainfall (RAIN). The flow will amount to the fraction RAIN/40.0 of 0.4 g/m^2. In other words, if the yearly rainfall amounts to 40.0 cm/year, 0.4 g N/m^2 will enter the soil solution from this source. The 0.4 g N/m^2 per year is an estimate obtained by Reuss (1971). However, if the daily precipitation should exceed 5 cm/day, there is a leaching of nitrogen into the soil sink at the rate of 0.004 g/m^2 per centimeter for each centimeter of moisture over 5 cm. Under circumstances where the daily precipitation does exceed 5 cm/day, the net flow is always from X(60) to X(66).

6.3 PHOSPHORUS SUBMODEL

The state variables represented in the phosphorus submodel are the following:

X(70) = solution phosphorus in the soil (g/m^2)

X(71) = phosphorus in plant roots (g/m^2)

X(72) = phosphorus in plant tops (g/m^2)

X(73) = soil organic phosphorus (g/m^2)

X(75) = labile pool of phosphorus (g/m^2)

X(76) = source and soil sink for phosphorus (g/m^2)

The following initial values are used in this submodel:

FPSR = 0.006 = starvation level of phosphorus for the plant represented as the ratio of plant phosphorus to plant biomass

FCPIP = 0.00105 = ratio of phosphorus to the plant biomass maintained in the living plant tissue

PHRI = 0.001 = this represents the amount of phosphorus (g/m^2) that will flow from X(76) to X(75) as the result of daily rainfall if the yearly rainfall amounts to 40.0 cm

(70-75).

```
 THETA = X(98)/60.
TEMP1 = X(75)*P7570*THETA/P7075
F = (X(70) - TEMP1)/DT
FLOW=F
```

(71-72).

```
      F=0.0
      TEMP=X(2)+X(3)+X(4)+X(5)+X(6)
      F1=X(72)/TEMP
      IF (F1 .GT. FCPIP) 71004,71005
71005 F=(FCPIP - F1)/DT*TEMP
71004 CONTINUE
      FLOW=F
```

$P7075 = 2.0 \times 10^{-4}$ = transfer coefficient from X(70) to X(75)

$P7570 = 5.0 \times 10^{-6}$ = transfer coefficient from X(75) to X(70)

$P7370 = 0.2 \times 10^{-4}$ = transfer coefficient from X(73) to X(70)

$P7675 = 5.184 \times 10^{-7}$ = transfer coefficient from X(76) to X(75)

X(72) = FCPIP · Aboveground Plant Biomass

X(71) = FCPIP · Belowground Plant Biomass

The majority of the data from the phosphorus submodel has been supplied either directly or indirectly by C. V. Cole (USDA, Fort Collins, Colorado). A partial list of references used to develop the material to date includes Cole and Olsen (1959*a*,*b*), Barrow (1967), Olsen and Kemper (1968), and Olsen and Watanabe (1963, 1970).

6.3.1 Movement of Phosphorus Between the Solution Pool and the Labile Pool (70-75)

This flow is modelled as an equilibrium between the concentration of phosphorus in the soil solution and the labile phosphorus in the soil. The flow can occur in either direction, i.e., from X(70) to X(75) or from X(75) to X(70) depending on the relative levels in the two pools. The flow is a function of the average amount of soil water in the top 60 cm of soil and the concentration of phosphorus in the solution and labile pools.

Adjustment: The transfer coefficients (P7075 and P7570) may have to be modified to suit soil type.

6.3.2 Movement of Phosphorus from the Plant Roots to the Plant Tops (71-72)

The flow from the plant roots to the tops is very similar to the flow from soil solution phosphorus to the roots (70-71). Again, the flow is designed to keep a constant concentration of phosphorus in the plant. When

(71-73).

```
F=FCPIP*RDR
FLOW=F
```

(72-73).

```
F=FCPIP*TDR
FLOW=F
```

(73-70).

```
 F = P7370 * G(X(90)) * X(73) * SF(X(98))
FLOW=F
```

the level of phosphorus in the plant tops falls below this designated level (FCPIP), the flow returns the phosphorus concentration to the desired amount. If the phosphorus level in the tops is equal to or greater than FCPIP, no flow takes place.

6.3.3 Movement of Phosphorus from the Plant Roots to the Soil Organic Matter (71-73)

The flow of phosphorus from the roots to the soil organic material is a function of the phosphorus content in the roots (FCPIP) multiplied by the root death rate (RDR). It is assumed that each plant group has the same phosphorus concentration. RDR is the sum of the death rates for each of the plant groups. The death rates are a function of root biomass, a death rate coefficient, and the phenological stage of the plant group. The death rates are calculated in the Producer Section (page 98).

6.3.4 Movement of Phosphorus from the Plant Tops to the Soil Organic Matter (72-73)

The phosphorus flow from the plant tops to the soil organic matter is essentially the same as the flow from the roots. The flow is a function of the amount of phosphorus in the tops multiplied by the top's death rate (TDR). TDR is the death rate sum of each of the plant groups. For additional information on the calculation of TDR refer to the Producer Section (page 96) under flows (2-20), (3-21), (4-22), (5-23), (5-24), and (6-25).

6.3.5 Movement of Soil Organic Phosphorus to the Solution Pool (73-70)

The release of soil organic phosphorus to the available pool of solution phosphorus is in phase with decomposition since they are driven by the same functions. The flow depends on the amount of soil organic

(75-71).

```
      TEMP=X(12)+X(13)+X(14)+X(15)+X(16)
      PC=X(70)/X(98)
      RU=(.27E-5/(1.+1.43/PC)+.6E-6/(1.+.084/PC))
      THETA=X(98)/X(60)
      IF(THETA.LE..09)71006,71007
71006 RPU=0.0
      GO TO 71008
71007 IF(THETA.GE..28)71009,71010
71009 RPU=1.0
      GO TO 71008
71010 RPU=5.37*THETA-.505
71008 FLOW=RU*RPU*TEMP
```

phosphorus [X(73)], soil temperature [X(90)], and soil water [X(98)]. The relationship with soil temperature is an exponential one (see Fig. 6.3 in the nitrogen submodel) where the function G(X(90)) can vary from 0.04 to about 3.5 as X(90) goes from 0°C to 30°C. The function SF(X(98)) assumes values from 0.0 to 2.0 as the soil water goes from 0.0 to 15.0 cm water in the top 60.0 cm of soil. The curve of this function is sigmoid in shape such that soil water greater than 15.0 cm causes little increase in the flow. At the lower end of the curve, soil water less than 7.0 cm causes little additional decrease (see Fig. 6.4).

6.3.6 Movement of Phosphorus from the Labile Pool by the Live Roots (75-71)

The purpose of having the flow for live root uptake from the labile pool instead of the solution pool is to avoid the problem of high turnover rate in the solution pool. In other words, because the amount of phosphorus in the solution is small and the uptake rate is high, occasionally the uptake by the roots will be greater than the amount in the solution pool for a given time step (Δt). The reason for the inadequate amount of phosphorus is that the time increment for running the model is 1 day or greater ($\Delta t \geq 1$). The adjustment of the phosphorus level in solution only once each day may not be enough to satisfy root demand. In this case, the pool [X(70)] may become too small (or even become negative) in the model.

The flow is directly related to the rate of uptake (RU), the relative phosphorus uptake (RPU), and the live root biomass (TEMP). The rate of uptake is determined by the concentration of phosphorus in the soil solution (PC). As phosphorus concentration increases, the rate of uptake increases as shown in Fig. 6.5.

(76-75).

```
F=P7675 + PHRI / 40.0 * RAIN
FLOW=F
```

(98-99).

```
X(98)=SMOS(1)+SMOS(2)+SMOS(3)+SMOS(4)+SMOS(5)+SMOS(6)
F = 0.0
FLOW=F
```

The relative phosphorus uptake (RPU) varies linearly from 0.0 to 1.0 as the volumetric water content (THETA) varies from 0.09 to 0.28 (these values were supplied by C. V. Cole using Watanabe et al., 1960).

Adjustment: The THETA values in the IF checks (0.09 and 0.28) will need to be adjusted for soil type. Those reported here are for Apishapa soil. Note that the rate of uptake (RU) will not vary with soil type (Watanabe et al., 1960).

6.3.7 Movement of Phosphorus from the Atmosphere and Soil to the Labile Pool (76-75)

The flow of phosphorus from the atmosphere and soil to the labile phosphorus pool is a function of demineralization and daily rainfall. The process of demineralization is treated as a constant and is handled by the transfer coefficient P7675. The amount of phosphorus contributed to the labile pool by rainfall is equal to 0.001 g/m^2 for each 40.0 cm of precipitation. Any amount of rainfall less than or more than 40.0 cm will cause a proportionate amount of 0.001 g P/m^2 to move into the labile pool.

Adjustment: The transfer coefficient (P7675) may have to be modified to suit soil type.

6.4 FLOW FROM SOIL WATER TO ATMOSPHERIC MOISTURE (98-99)

This is a dummy flow for the purpose of calculating the soil water in the top 60 cm of soil [X(98)]. X(98) is used to determine the amount of the flow of a nutrient from organic matter to the solution pool [see flows (63-60) and (73-70)] and also to determine the equilibrium between X(60) and X(65) and between X(70) and X(75).

6.5 OUTPUT

Fig. 6.6 illustrates the dynamics of three compartments of the nitrogen submodel. Fig. 6.7 illustrates the dynamics of the same compartments of the phosphorus submodel. The graphs were generated during the simulation run reported in Chapter 9.

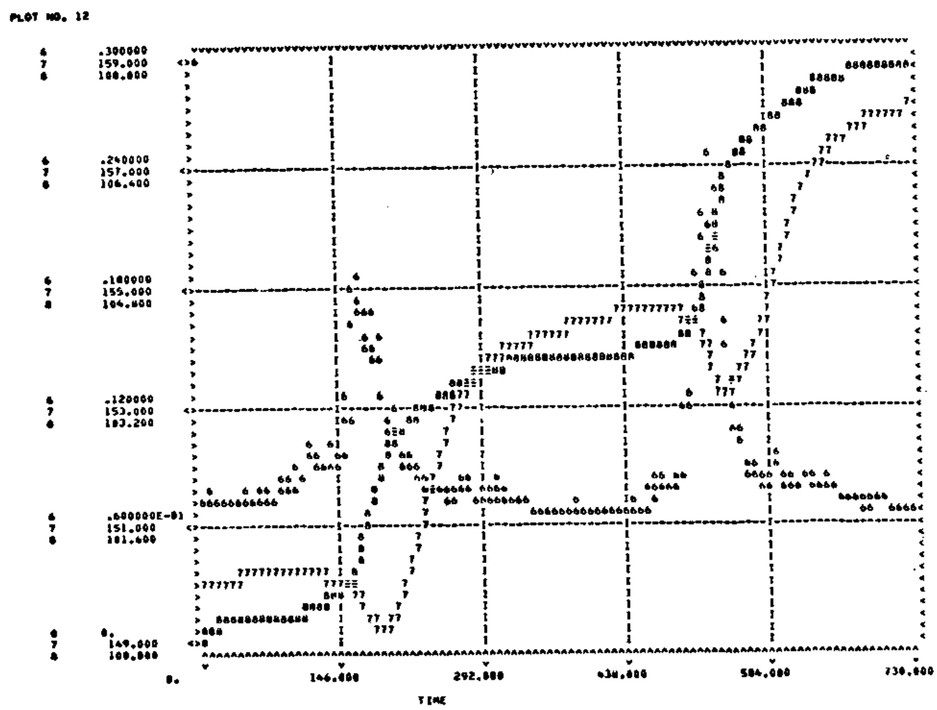

Fig. 6.6. Amount of soil solution N (6), soil organic N (7), and labile pool N (8) vs. time.

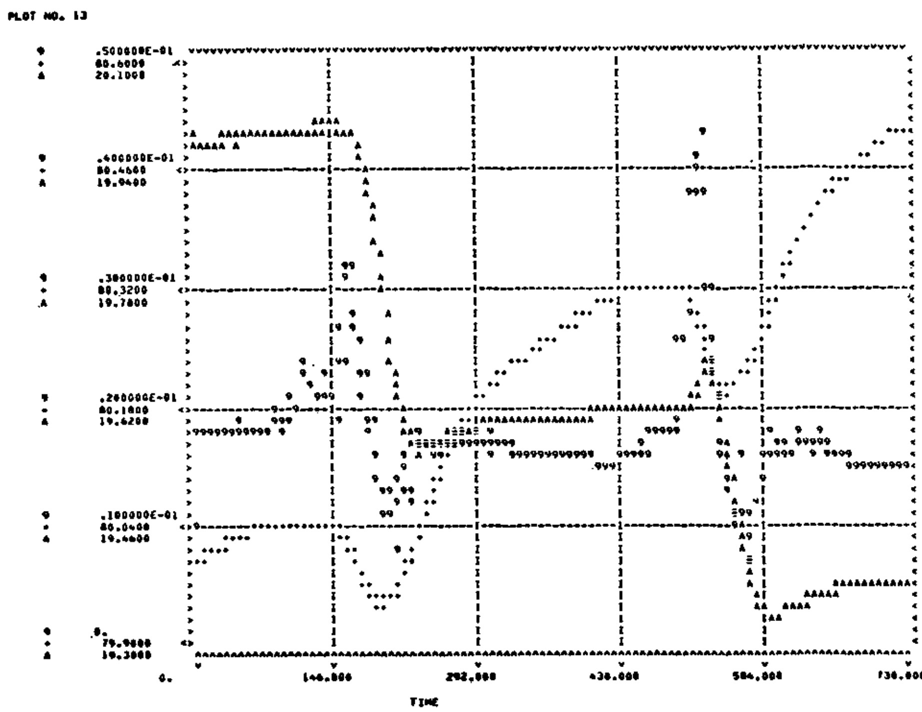

Fig. 6.7. Amount of soil solution P (9), soil organic P (+), and labile pool P (A) vs. time.

6.6 LITERATURE CITED

Barrow, N. J. 1967. Relationship between uptake of phosphorus by plants and the phosphorus potential and buffering capacity of the soil--An attempt to test Schofield's hypothesis. Soil Sci. 104:99-106.

Cole, C. V., and S. R. Olsen. 1959*a*. Phosphorus solubility in calcareous soils: I. Dicalcium phosphate activities in equilibrium solutions. Soil Sci. Soc., Proc. 23:116-118.

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Olsen, S. R., and W. D. Kemper. 1968. Movement of nutrients to plant roots. Advance. Agron. 20:91-151.

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Watanabe, F. S., S. R. Olsen, and R. E. Danielson. 1960. Phosphorus availability as related to soil water. 7th Int. Congr. Soil Sci., Trans. 111:450-456.

CHAPTER 7. SUBROUTINES

7.1 INTRODUCTION

In this chapter each of the user-defined subroutines is discussed. Those routines which are largely mathematical in nature are described in detail. Those that are of a biological nature are discussed in Chapters 2 through 6 and are included here only for completeness.

7.2 SIMCOMP ROUTINES

The compiler SIMCOMP calls for user-supplied subroutines (see Fig. 7.1). These are START (used for initiation prior to a simulation run), CYCL1 (called at the beginning of each update cycle), CYCL2 (called at the end of each update cycle), and FINIS (called at the end of the simulation run). The listings of these routines are found as integral parts of the listing in Chapter 9 (except FINIS which is not used in this model). The biological content of these routines has been covered in Chapters 2 through 6. The bookkeeping duties of these routines are covered by the comment cards contained in the listing.

(This space left blank intentionally.)

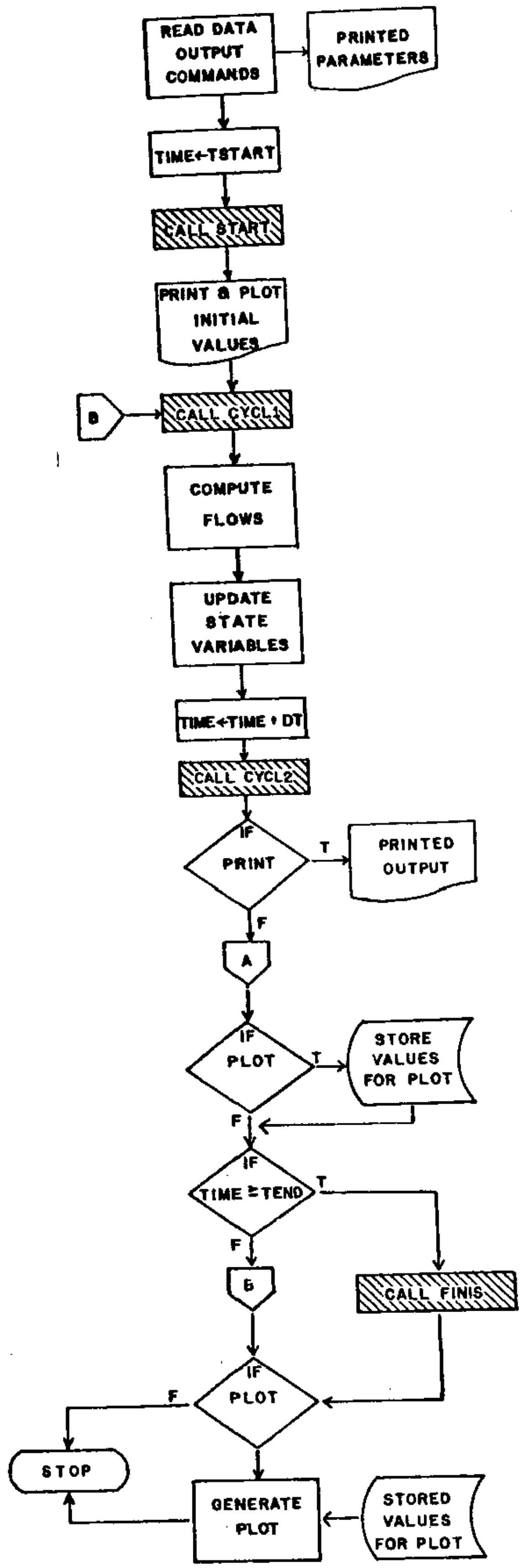

Fig. 7.1. Execution sequence.

```
      FUNCTION ATANF(A,B,C,D,U)
C...A  IS THE X-LOCATION OF THE INFLECTION POINT
C...B  IS THE Y-LOCATION OF THE INFLECTION POINT
C...C  IS THE STEP SIZE(DISTANCE FROM THE MAXIMUM POINT TO THE MINIMUM
C...   POINT)
C...D  IS THE SLOPE OF THE LINE AT THE INFLECTION POINT.
C...U  IS THE INDEPENDENT VARIABLE
C...THIS FUNCTION IS EXPLAINED IN THE TR ON FUNCTIONS
      ATANF=B + ATAN(3.1415*D*(U-A))*C/3.1415
      RETURN
      END
C**********************************************************************

      FUNCTION ATANX(X1,X2,X3)
      C1=3.077683537*(1./X2)
      ATANX=.3183098861*ATAN(C1*(X3-X1))+0.5
C...ATANX VARIES FROM 0.0 TO 1.0
C...X1 IS THE X-AXIS MIDPOINT OF THE SIGMOID ARCTAN CURVE
C...X2 IS THE X-AXIS SPREAD FROM .1 TO .5 AND .5 TO .9 ON THE Y-AXIS
C...X3 IS THE VALUE ON THE X-AXIS THAT WILL GIVE AN ACRTAN VALUE ON Y-AXIS.
      RETURN
      END
```

7.3 MATHEMATICAL AND OTHER ROUTINES

The functions ATANF and ATANX are each arc tangent functions. ATANF is a function of five variables, and Fig. 7.2 shows a sketch of ATANF with its parameters. The function ATANX has three variables, and Fig. 7.3 shows a sketch of the function with its parameters.

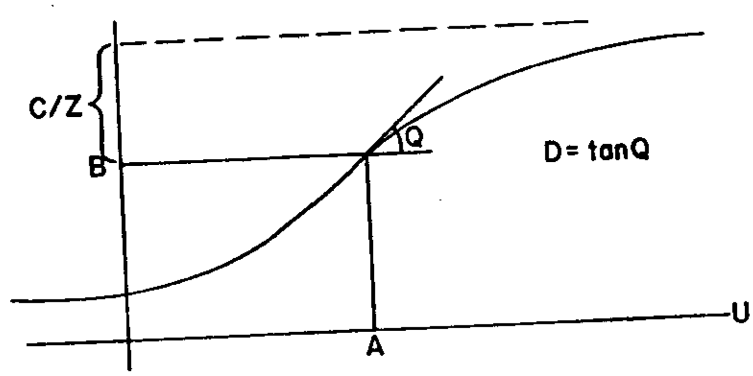

Fig. 7.2. The function ATANF and its parameters.

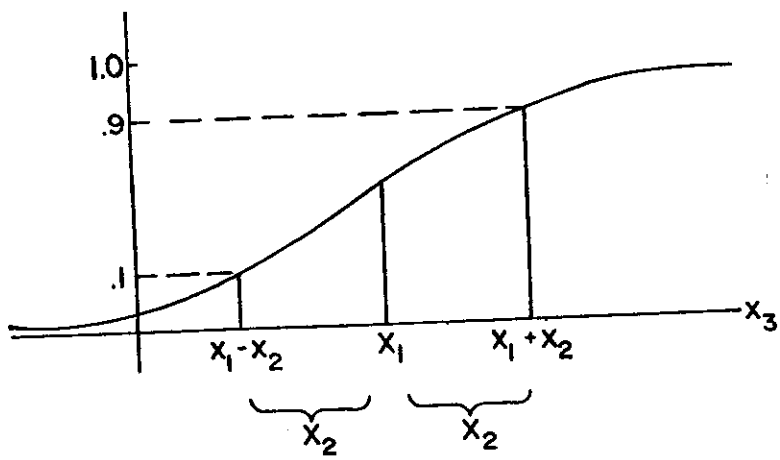

Fig. 7.3. The function ATANX and its parameters.

A more complete discussion of the arc tangent function can be found in any text on the circular trigonometric functions and their inverses. A more detailed discussion of these particular functions is given by Parton and Innis (1972).

```
C***********************************************************************M***
      FUNCTION G(Y)
      G=0.83*(EXP(0.055*Y)-0.95)
      RETURN
      END
C****************************************************************************

      FUNCTION SF(Y)
      SF=2.0*ATANX(11.0,4.0,Y)
      RETURN
      END
C****************************************************************************

      FUNCTION CLI(AA,BB,CC,DD,EE)
C...CALCULATED LINEAR INTERPOLATION BETWEEN TWO VALUES
      S=AA-BB
      IF(S.EQ.0.0) 2, 1
    1 CLI=(DD-CC)/(BB-AA)*(EE-AA)+CC
      RETURN
    2 CLI=(CC+DD)/2
      RETURN
      END


C****************************************************************************

      SUBROUTINE GETS(PFINT,INDX)
C...ARRANGES FOOD IN ORDER OF PREFERENCE
      DIMENSION TFINT(11),INDX(11),PFINT(11)
      DO 5 I=1,11
      TFINT(I)=PFINT(I)
    5 INDX(I)=I
      DO 10 I=1,10
      IJ=I+1
      DO 10 J=IJ,11
      IF(TFINT(I).GE.TFINT(J)) GO TO 10
      SAVE=TFINT(I)
      TFINT(I)=TFINT(J)
      TFINT(J)=SAVE
      KEEP=INDX(I)
      INDX(I)=INDX(J)
      INDX(J)=KEEP
   10 CONTINUE
      RETURN
      END
C****************************************************************************
```

The functions G and SF are quite specific to the nutrient submodels and are discussed in detail in Chapter 6 (pages 173 and 186).

The function CLI is a linear interpolation, extrapolation function. Fig. 7.4 shows the shape of the curve as well as the parameter values. EE is the independent variable. CLI performs an interpolation if AA ≤ EE ≤ BB. It performs a linear extrapolation if EE < AA or EE > BB. If AA = BB, then CLI is set equal to (CC + DD)/2.

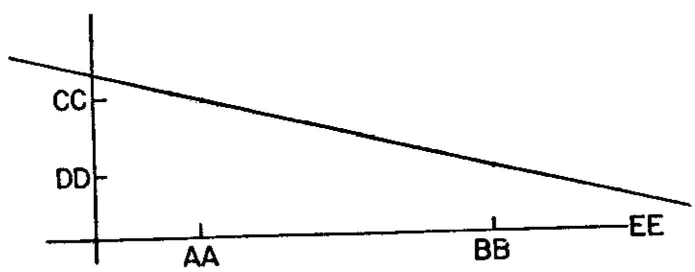

Fig. 7.4. The function CLI and its parameters.

The subroutine GETSET takes the array PFINT (with 11 locations) as input and returns the array INDX (an array of indices also with 11 locations) such that PFINT(INDX(J)) is a monotone non-increasing function of J (i.e., the indices are arranged in order of non-increasing PFINT).

The subroutine STCHP is the stochastic temperature and precipitation generator; it is discussed in Chapter 2 (page 9).

The subroutine CYCL2 and the functions HMAIN and HEFT are discussed in Chapter 5 (pages 148, 158, and 154, respectively).

7.4 FORTRAN SUBROUTINES AND FUNCTIONS

The following list of subroutines and functions are provided by the CDC 6400 FORTRAN compiler.

SIN = sine of the argument in radians

COS = cosine of the argument in radians

ATAN = arc tangent of the argument in radians

EXP = exponential function using base e (the base of the natural logarithms)

AMAX1 = computes the maximum (floating point) of the list of arguments (floating point)

ALOG10 = computes the base 10 logarithm of the argument (floating point)

7.5 LITERATURE CITED

Parton, W. J., and G. S. Innis. 1972. Some graphs and their functional forms. U.S. IBP Grassland Biome Tech. Rep. No. 153. Colorado State Univ., Fort Collins. 41 p.

CHAPTER 8. DATA

8.1 INTRODUCTION

This chapter is divided into two parts. The first lists the data used in the model runs listed in Chapter 9 and discussed in Chapter 10. The second describes the data which the modellers have identified as important, but difficult or impossible to obtain either for model development or validation.

8.2 DATA FOR THIS RUN

The data "User-Defined Variables" of Chapter 9 (page 207) were entered into the CDC 6400 at Colorado State University for the simulation run presented in this document. INDEFINITE values were (hopefully) either not used in this simulation or were calculated prior to their use. Appendix I contains an alphabetical list of these parameters and variables, defines them, and gives their units. Many of the values in the data listing below were recalculated during the simulation run. Therefore, the values shown should be treated as initial values.

8.3 DATA NEEDS

Two distinct data needs are identified: (i) data needed to validate the existing model and (ii) data needed to improve model mechanisms in future work.

For validation we desire to achieve agreement between the model output and the field measurements to within one experimentally determined standard deviation 80% of the time. For this we need data on the state variables of the system measured (essentially) simultaneously and measured simultaneously with the driving variables. The simultaneity must be in both time and space to be useful. There must be sufficient measurements to determine variable means and deviations. Because the validation criterion is stated in terms of the precision of the field measurements, it is incumbent upon the modelling team to refine the predictions when the field results become more narrowly distributed. The modelling group accepts this challenge on the following premise: Most of the variability in the measurements stems from lumping of variables, uncertainty of abiotic conditions, etc. These are basically due to human uncertainties and ignorance. As these are reduced in the field effort (i.e., as we gain better understanding of our system), they can be equally reduced in the models.

The future data needs are presented below in sections paralleling Chapters 2 through 6.

8.3.1 Abiotic Section

8.3.1.1 Validation data needs. The abiotic parameters need for validation of the model include:

1. Soil water at the specified soil water layers.
2. The average daily canopy air temperature.
3. The average daily soil temperature at 15-cm intervals down to 180 cm.
4. The maximum and minimum air temperatures and the daily rainfall.
5. The average daily relative humidity, cloud cover, and wind speed.

All of these parameters are not observed at U.S. IBP Grassland Biome sites; however, many of the parameters can be approximated by using weather data from the local U.S. Weather Bureau Stations.

8.3.1.2 Model improvement data needs. Improvement of the abiotic section can be accomplished adequately by performing a detailed analysis of the meteorological data observed at the Grassland Biome sites.

8.3.2 Producer Section

8.3.2.1 Validation data needs. Data needed to validate the producer section include values for as many of the state variables as possible. Thus, the live shoot biomass of *Bouteloua gracilis* at several dates during the growing season (or year) is needed to validate the simulated X(2). Also, field observations on phenology of the various species through the year should be compared with the simulated phenology.

8.3.2.2 Model improvement data needs. The producer section will be improved when the following information becomes available and incorporated:

1. Phenological progression vs. microclimatic change.
2. Photosynthesis.
3. Shoot/root transfers.
4. Root respiration.
5. Root death.
6. Live shoot to standing dead.

The above processes, to be most useful in modelling the Grassland Biome, should be characteristic of field plants (populations) and should include responses to temperature, moisture, insolation, and the nutrients N and P.

8.3.3 Consumer Section

8.3.3.1 Validation data needs. As there is only one state variable [X(40)] in the consumer section, only data on the cow biomass is needed for validation. For other consumers the same validation data are needed.

8.3.3.2 Model improvement data needs. This model could be greatly improved by the collection and analysis of data on the following items simultaneously for at least 1 year under different grazing intensities at several locations and all sites.

1. Food categories (before, during, and after grazing): Biomass, phenology, digestibility, nutrient content, and energy content.
2. Metabolism: Basal and activity.
3. Abiotic conditions: All.
4. Intake (actual amounts by class (species?)): Energy content, nutrient content, phenology, and biomass.
5. Urine, feces, and gas production.
6. Real daily gain.

8.3.4 Decomposer Section

8.3.4.1 Validation data needs. The required data for the decomposer section are periodic observations of:

1. Standing crop of litter.
2. Standing crop of belowground dead, either total or in layers (0 to 5, 5 to 15, and 15 to 60 cm).
3. Standing crop of microbes, either total or in layers (litter, 0 to 5, 5 to 15, and 15 to 60 cm).

8.3.4.2 Model improvement data needs. The most important information for developing the model concerns the turnover rates of roots. Also useful would be laboratory experiments, employing Grassland Biome site soils, on the decomposition of various plant materials, especially roots. Varying temperature and moisture simultaneously over ranges reasonable for a field situation would give information on the interaction between temperatures and moisture in their effect on the rate of decomposition. The materials used should be characterized as to nitrogen and lignin content, and phenological stage.

8.3.5 Nutrient Section

8.3.5.1 Validation data needs. With respect to the validation of the nutrient section, measurements on the state variables soil solution N and P, plant root N and P, plant top N and P, soil organic N and P, and labile pool N and P will be adequate. These measurements, of course, should be made in concert with other state variables and parameters that have an effect on nitrogen and phosphorus values in the model. The parameters include daily rainfall, plant root biomass (alive and dead), plant top biomass (alive and dead), and soil water.

8.3.5.2 Model improvement data needs.

Phosphorus. In order to improve the model, quite different needs are necessary. The supplied data are adequate for our purpose of describing the equilibrium between the solution pool and the labile pool. The data that are available to describe the input of phosphorus to the system as a result of the weathering of the soil is probably also sufficient for our purposes. The data and mechanism picture is much less attractive; however, when we consider the interaction of the biotic system with the phosphorus cycle. Although there are considerable data on the uptake of phosphorus by plant roots, the mechanisms which control this uptake are not fully understood. In particular, the biotic variables such as phenology, plant moisture stress, etc., are poorly understood. Also, once the nutrient is in the roots of the plant, the translocation to the tops and the associated translocation from tops to roots are not well understood. Similarly, in the process of senescence the plant apparently is able to preserve its nutrients which results in the fact that the dying plant material contains a lower nutrient content than do vigorously growing plant parts. Again, empirical data are available to associate this nutrient curve with phenology or senescence or some such variable, but the actual mechanism which is operational and the controls which function on this flow are not well known. Once the roots have died or the dead material has fallen into the litter component, the further processing of the nutrients in this biomass is also poorly understood. In the root compartment, part of the trouble stems from the difficulty of identifying dead root material, particularly in separating plant roots themselves from the associated microorganisms. This dead root material may serve as an important buffer in terms of absorbing large amounts of phosphorus or holding large amounts of phosphorus in forms which may make it unavailable, at least at the present, to the living plant. Although some hypotheses are available on these mechanisms, the understanding is, again, at a very low level.

Another severe limitation on our understanding is focused on the processing of the soil organic matter by soil microorganisms to mineralize phosphorus and move it into the solution pool and from there into the labile pool or into the roots. Separation and clear identification of the several components involved here is difficult, and that difficulty further compounds the problem of identifying and investigating the mechanisms whereby material is transported from one of these compartments to another.

Nitrogen. The status of the nitrogen submodel is similar to that of the phosphorus submodel except that the portion that is well understood is even smaller. Part of the reason for this is that the nitrogen system is not as closed as the phosphorus. For example, significant amounts of nitrogen enter the cycle via rainfall, and significant amounts escape from the system in various ways. Suffice it to say that the needs of the nitrogen submodel are somewhat greater than those of the phosphorus submodel. One of the significant additions is that there are two active forms of nitrogen in the system, and the buffer mechanism is somewhat in doubt. It is hypothesized that the dead root material of the system plays a role similar to the labile pool in the phosphorus cycle as far as providing a dynamic buffer, at least for one of the two main components of the nitrogen subsystem.

8.4 CONCLUSIONS

Adequate representation of the two nutrient submodels in the system is severly limited by our poor understanding of the biological and physical mechanisms that are operational. If this problem is to be solved and the weakness eliminated, significant efforts will need to be devoted to both the nitrogen and phosphorus cycles in the biotic as well as the abiotic segments. Alternatively, of course, one can suggest another representation of the phosphorus or nitrogen models which would not require these data. The required information must describe the flows which occur within these subsystems as a function of the other state variables in the system. These other state variables include such things as volumetric water content, soil properties, species-specific root properties, and translocation properties as well as other biotic variables. The design of the necessary experiments for these activities can and should be guided by the model development to date, or alternative model efforts which do not require these data must be proposed.

CHAPTER 9. LISTING

This chapter contains a listing of the SIMCOMP program discussed in this report. The output shown is limited to a small number of printouts. The plots are distributed in Chapters 2 through 6 of the report. Most of these plots occur at or near the end of the chapters.

```
STORAGE.        ATWT,ATWT1,ATWT2,ANUM1,ANUM2,ACRE1,ACRE2,ANUM,ACRES
STORAGE.        FINT(11),AFECE,AURIN,ARESP,APAL(11),TNDX(11),HUNG,ADIG(11)
STORAGE.        ASTP,APHEN(11),AVDIG,WETDY(6),AX(11),APTC(11),APP(5)
STORAGE.        AGAIN,APFRN,AFIN,RINT,ERR,ADGVA,ADGVB,ADGVC,ADGVF,ATIM
STORAGE.        ST1(5),ST2(5),TP1(5),TP2(5),SA,TCD,STEMP,TMAX,TMIN
STORAGE.        SLA3(5),SHOT(5),SDTH(6),SPSX
STORAGE.        RTRS(5),RTDTH(5),TPRT(5),CRT(5)
STORAGE.        P6360,P6560,P6065,P7370,SMOGG,FNNIP
STORAGE.        RDR,TDR,FNSR,FNCIP,P7075,P7570,FCPIP,FPSR,P7675,PHRI
STORAGE.        WF1(5),WF2(5),WF3(5),WF4(5),WASM(5),SM1(5),SM2(5)
STORAGE.        WF5(5),WF6(5),SASM(5)
STORAGE.        PLAI,PRIP,PSO1(10,5),PTA,PTE,PRA,PISC1,PILT1,PEVTT
STORAGE.        WSP,CLP,TMP,TNP,CLD(12),PMOD(12)
STORAGE.        DEPTH,DAHOR,RADS(50),NOBSD,NLYA,NLYS,SOLA1,RHP
STORAGE.        PILTT,PEVAP,EVAST,PRF,RAIN,PISCT,EVATT
STORAGE.        SAVTP(13),HEAT(12),SBOT(12)         ,ZMOND,PRIPT
STORAGE.        PISC,PILT,SMOS(10),PTEMP,PRD
STORAGE.        SWP1(5),SWP2(5),SWP3(5),SWP4(5),SWP5(5),SWP6(5)
STORAGE.        SFC1(5),SFC2(5),SFC3(5),SFC4(5),SFC5(5),SFC6(5)
STORAGE.        SPROD,SSDTH,SRDTH,SRTRS,SCRT
STORAGE.        DELT,H,PHI,TP(2),NWK,NDAY,SUN,Y1,Y2,MON
STORAGE.        SP2(5),SP3(5),SP4(5),SP5(5),SP6(5),PHEN(5),TMIS(5)
STORAGE.        EP(5),SRAC(20,5),SRACR(5),SPTW(20,5),SPTWR(5)
STORAGE.        SMR1(5),SMR2(5)
STORAGE.        CNET(5),COUT(5),CIN(5),PS(5),RS(5),EBM(5)
STORAGE.        ESM(5 ,EAT(5),EATR(5),ESMR(5),ENS(5), SLA1(5),SLA2(5)
STORAGE.              H0241,H0341,H0441,H0541,H0641,H1242,H1243,H1244,H1342
STORAGE.             H1343,H1344,H1442,H1443,H1444,H1542,H1543,H1544,H1642
STORAGE.             H2041,H2141,H2241, H2341,H2441,H2541,H5101,H5201,H5301
STORAGE.          H5401,H4142,H4045      ,H1643,H1644 ,H4042,H3541,H3545
STORAGE.               HS1(5),HS11(5),HS40(5), HSO40(5),HHO40(5),HSI40(5)
STORAGE.        HHI40(5),HS19(6)
STORAGE.               HMER(4),HMOIS(4),HETMP(4),SLOS(6),HTORL   ,HMOI(4)
STORAGE.               HTOMI,HTOCO,HLITI,HLITO,HBGDI,HBGDO,HKSP,HKHP,HKSF
STORAGE.             HKHF,HECEF,HMAXL
          C****************************************************************************
          C...SHOOT GROWTH
(1-2).

                FLOW=SHOT(1)
                SPROD=SPROD+FLOW*DT
(1-3).

                FLOW=SHOT(2)
                SPROD=SPROD+FLOW*DT
(1-4).

                FLOW=SHOT(3)
                SPROD=SPROD+FLOW*DT
(1-5).

                FLOW=SHOT(4)
                SPROD=SPROD+FLOW*DT
```

```
(1-6).

                  FLOW=SHOT(5)
                  SPROD=SPROD+FLOW*DT
            C***********************************************************************
            C...SOIL TEMP FOR PRODUCERS
(1-90).

                  X(90) = (SAVTP(1)+SAVTP(2)+SAVTP(3)+SAVTP(4)+SAVTP(5))/5.0
                  IF (X(90) .LT. 0.0) X(90) = 0.0
                  FLOW=0.0
            C***********************************************************************
            C...SHOOT TO ROOT TRANSFERS
(2-12).

                  F = CRT(1)
                  IF(EP(1).GT.0.4317.AND.X(2).LT.1.0)F=-X(12)/(30000.*X(2))*X(90)
            C...0.4317 CORRESPONDS TO A VALUE OF 11.0 FOR PHEN
                  FLOW=F
                  SCRT=SCRT+FLOW*DT
(3-13).

                  F = CRT(2)
                  IF(EP(2).GT.0.4317.AND.X(3).LT.1.0)F=-X(13)/(30000.*X(3))*X(90)
                  FLOW=F
                  SCRT=SCRT+FLOW*DT
(4-14).

                  F = CRT(3)
                  IF(EP(3).GT.0.4317.AND.X(4).LT.1.0)F=-X(14)/(30000.*X(4))*X(90)
                  FLOW=F
                  SCRT=SCRT+FLOW*DT
(5-15).

                  F = CRT(4)
                  IF(EP(4).GT.0.4317.AND.X(5).LT.1.0)F=-X(15)/(3000.0*X(5))*X(90)
                  FLOW=F
                  SCRT=SCRT+FLOW*DT
(6-16).

                  F = CRT(5)
                  FLOW=F
                  SCRT=SCRT+FLOW*DT
            C***********************************************************************
            C...SHOOT TO STANDING DEAD
(2-20).

                  F=X(2)*SDTH(1)*(ATANX(11.,4.0,PHEN(1)) + 0.5/EXP(0.1*TMAX))
                  IF (X(2)-F.LT.0.1) F = 0.0
                  TDR=TDR+F
                  FLOW=F
(3-21).

                  F=X(3)*SDTH(2)*(ATANX(9.0,4.0,PHEN(2)) + 0.5/EXP(0.1*TMAX))
```

```
                      IF (X(3)-F.LT.0.1) F = 0.0
                      TDR=TDR+F
                      FLOW=F
        (4-22).
                      F=X(4)*SDTH(3)*(ATANX(9.0,4.0,PHEN(3)) + 0.5/EXP(0.1*TMAX))
                      IF (X(4)-F.LT.0.1) F = 0.0
                      TDR=TDR+F
                      FLOW=F
        (5-23).
                      F=X(5)*SDTH(4)*(ATANX(9.0,4.0,PHEN(4)) + 0.5/EXP(0.1*TMAX))
                      IF (X(5)-F.LT.0.1) F = 0.0
                      TDR=TDR+F
                      FLOW=F
        (5-24).
                      F=X(5)*SDTH(5)*(ATANX(9.0,4.0,PHEN(4)) + 0.5/EXP(0.1*TMAX))
                      IF (X(5)-F.LE.1.0) F = 0.0
                      TDR = TDR + F
                      FLOW=F
        (6-25).
                      F=X(6)*SDTH(6)*(ATANX(9.0,4.0,PHEN(5)) + 0.5/EXP(0.1*TMAX))
                      TDR=TDR+F
                      FLOW=F
                C**********************************************************************
                C...ROOT RESPIRATION
        (12-1).
                       F =RTRS(1)* X(90) * X(12)
                      FLOW=F
                      SRTRS=SRTRS+FLOW*DT
        (13-1).
                       F =RTRS(2)* X(90) * X(13)
                      FLOW=F
                      SRTRS=SRTRS+FLOW*DT
        (14-1).
                       F =RTRS(3)* X(90) * X(14)
                      FLOW=F
                      SRTRS=SRTRS+FLOW*DT
        (15-1).
                       F =RTRS(4)* X(90) * X(15)
                      FLOW=F
                      SRTRS=SRTRS+FLOW*DT
        (16-1).
                       F =RTRS(5)* X(90) * X(16)
                      FLOW=F
                      SRTRS=SRTRS+FLOW*DT
                C**********************************************************************
                C...ROOT DEATH
        (12-42).

                      STEM=PHEN(1)
```

```
                    IF(STEM.LE.1.0) STEM=14.0
                    H12XX =  X(12) * RTDTH(1) * EXP(.115*STEM)     * 0.1
                    H1242 = 0.22 * H12XX
                    FLOW = H1242/DT
                    RDR = RDR + H12XX
(12-43).
                      H1243 = 0.45 * H12XX
                    FLOW = H1243/DT
(12-44).
                      H1244 = 0.33 * H12XX
                    FLOW = H1244/DT
(13-42).
                    STEM=PHEN(2)
                    IF(STEM.LE.1.0) STEM=14.0
                    H13XX =  X(13) * RTDTH(2) * EXP(.115*STEM)       * 0.1
                    H1342 = 0.22 * H13XX
                    FLOW = H1342/DT
                    RDR = RDR + H13XX
(13-43).
                      H1343 = 0.45 * H13XX
                    FLOW = H1343/DT
(13-44).
                      H1344 = 0.33 * H13XX
                    FLOW = H1344/DT
(14-42).
                    STEM=PHEN(3)
                    IF(STEM.LE.1.0) STEM=14.0
                    H14XX       = X(14) * RTDTH(3) * EXP(.115*STEM)     * 0.1
                    H1442 = 0.12 * H14XX
                    FLOW = H1442/DT
                    RDR = RDR + H14XX
(14-43).
                      H1443 = 0.24 * H14XX
                    FLOW = H1443/DT
(14-44).
                      H1444 = 0.64 * H14XX
                    FLOW = H1444/DT
(15-42).
                    STEM=PHEN(4)
                    IF(STEM.LE.1.0) STEM=14.0
                    H15XX =       X(15) * RTDTH(4) * EXP(.115*STEM)   * 0.1
                    H1542 = 0.11 * H15XX
                    FLOW = H1542/DT
                     RDR = RDR + H15XX
```

```
(15-43).

                H1543 = 0.22 * H15XX
              FLOW = H1543/DT
(15-44).

                H1544 = 0.67 * H15XX
              FLOW = H1544/DT
(16-42).

              STEM=PHEN(5)
              IF(STEM.LE.1.0) STEM=14.0
              H16XX  = X(16) * RTDTH(5) * EXP(.115*STEM)     * 0.1
              H1642 = 0.20 * H16XX
              FLOW = H1642/DT
              RDR = RDR + H16XX
(16-43).

                H1643 = 0.42 * H16XX
              FLOW = H1643/DT
(16-44).

                H1644 = 0.38 * H16XX
              FLOW = H1644/DT
        C*************************************************************************
        C...STANDING DEAD TO LITTER
(20-41).

              STEM = PISC1+SMOS(1)-.35
              IF(STEM.LT.0.0)STEM=0.0
              FLOW=STEM*STEMP*X(20)*SLOS(1)
              H2041 = FLOW*DT
(21-41).

              STEM = PISC1+SMOS(1)-.35
              IF(STEM.LT.0.0)STEM=0.0
              FLOW=STEM*STEMP*X(21)*SLOS(2)
              H2141 = FLOW*DT
(22-41).

              STEM = PISC1+SMOS(1)-.35
              IF(STEM.LT.0.0)STEM=0.0
              FLOW=STEM*STEMP*X(22)*SLOS(3)
              H2241 = FLOW*DT
(23-41).

              STEM = PISC1+SMOS(1)-.35
              IF(STEM.LT.0.0)STEM=0.0
              FLOW=STEM*STEMP*X(23)*SLOS(4)
              H2341 = FLOW*DT
(24-41).

              STEM = PISC1+SMOS(1)-.35
              IF(STEM.LT.0.0)STEM=0.0
```

```
                  FLOW=STEM*STEMP*X(24)*SLOS(5)
                  IF (X(24).LE.1.0) FLOW=0.0
                  H2441 = FLOW*DT
 (25-41).
                  STEM = PISC1+SMOS(1)-.35
                  IF(STEM.LT.0.0)STEM=0.0
                  FLOW=STEM*STEMP*X(25)*SLOS(6)
                  H2541 = FLOW*DT
            C************************************************************************
            C...CONSUMER INTAKE FLOWS
 (2-40).

                  FLOW = FINT(1)
 (3-40).

                  FLOW = FINT(2)
 (4-40).

                  FLOW = FINT(3)
 (5-40).

                  FLOW = FINT(4)
 (6-40).

                  FLOW = FINT(5)
 (20-40).

                  FLOW = FINT(6)
 (21-40).

                  FLOW = FINT(7)
 (22-40).

                  FLOW = FINT(8)
 (23-40).

                  FLOW = FINT(9)
 (24-40).

                  FLOW = FINT(10)
 (25-40).

                  FLOW = FINT(11)
            C************************************************************************
            C...CONSUMER OUTPUT FLOWS
 (40-01).

                  FLOW = ARESP
 (40-42).

                  FLOW = AURIN
                  H4042 = FLOW*DT
```

```
(40-45).

            FLOW = AFECF
            H4045 = FLOW*DT
      C*****************************************************************************
      C...LEACHING OF LITTER
      C...LEACHING IS REPRESENTED BY THE FLOW OF SOFT MATERIAL FROM THE LITTER TO
      C...THE BELOWGROUND DEAD.  A 2.5 CM RAIN IN A DAY WILL LEACH THE MAXIMUM AMOUNT-
      C...10 PCT.
(41-42).

              IF(RAIN.GT.2.5)20100,20101
      20100 FLOW = 0.1 * X(41) * HS40(1)
            GO TO 20102
      20101 FLOW = 0.1 * X(41) * HS40(1) * RAIN / 2.5
      20102 H4142 = FLOW*DT
      C*****************************************************************************
      C...DECOMPOSITION
(41-51).

            FLOW =   HS040(1) + HH040(1)
(42-52).

              FLOW = HS040(2) + HH040(2)
(43-53).

              FLOW = HS040(3) + HH040(3)
(44-54).

              FLOW = HS040(4) + HH040(4)
(45-51).

              FLOW = HH040(5) + HS040(5)
      C*****************************************************************************
      C...MICROBIAL RESPIRATION
(51-1).

             HIN = HS040(1) + HH040(1)    + HH040(5) + HS040(5)
            IF(HMER(1).GT.HIN)20080,20082
      20082 FLOW =HECFF* HIN
            GO TO 20108
      20080 HCHNG = HMER(1) - HIN
            HMAXLOS = HMAXL * X(51)
            IF(HCHNG.GT.HMAXLOS)20104,20106
      20104 FLOW = HMAXLOS  + HIN
            GO TO 20108
      20106 FLOW = HMER(1)
      20108 H5101 = FLOW*DT
(52-1).

             HIN = HS040(2) + HH040(2)
            IF(HMER(2).GT.HIN)20083,20084
      20084 FLOW =HECEF* HIN
            GO TO 20114
```

```
              20083 HCHNG = HMER(2) - HIN
                    HMAXLOS = HMAXL * X(52)
                    IF(HCHNG.GT.HMAXLOS)20110,20112
              20110 FLOW = HMAXLOS   + HIN
                    GO TO 20114
              20112 FLOW = HMER(2)
              20114 H5201 = FLOW*DT
(53-1).
                     HIN = HS040(3) + HH040(3)
                    IF(HMER(3).GT.HIN)20086,20087
              20087 FLOW =HECEF* HIN
                    GO TO 20120
              20086 HCHNG = HMER(3) - HIN
                    HMAXLOS = HMAXL * X(53)
                    IF(HCHNG.GT.HMAXLOS)20116,20118
              20116 FLOW = HMAXLOS    + HIN
                    GO TO 20120
              20118 FLOW = HMER(3)
              20120 H5301 = FLOW*DT
(54-1).
                     HIN = HS040(4) + HH040(4)
                    IF(HMER(4).GT.HIN)20089,20090
              20090 FLOW =HECEF* HIN
                    GO TO 20126
              20089 HCHNG = HMER(4) - HIN
                    HMAXLOS = HMAXL * X(54)
                    IF (HCHNG.GT.HMAXLOS)20122,20124
              20122 FLOW = HMAXLOS    + HIN
                    GO TO 20126
              20124 FLOW = HMER(4)
              20126 H5401 = FLOW*DT
              C               ****************************
              C               *      NITROGEN MODEL      *
              C               ****************************
(60-65).
                    THETA=X(98)/60.0
                    F   = (X(60)-X(65)*P6560/P6065*THETA)/DT
                    FLOW=F
(61-62).
                    F=0.0
                    TEMP=X(2)+X(3)+X(4)+X(5)+X(6)
                    F1=X(62)/TEMP
                    IF (F1 .GT. FNCIP) 70004, 70005
              70005 F=(FNCIP-F1)/DT*TEMP
              70004 CONTINUE
                    FLOW=F
(61-63).
                    F=FNNIP*RDR
                    FLOW=F
```

```
      (62-63).
                      F=FNCIP*TOR
                      FLOW=F
      (63-60).
                      F=P6360*X(63) * G(X(90)) * SF(X(98))
                      SMOGG = SMOGG + F*DT
                      FLOW=F
      (63-66).
                       F = 0.1/365.
                      FLOW=F
      (65-61).

                      TEMP = X(12)+X(13)+X(14)+X(15)+X(16)
                      PC = X(60)/X(98)
                      RU=(.27E-5/(1.+1.43/PC)+.6E-6/(1.+.084/PC))
                      THETA=X(98)/60.0
                      IF(THETA.LE..09)50002,50003
                50002 RPU=0.0
                      GO TO 50004
                50003 IF(THETA.GE..28)50005,50006
                50005 RPU=1.0
                      GO TO 50004
                50006 RPU = 5.37 * THETA - .505
                50004 CONTINUE
                      FLOW = RU*RPU*TEMP
      (66-60).

                        F=.4/40.0* RAIN
                      IF (RAIN .GT. 5.0) GO TO 70000
                      GO TO 70001
                70000 F = (RAIN - 5.0) * 0.004 - F
                70001 CONTINUE
                      FLOW=F
                C                *******************************
                C                *      PHOSPHOROUS MODEL      *
                C                *******************************
      (70-75).
                       THETA = X(98)/60.
                      TEMP1 = X(75)*P7570*THETA/P7075
                      F = (X(70) - TEMP1)/DT
                      FLOW=F
      (71-72).
                      F=0.0
                      TEMP=X(2)+X(3)+X(4)+X(5)+X(6)
                      F1=X(72)/TEMP
                      IF (F1 .GT. FCPIP) 71004,71005
                71005 F=(FCPIP - F1)/DT*TEMP
                71004 CONTINUE
                      FLOW=F
      (71-73).
                      F=FCPIP*RDR
                      FLOW=F
      (72-73).
                      F=FCPIP*TOR
```

```
                    FLOW=F
   (73-70).
                     F = P7370 * G(X(90)) * X(73) * SF(X(98))
                    FLOW=F
   (75-71).

                    TEMP=X(12)+X(13)+X(14)+X(15)+X(16)
                    PC=X(70)/X(98)
                    RU=(.27E-5/(1.+1.43/PC)+.6E-6/(1.+.084/PC))
                    THETA=X(98)/X(60)
                    IF(THETA.LE..09)71006,71007
              71006 RPU=0.0
                    GO TO 71008
              71007 IF(THETA.GE..28)71009,71010
              71009 RPU=1.0
                    GO TO 71008
              71010 RPU=5.37*THETA-.505
              71008 FLOW=RU*RPU*TEMP
   (76-75).

                    F=P7675 + PHRI / 40.0 * RAIN
                    FLOW=F
              C*****************************************************************************
              C...SOIL MOISTURE FOR NUTRIENTS
   (98-99).

                    X(96)=SMOS(1)+SMOS(2)+SMOS(3)+SMOS(4)+SMOS(5)+SMOS(6)
                    F = 0.0
                    FLOW=F
              C*******************************************************************

                    FUNCTION CLI(AA,BB,CC,DD,EE)
              C...CALCULATED LINEAR INTERPOLATION BETWEEN TWO VALUES
                    S=AA-BB
                    IF(S.EQ.0.0) 2, 1
                  1 CLI=(DD-CC)/(BB-AA)*(EE-AA)+CC
                    RETURN
                  2 CLI=(CC+DD)/2
                    RETURN
                    END
              C*******************************************************************

                    SUBROUTINE GETS(PFINT,INDX)
              C...ARRANGES FOOD IN ORDER OF PREFERENCE
                    DIMENSION TFINT(11),INDX(11),PFINT(11)
                    DO 5 I=1,11
                    TFINT(I)=PFINT(I)
                  5 INDX(I)=I
                    DO 10 I=1,10
                    IJ=I+1
                    DO 10 J=IJ,11
                    IF(TFINT(I).GE.TFINT(J)) GO TO 10
                    SAVE=TFINT(I)
```

```
      TFINT(I)=TFINT(J)
      TFINT(J)=SAVF
      KEEP=INDX(I)
      INDX(I)=INDX(J)
      INDX(J)=KEEP
   10 CONTINUE
      RETURN
      END
C***********************************************************************

      FUNCTION HEFT(HT)
C...CALCULATES THE EFFECT OF TEMPERATURE ON THE RATE OF DECOMPOSITION
      IF(HT.LE.40.0.AND.HT.GT.0.0)20014,20016
20014 HEFT = EXP(-5.9132 + 0.31887*HT - 0.004357*HT*HT)
      GO TO 20015
20016 IF(HT.LE.0.0.OR.HT.GE.45.)20017,20018
20017 HEFT = 0.0
      GO TO 20015
20018 HEFT = 9.0 - HT/5.0
20015 RETURN
      END
C*******************************************************************************

      FUNCTION HMAIN(HT)
C...CALCULATES THE EFFECT OF TEMPERATURE ON THE MAINTENANCE ENERGY REQUIREMENT
C...OF MICROBES
      HMAIN  = 2.51 * EXP(-10000./HT + 32.24)
      RETURN
      END
C*********************************************************************

      FUNCTION ATANF(A,B,C,D,U)
C...A  IS THE X-LOCATION OF THE INFLECTION POINT
C...B  IS THE Y-LOCATION OF THE INFLECTION POINT
C...C  IS THE STEP SIZE(DISTANCE FROM THE MAXIMUM POINT TO THE MINIMUM
C...   POINT)
C...D  IS THE SLOPE OF THE LINE AT THE INFLECTION POINT.
C...U  IS THE INDEPENDENT VARIABLE
C...THIS FUNCTION IS EXPLAINED IN THE TR ON FUNCTIONS
      ATANF=B + ATAN(3.1415*D*(U-A))*C/3.1415
      RETURN
      END
C*********************************************************************

      FUNCTION ATANX(X1,X2,X3)
      C1=3.077683537*(1./X2)
      ATANX=.3183098861*ATAN(C1*(X3-X1))+0.5
C...ATANX VARIES FROM 0.0 TO 1.0
C...X1 IS THE X-AXIS MIDPOINT OF THE SIGMOID ARCTAN CURVE
C...X2 IS THE X-AXIS SPREAD FROM .1 TO .5 AND .5 TO .9 ON THE Y-AXIS
C...X3 IS THE VALUE ON THE X-AXIS THAT WILL GIVE AN ACRTAN VALUE ON Y-AXIS.
      RETURN
      END
```

```
C***************************************************************M***
      FUNCTION G(Y)
      G=0.83*(EXP(0.055*Y)-0.95)
      RETURN
      END
C*******************************************************************
      FUNCTION SF(Y)
      SF=2.0*ATANX(11.0,4.0,Y)
      RETURN
      END
C*******************************************************************
      SUBROUTINE CYCL1
      DIMENSION RAT(10),DRAIN(10)
      DIMENSION INDX(11)
C                 ****************************************
C                 *      ABIOTIC MODEL                   *
C                 ****************************************
C...SITE SPECIFIC PARAMETERS-PEA,PTE,PHI,NLYA,NLYS,DEPTH,DAHOR,
C...SPOT(I),PSO1(I,1),PRD,PRF,CLD(I),FSS
C...DAY OF YEAR CALCULATED.
      NDAY=NDAY+1
      IF(NDAY.GT.365)NDAY=1
C...WEEK OF YEAR CALCULATED.
      RNWKS=INT(1.+TIME/7.0)
      NW=RNWKS  $NW=MOD(NW,52)
      IF(NW.EQ.0) NW=52
      NWK=NW
      MON=NDAY/30.25+ 1.  $IF(MON.GT.12) MON=12.
      NOBSD = 1
C...DETERMINE THE DRIVING VARIABLES FOR THE WATER AND HEAT FLOW MODELS
C...IF NOBSD=1 THE DRIVING VARIABLES ARE SIMULATED STOCHASTICALLY, IF NOBSD
C...=2 OBSERVED WEATHER DATA IS USED TO DRIVE THE MODEL.
      PRIP=0.    $IF(NOBSD.EQ.1) CALL STCHP
      IF(NOBSD.EQ.2) GO TO 40096     $GO TO 40097
40096 CONTINUE
C...OBSERVED MAXIMUM AND MINIMUM AIR TEMPERATURE AND RAINFALL DATA ARE
C...USED TO DRIVE THE ABIOTIC MODEL
40097 CONTINUE
C...SOLAR INSOLATION CALCULATIONS.
      IF(NOBSD.EQ.2)CLP=CLD(MON)
      DELT=0.401426*SIN(6.283185*(NDAY-77)/365.0)
      H=ACOS(-TAN(PHI)*TAN(DELT))
      SU1  =596.*(H*SIN(PHI)*SIN(DELT)+COS(PHI)*COS(DELT)*SIN(H))
      SUN=SU1*(1.0-(.18+.0053*CLP))
      SOLA1 = SUN*.026
      TP(1)=H/3.14159
      TP(2)=1.0-TP(1)
      Y1=TP(1)*24.
      Y2=TP(2)*24.0
C                 ******************************************
```

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C                       *       WATER FLOW MODEL                    *
C                       *********************************************
      RAIN = PRIP * 2.54
      PT7P=0.0
      PBM=X(2)+X(3)+X(4)+X(5)+X(6)+X(20)+X(21)+X(22)+X(23)+X(24)+X(25)
C...CALCULATE THE LEAF AREA INDEX FOR THE STANDING CROP(PLAI)
      PLAI=PBM/150.
      IF(NDAY.EQ.1)   PRIPT=0.
      PRIPT=PRIPT+PRIP
C...CALCULATE THE AVERAGE HEIGHT OF VEGETATION (PH) AND PERCENTAGE OF AREA
C...COVERED BY VEGETATION(PC)
      PISC=PILT=0.0  $IF(PRIP.LE.0.0) GO TO 40000
      PC=PLAI  $IF(PC.GT.1.) PC=1.
      PH=ATANF(300.,12.,34.,.002,PBM)  $IF(PH.LE.0.0) PH=0.0
      PHC=PC*PH
C...CALCULATE THE AMOUNT OF WATER INTERCEPTED BY THE STANDING CROP(PISC)
      IF(PHC.LE.8.5) PA=.9 + .04*PHC
      IF(PHC.GT.8.5) PA=1.22 + (PHC-8.5)*.35
      IF(PHC.LE.3.0) PB=PHC*.333  $IF(PHC.GT.3.0) PB=1. +(PHC -3.)*.182
      PISC=PA*.026*PRIP + .037*PB  $IF(PISC.GT.PRIP) PISC=PRIP
      PRIP=PRIP -PISC        $IF(PRIP.EQ.0.0) GO TO 40000
C...CALCULATE THE AMOUNT OF WATER INTERCEPTED BY LITTER(PILT)
      ZZH=(-1.+.45*ALOG10(X(41) + 1.))*ALOG(10.)
      PILT=(.015*PRIP + .025)*EXP(ZZH)
      IF(PRIP.LE.PILT) PILT=PRIP  $PRIP=PRIP-PILT
40000 CONTINUE
      IF(NDAY.EQ.1)   PILTT=PISCT=0.0
      PILTT=PILTT + PILT     $PISCT=PISCT + PISC
      PRIP=PRIP*2.54  $PILT=PILT*2.54  $PISC=PISC*2.54
      PISC1=PISC1 + PISC   $PILT1=PILT1 + PILT
C...CALCULATE THE FIELD CAPACITY FOR THE SOIL WATER LAYERS(PSO1(I,2))
      DO  40001  I=1,NLYS   $PPT=PSO1(I,1)
C...SITE SPECIFIC EQUATIONS--THE FUNCTIONAL RELATIONSHIP OF THE FIELD CAPACITY
C...TO THE DEAD ROOT BIOMASS WILL HAVE TO BE MODIFIED AS A FUNCTION OF SOIL
C...TYPE.
C...IF PPT=2 THE SOIL WATER LAYER IS IN THE B HORIZON, IF PPT=1 THE SOIL WATER
C...LAYER IS IN THE A HORIZON
      IF(PPT.EQ.2) PSO1(I,2)=28.5 + X(42)*PSO1(I,3)/(80.*PSO1(I,5)/15.)
      IF(PPT.EQ.1) PSO1(I,2)=16.  + X(42)*PSO1(I,3)/(250.*PSO1(I,5)/15.)
40001 CONTINUE
C...CALCULATE THE INFILTRATION RATE AND DETERMINE THE AMOUNT OF WATER THAT
C...DRAINS FROM THE SOIL WATER LAYERS UNDER HIGH SOIL WATER CONDITIONS(
C...GREATER THAN FIELD CAPACITY)
      SMOS(1)=SMOS(1) + PRIP
      DO  40002  I=1,NLYS   $PQZM=PSO1(I,2)*PSO1(I,5)/100.
      IF(SMOS(I).GT.PQZM) GO TO 40003    $GO TO 40002
40003 SMOS(I+1)=SMOS(I+1) + (SMOS(I)-PQZM)   $SMOS(I)=PQZM
40002 CONTINUE
C...CALCULATE THE SOIL WATER DRAINAGE FROM SOIL WATER LAYERS WHEN THE
C...MOISTURE CONTENT OF THE SOIL IS LESS THAN OR EQUAL TO THE FIELD
C...CAPACITY.
      DO  40100  I=1,NLYS
      PQZM=PSO1(I,2)*PSO1(I,5)*.01
```

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C...SITE SPECIFIC PARAMETER---PRD IS A FUNCTION OF THE SOIL TYPE. INCREASING PRD
C...CAUSES THE DRAINAGE TO INCREASE(PRD=.02 FOR THE PAWNEE SITE)
      DRAIN(I)=PRD*EXP((SMOS(I)-PQZM)*15./PSO1(I,5))
      PQMZ=PSO1(I,4)*PSO1(I,5)*.01   $IF(SMOS(I).LE.PQMZ) DRAIN(I)=0.0
      SMOS(I)=SMOS(I) - DRAIN(I)
40100 SMOS(I+1)=SMOS(I+1) + DRAIN(I)
C...CALCULATE THE POTENTIAL EVAPOTRANSPIRATION RATE (PEVAP)-- IF NOBSD=1
C...PENNMANS(1948) EQUATION IS USED, IF NOBSD=2 THORNTHWAITES EQUATION
C...(1939) IS USED
      PTEMP=(TMIN+2.0*TMAX)/3.0
      IF(NOBSD.EQ.1) GO TO 40098       $PEA=1.   $PTE=34.
C...---SITE SPECIFIC PARAMETERS-- PEA,PTE ARE SITE SPECIFIC PARAMETERS THAT
C...ARE A FUNCTION OF THE MEAN MONTHLY TEMPERATURES OF THE PARTICULAR SITE
      IF(PTEMP.LE..05)PTEMP=.05
      PEVAP=2.8*(10.*PTEMP/PTE)**PEA/30.
      GO TO 40099
40098 CALL PENN
40099 CONTINUE
      PEVTT=PEVTT + PEVAP/2.54
C...CALCULATE THE BARE SOIL EVAPORATION WATER LOSS(PEVAS)
C...--SITE SPECIFIC EQUATION-- THE FUNCTIONAL RELATIONSHIP BETWEEN PEVAP AND PA,
C...PB,PC AND PD ARE SITE SPECIFIC EQUATIONS(VARY WITH THE SOIL TYPE)
      PA=ATANF(.625,14.9,13.,1.5,PEVAP)
      IF(PEVAP.GT..50) PA= 13.5+(PEVAP-.50)*11.
      IF(PA.GT.15.0) PA=15.0
      PB=.5
      IF(PEVAP.GE..75) PC=1.
      IF(PEVAP.LT..75) PC=1. +(.75-PEVAP)
      IF(PEVAP.LE..55) PC=1.2
      IF(PEVAP.GE..65) PD=.30
      IF(PEVAP.LT..65) PD=.20 + (PEVAP-.55)
      IF(PEVAP.LT..55) PD=.20 + (.55-PEVAP)/1.25
      IF(PEVAP.LT..3) PD=.40
C...DETERMINE THE VOLUMETRIC WATER CONTENT OF THE A HORIZON(PSM)
      SMH=0.0  $DO  40089  I=1,NLYA
40089 SMH=SMOS(I)+ SMH       $PSM=SMH*100./DAHOR
      PEVA=ATANF(PA,.5,PC,PD,PSM)
      IF(PEVA.LT.0.0) PEVA=0.0
      IF(PEVA.GT.1.0) PEVA=1.0
      PEVAS=PEVA*PEVAP
C...CALCULATE THE TRANSPIRATION WATER LOSS(PEVAT)
C...--SITE SPECIFIC EQUATION---THE FUNCTIONAL RELATIONSHIP BETWEEN PEVAP AND PA,
C...PB,PC AND PD ARE SITE SPECIFIC EQUATIONS(VARY WITH THE SOIL TYPE)
      PA=ATANF(.6,18.7,20.,1.5,PEVAP)
      IF(PEVAP.GT..50) PA=16. + (PEVAP-.50)*18.
      IF(PA.GT.22.5) PA=22.5
      IF(PEVAP.GT..65) PB=.55
      IF(PEVAP.LE..65) PB=.55 -(.65-PEVAP)
      IF(PEVAP.LT..60) PB=.50
      IF(PEVAP.GE..65) PC=1.15
      IF(PEVAP.LT..65) PC=1.15 + (.65-PEVAP)
      IF(PEVAP.LE..60) PC=1.20
      IF(PEVAP.GT. .65) PD=.19
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      IF(PEVAP.LE..65) PD=.13 +(PEVAP-.55)*.6
      IF(PEVAP.LT..55) PD=.13 + (.55-PEVAP)*.2
      IF(PEVAP.LT..45) PD=.15 + (.45-PEVAP)*.7
      IF(PEVAP.LT..35) PD=.22
C...CALCULATE THE VOLUMETRIC WATER CONTENT OF THE SOIL PROFILE(A AND B
C...HORIZONS)
      SMH=0.0   $DO  40082  I=1,NLYS
40082 SMH=SMH+ SMOS(I)    $PSM=SMH*100./DEPTH
      PEVA=ATANF(PA,PB,PC,PD,PSM)
      IF(PEVA.GT.1.) PEVA=1.  $IF(PEVA.LT.0.0) PEVA=0.0
C...CALCULATE THE LEAF AREA INDEX FOR LIVE ABOVEGROUND BIOMASS(PLA2)
      PLA2=(X(2)+X(3)+X(4)+X(5)+X(6))/150.0
      ZXZ=4.0*ALOG10(PLA2 + 1.)
      IF(ZXZ.GT.1.2) ZXZ=1.2
      IF(ZXZ.LE.0.0) ZXZ=.01
      PEVAT=PEVA*PEVAP*ZXZ
      PEVAP1=PEVAP
C...EVAPORATE WATER FROM THE INTERCEPTED WATER (PISC1,PILT1)
      IF(PEVAP.LE.PISC1)GO TO 40009
      GO TO 40008
40009 PISC1=PISC1-PEVAP  $PTZP=PEVAP   $GO TO 40010
40008 PEVAP1=PEVAP1-PISC1 $PISC1=0.0 $IF(PEVAP1.LE.PILT1)GO TO 40007
      GO TO 40006
40007 PILT1=PILT1-PEVAP1$PTZP=PEVAP  $GO TO 40010
40006 PEVAP1=PEVAP1-PILT1 $PILT1=0.0
C...DETERMINE IF THE BARE SOIL OR TRANSPIRATION METHOD IS USED TO
C...EVAPORATE WATER FROM THE SOIL PROFILE
      IF(PEVAS.LT.PEVAT) GO TO 40005
      IF(PEVAS.GT.PEVAP1) PEVAS=PEVAP1
      IF(NDAY.EQ.1)  EVAST= EVATT =0.
      PTZP=PEVAS
      EVAST= EVAST + PEVAS/2.54
      ZR=0.0
C...EVAPORATE WATER FROM THE SOIL WATER LAYERS IN THE A HORIZON(BARE SOIL
C...EVAPORATION METHOD)
      DO  40200  I=1,NLYA    $Q=SMOS(I)*100./PS01(I,5)
C...CALCULATE THE SOIL WATER TENSION(TE) IN BARS
C...---SITE SPECIFIC EQUATIONS--THE RELATIONSHIP OF THE SOIL WATER TENSION
C...TO THE VOLUMETRIC SOIL WATER CONTENT(Q) IS A FUNCTION OF SOIL TYPE
C...CALCULATE TE FOR THE SOIL WATER LAYERS IN THE A HORIZON(IP=1)
      IP=PS01(I,1)  $TE=0.
      IF(IP.EQ.1.AND.Q.GE.PS01(I,2))    TE=(60.-Q)*.3/(60.-PS01(I,2))
      IF(IP.EQ.1.AND.Q.LT.PS01(I,2)) TE=.3+(PS01(I,2)-Q)*2.7/(PS01(I,2)-
     111.5)
      IF(IP.EQ.1.AND.Q.LT.11.5) TE=3. + (11.5-Q)*3.40
      IF(IP.EQ.1.AND.Q.LT.8.0) TE=15. + (8.-Q)*20.
C...CALCULATE TE FOR THE SOIL WATER LAYERS IN THE B HORIZON(IP=2)
      IF(IP.EQ.2.AND.Q.GE.PS01(I,2))TE=(60.-Q)*.3/(60.-PS01(I,2))
      IF(IP.EQ.2.AND.Q.LT.PS01(I,2))TE=.3+(PS01(I,2)-Q)*2.7/(PS01(I,2)-
     117.1)
      IF(IP.EQ.2.AND.Q.LT.17.1) TE=3. + (17.1-Q)*3.0
      IF(IP.EQ.2.AND.Q.LT.13.) TE=15.  + (13.-Q)*18.
      IF(TE.LE.0.0) TE=0.01
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C...CALCULATE THE RATIO OF THE ROOT DENSITY(PSO1(I,3) TO THE SOIL
C...MOISTURE TENSION(TE) FOR THE I TH SOIL WATER LAYER.
                  RAT(I)=PSO1(I,3)/TE
      IF(SMOS(I).LT.PSO1(I,4)*PSO1(I,5)*.009) RAT(I)=0.0
      ZR=ZR + RAT(I)
40200 CONTINUE
C...EVAPORATE WATER FROM THE DIFFERENT SOIL WATER LAYERS
      IF(ZR.LE.0.0)ZR=.01     $DO  40300  I=1,NLYA
40300 SMOS(I)=SMOS(I)-(RAT(I)/ZR)*PEVAS    $GO TO 40010
C...EVAPORATE WATER FROM THE SOIL WATER LAYERS USING THE TRANSPIRATION
C...WATER LOSS METHOD
40005 IF(PEVAT.GT.PEVAP1) PEVAT=PEVAP1  $ZR=0.0  $DO  40012  I=1,NLYS
C...CALCULATE THE SOIL WATER TENSION(TE) IN BARS
C...---SITE SPECIFIC EQUATIONS--THE RELATIONSHIP OF THE SOIL WATER TENSION
C...TO THE VOLUMETRIC SOIL WATER CONTENT(Q) IS A FUNCTION OF SOIL TYPE
      Q=SMOS(I)*100./PSO1(I,5)    $IP=PSO1(I,1)  $TE=0.
C...CALCULATE TE FOR THE SOIL WATER LAYERS IN THE A HORIZON(IP=1)
      IF(IP.EQ.1.AND.Q.GE.PSO1(I,2))   TE=(60.-Q)*.3/(60.-PSO1(I,2))
      IF(IP.EQ.1.AND.Q.LT.PSO1(I,2)) TE=.3+(PSO1(I,2)-Q)*2.7/(PSO1(I,2)-
     111.5)
      IF(IP.EQ.1.AND.Q.LT.11.5) TE=3. + (11.5-Q)*3.40
      IF(IP.EQ.1.AND.Q.LT.8.0) TE=15. + (8.-Q)*20.
C...CALCULATE TE FOR THE SOIL WATER LAYERS IN THE B HORIZON(IP=2)
      IF(IP.EQ.2.AND.Q.GE.PSO1(I,2))TE=(60.-Q)*.3/(60.-PSO1(I,2))
      IF(IP.EQ.2.AND.Q.LT.PSO1(I,2))TE=.3+(PSO1(I,2)-Q)*2.7/(PSO1(I,2)-
     117.1)
      IF(IP.EQ.2.AND.Q.LT.17.1) TE=3. + (17.1-Q)*3.0
      IF(IP.EQ.2.AND.Q.LT.13.) TE=15.  + (13.-Q)*18.
      IF(TE.LE.0.0) TE=0.01
C...CALCULATE THE RATIO OF THE ROOT DENSITY(PSO1(I,3)) TO THE SOIL
C...WATER TENSION FOR THE I TH SOIL WATER LAYER
                  RAT(I)=PSO1(I,3)/TE
      IF(SMOS(I).LT.PSO1(I,4)*PSO1(I,5)*.009) RAT(I)=0.0
      ZR=ZR + RAT(I)
40012 CONTINUE
      IF(ZR.LE.0.0) ZR=.01
      PTZP=PEVAT
      IF(NDAY.EQ.1)  EVATT= EVAST=0.
       EVATT= EVATT + PEVAT/2.54
      DO  40013  I=1,NLYS
C...EVAPORATE WATER FROM THE I TH SOIL WATER LAYER
40013 SMOS(I)=SMOS(I) - (RAT(I)/ZR)*PEVAT
40010 CONTINUE
C                    ****************************************
C                    *       HEAT FLOW MODEL                *
C                    ****************************************
      ZMOND=ZMOND + 1.   $IF(ZMOND.GT.30.) ZMOND=1.0
      NXZT=MON + 1   $IF(NXZT.GT.12) NXZT=1
      IF(MON.EQ.1.AND.NDAY.EQ.1) ZMOND=1.0
C...CALCULATE THE AVERAGE DAILY SOIL TEMPERATURE AT 180 CM(SAVTP(13))
      SAVTP(13)=SBOT(MON)+ (SBOT(NXZT )-SBOT(MON))*ZMOND/30.
      ARM=X(2)+X(3)+X(4)+X(5)+X(6)+X(20)+X(21)+X(22)+X(23)+X(24)+
     1X(25)+X(41)
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C...CALCULATE THE AVERAGE DAILY CANOPY AIR TEMPERATURE(SAVTP(1))
      SAVTP(1)=PTFMP+ 12.*PEVAP*(1.-PTZP/PEVAP)*(1.-ABM/300.)
C...CALCULATE THE SOIL TEMPERATURES AT THE DIFFERENT LEVELS IN THE SOIL
C...PROFILE(SAVTP(I),I=2,12)
C...---SITE SPECIFIC PARAMETER--FSS IS THE DENSITY OF THE SOIL(GM/CENTIMETER
C...CUBED)
      DO  40080  I=1,11   $SA1=.002  $SA2=.30    $FSS=1.82
C...CALCULATE THE SOIL CONDUCTIVITY(SA1) AND THE SPECIFIC HEAT CAPACITY(SA2)
C...FOR THE SOIL TEMPERATURE LAYERS
      AT=DT1=DT3=DT4=DT2=0.$DO  40081  K=1,NLYS
      SK=0.0     $AT=PSO1(K,5) + AT   $UPL=(I-1)*15.  $ULO=(I+1)*15.
      IF(AT.GT.UPL.AND.AT.LE.ULO) GO TO 40060
      IF(AT.GT.ULO.AND.DT1.LE.ULO) GO TO 40050     $GO TO 40081
40060 SMIS=SMOS(K)*100./PSO1(K,5)  $ PA=(SMIS-PSO1(K,4))/(PSO1(K,2)-PSO1
     1(K,4))
      IF( PA.LE..20) SK=.0015
      IF( PA      .GE..20.AND. PA      .LT..40) SK=.0018
      IF( PA      .GE..40.AND. PA      .LT..60) SK=.002
      IF( PA      .GE..60.AND. PA      .LT..80) SK=.0025
      IF( PA      .GF..80) SK=.003
      DT2=DT2+ SK*PSO1(K,5)         $DT3=DT3 + PSO1(K,5)
      SMIS=SMIS/100.    $DT4=DT4 + (SMIS+.18*(1.-SMIS))*PSO1(K,5)
40081 DT1=AT         $IF(DT3.LE.0.) GO TO 40066
      SA1=DT2/DT3  $SA2=DT4/DT3
40066 CONTINUE
      SKK=SA1*86400./( FSS*SA2*225.)
      SKK=SKK*.45
      K=I+ 1
C...DETERMINE THE DAILY CHANGE OF TEMPERATURE AT THE I TH POINT IN THE
C...SOIL PROFILE (HEAT(I-1))
      HEAT(I)=SKK*(SAVTP(K-1)-2.*SAVTP(K) + SAVTP(K+1))
      ZQF=ABS(HEAT(I))     $ZZT=HEAT(I)/ZQF
      IF(ZQF.GT.5.) HEAT(I)=5.*ZZT
      IF(I.GT.1) HEAT(I)=SKK*(SAVTP(K-1) + HEAT(I-1)*1.-2.*SAVTP(K) +
     1 SAVTP(K+1))
40080 CONTINUE
C...CALCULATE THE NEW AVERAGE DAILY SOIL TEMPERATURE AT THE I TH POINT IN
C...THE SOIL PROFILE
      DO  40091  I=2,12
40091 SAVTP(I)=SAVTP(I) + HEAT(I-1)
      SRDTH = SRDTH + RDR*DT
      SSDTH = SSDTH + TDR*DT
      IF(NDAY.EQ.1) SRDTH = SSDTH = SPROD = SRTRS = SCRT = 0.0
      IF(NDAY.EQ.1)HTOCO = HLITI = HLITO = HBGDI = HBGDO = 0.0
C...NUTRIENT STRESS CALCULATIONS FOR BOTH NITROGEN AND PHOSPHOROUS
      RDR=0.0
      TDR=0.0
      SNS=6.0*ATANX(.25,.4,X(60))*ATANX(.030,.05,X(70))
C...TEMPERATURES FOR PHOTOSYNTHESIS, RESPIRATION, AND PHENOLOGY
      SA=(TMAX+TMIN)/2.
      SB=TMAX-TMIN
      STEMP = AMAX1(SA,0.0)
      PHFF=3.1415/(Y1+4.0)
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      PHFFI=1.0/PHFF
      TCD=SP*(-PHFFI*(COS(PHFF*Y1)-1.0))/Y1+TMIN
C...TCD IS THE AVERAGE PHOTOPERIOD TEMPERATURE OBTAINED BY INTEGRATING OVER
C...A TRUNCATED SIN WAVE.
C...PHENOLOGY DEFINITIONS
C                  ****************************************
C                  *      PHENOLOGICAL CALCULATIONS       *
C                  ****************************************
C   1.  PRE-EMERGENCE GROWTH/WINTER DORMANCY
C   2.  FIRST VISIBLE GROWTH
C   3.  FIRST LEAVES FULLY EXPANDED
C   4.  MIDDLE LEAVES FULLY VISABLE
C   5.  FIRST LEAVES SHED OR SENESCENT,MIDDLE LEAVES FULLY EXPANDED
C   6.  LATE LEAVES FULLY EXPANDED
C   7.  DEVELOPING BUDS, MIDDLE-LATE VEGETATIVE
C   8.  MATURE BUDS/LATE VEGETATIVE
C   9.  BUDS AND FLOWERS
C   10. BUDS, FLOWERS, GREEN FRUIT
C   11. BUDS, FLOWERS, GREEN FRUIT, RIPE FRUIT
C   12. GREEN FRUIT AND RIPE FRUIT
C   13. RIPE FRUIT AND DISPERSING SEEDS
C   14. FLOWERING INDUCED DORMANCY
C   15. STANDING DEAD PHASE 1
C   16. STANDING DEAD PHASE 2
      DO 54000 JS=1,5
C...20 DAY RUNNING AVERAGE OF SOIL DROUGHT*MAX AIR TEMP, TO BREAK FLOWFRING
C...INDUCED DORMANCY.
      DO 531 JKS=1,19
      SPTW(JKS,JS)=SPTW(JKS+1,JS)
531   CONTINUE
      SPTW(20,JS)=TMAX*(5.0-WASM(JS))
      SPTWR(JS)=0.0
      DO 541 JKB=1,20
      SPTWR(JS)=SPTWR(JS)+SPTW(JKB,JS)
541   CONTINUE
      SPTWR(JS)=SPTWR(JS)/20.0
C...20 DAY RUNNING AVERAGE OF INSOLATION*SOIL DROUGHT*MAX AIR TEMPERATURE
C...FOR VEGETATIVE PHENOLOGICAL PROGRESSION.
      DO 530 JSS=1,19
      SRAC(JSS,JS)=SRAC(JSS+1,JS)
530   CONTINUE
      SRAC(20,JS)=SUN*TMAX*(5.0-WASM(JS))
      SRAC(20,JS)=AMAX1(SRAC(20,JS),0.0)
      SRACR(JS)=0.0
      DO 540 JRS=1,20
      SRACR(JS)=SRACR(JS)+SRAC(JRS,JS)
540   CONTINUE
      SRACR(JS)=SRACR(JS)/20.0
      IF(PHEN(JS).GT.7.0) GO TO 550
      TMIS(JS)=0.0
      PHEN(JS)=SP2(JS)*SRACR(JS)
      GO TO 560
C...PROGRESSION OF REPRODUCTIVE PHENOLOGICAL STAGES.
```

```
550   TMIS(JS)=TMIS(JS)+SUN*TMAX
C...ADDITION OF RAIN HERE SPEEDS FLOWERING PER PHIL SIMS.
      IF(RAIN.GT.1.0)TMIS(JS)=TMIS(JS)+SUN*TMAX*RAIN
      PHEN(JS)=7.0+7.0*ATANX(SP5(JS),SP6(JS),TMIS(JS))
      IF(PHEN(JS).GT.13.0.AND.SPTWR(JS).LT.SP4(JS))PHEN(JS)=1.0
560   CONTINUE
C...EP IS THE EFFECT OF PHENOLOGY ON PHOTOSYNTHESIS AND RESPIRATION.
      IF(PHEN(JS).LE.7.0) EP(JS)=1.0
       IF(PHEN(JS).GT.7.0)EP(JS)=-.14257*PHEN(JS)+2.0
      IF(X(90).LT.SP3(JS))EP(JS)=PHEN(JS)=0.0
C...FLOWERS AND FRUITS ABORTED IF WINTER OCCURS BEFORE FRUIT ARE SET.
      IF(X(90).LT.SP3(JS).AND.PHEN(JS).GT.7.0)PHEN(JS)=1.0
C                 ***************************
C                 *      PRODUCER MODEL     *
C                 ***************************
C...CALCULATIONS FOR SHOOT AND ROOT GROWTH.
C...EAT IS THE EFFECT OF AIR TEMPERATURE ON PHOTOSYNTHESIS
      EAT(JS)=ATANX(ST1(JS),ST2(JS),TCD)
C...EATR IS THE EFFECT OF AIR TEMPERATURE ON RESPIRATION
      EATR(JS)=TR1(JS)*EXP(TR2(JS)*TCD)
C...WASM IS THE WEIGHTED AVERAGE SOIL MOISTURE, BASED ON ROOT/DEPTH
      WASM(JS)=(WF1(JS)*SMOS(1)+WF2(JS)*SMOS(2)+WF3(JS)*SMOS(3)+
     1WF4(JS)*SMOS(4)+WF5(JS)*SMOS(5)+WF6(JS)*SMOS(6))/SASM(JS)
C...ESM IS THE EFFECT OF SOIL MOISTURE ON PHOTOSYNTHESIS
      ESM(JS)=ATANX(SM1(JS),SM2(JS),WASM(JS))
C...ESMR IS THE EFFECT OF SOIL MOISTURE ON RESPIRATION
      ESMR(JS)=0.6*ATANX(SMR1(JS),SMR2(JS),WASM(JS))+.1
      STEM=X(JS+1)
C...EBM IS THE EFFECT OF BIOMASS ON PHOTOSYNTHESIS
      EBM(JS)=SLA1(JS)*STEM-SLA2(JS)*STEM*STEM+SLA3(JS)
      IF(EBM(JS).LT.1.0)EBM(JS)=1.0
C...ENS IS THE EFFECT OF NUTRIENT STRESS
      ENS(JS)=SNS
C...CIN IS GROSS PHOTOSYNTHESIS
      CIN(JS)=PS(JS)*ESM(JS)*EAT(JS)*EP(JS)*SUN*EBM(JS)
C...COUT IS RESPIRATION
      COUT(JS)=RS(JS) * ESMR(JS) * EATR(JS) * EP(JS) * STEM
C...CNET IS NET PHOTOSYNTHESIS
      CNET(JS)=CIN(JS)-COUT(JS)
C...THIS IF-CHECK PUTS A MAXIMUM ON THE APPARENT PHOTOSYNTHETIC RATE
C...OTHERWISE, PS RATE RISES ABOVE A BIOLOGICALLY REASONABLE MAXIMUM OF
C...ABOUT 8GM/MSQ/DAY WITH 40GM OF BO-GR ON THAT MSQ OF GROUND.
      IF(CNET(JS)*DT.GT.SPSX*EBM(JS))CNET(JS)=SPSX*EBM(JS)/DT
C...ENS IN CRT INCREASES THE SHOOT/ROOT RATIO WITH HIGH N AND P
C...CONDITIONS, THEREBY INCREASING THE SHOOT BIOMASS AND THE
C...PHOTOSYNTHETIC RATE. HENCE, ENS IN CIN AND COUT ARE NOT NEEDED.
C...CRT IS CARBON MOVED TO THE ROOT SYSTEM
      CRT(JS)=TPRT(JS)*(6.0-ENS(JS))*CNET(JS)*STEM/(X(JS+11)*WASM(JS))
C...THIS IF CHECK SAYS ONLY DURING VEGETATIVE GROWTH IS THE ROOT-SHOOT
C...RATIO AFFECTED BY SOIL NUTRIENTS N AND P
      IF(PHEN(JS).GT.7.0)CRT(JS)=CRT(JS)/(6.0-ENS(JS))
      SHOT(JS)=CNET(JS)
      IF(STEM.LT.0.1)SHOT(JS)=CRT(JS)=0.0
```

```
54000 CONTINUE
C*************************************************************************
C...CALCULATE STANDING DEAD PHENOLOGIES.
      DO 69996 M=1,5
      IF (PHEN(M).GT.5.0.AND.PHEN(M) .LT.6.0) WETDY(M)=0.0
      WETDY(M) = WETDY(M) + (PISC1+SMOS(1))*STEMP
      APHEN(M)= PHEN(M)
      APHEN(M+5) =((2.0/APP(M)) *WETDY(M))+14.
69996 CONTINUE
      DO 69997 I = 1,11
      IF(APHEN(I) .GT. 16.) APHEN(I) = 16.
69997 IF(APHEN(I) .LT. 0.0) APHEN(I) = 0.0
C
C                   ***********************************
C                   *      DECOMPOSER CALCULATIONS      *
C                   ***********************************
C...MAINTENANCE ENERGY REQUIREMENT (GRAMS SUBSTRATE PER DAY)
C...IS A FUNCTION OF TEMPERATURE
      HMER(1) = (HMAIN (TMAX+273.)/4. + HMAIN (SA+273.)/2.
     1 + HMAIN (TMIN+273.)/4.) * X(51)
      HMER(2) = (HMAIN (TMAX+273. - SB/4.)/4. + HMAIN (SA+273.)/2.
     1 + HMAIN (TMIN+273.+ SB/4.)/4.) * X(52)
      HMER(3) = HMAIN (SAVTP(2) + 273. ) * X(53)
      HMER(4) = HMAIN (SAVTP(3) + 273. ) * X(54)
C...CALCULATE THE EFFECT OF MOISTURE ON THE RATE OF DECOMPOSITION
      HMOI(2) = SMOS(1) / 5.
      HMOI(3) = (SMOS(2) + SMOS(3)) / 10.
      DO 20002 K = 2,3
      HMO = HMOI(K)
      IF(HMO.LT.0.064)20000,20001
20000 HMOIS(K) = 0.0
      GO TO 20002
20001 IF(HMO.LT.0.10)20003,20004
20003 HMOIS(K) = -1.191 + 18.61 * HMO
      GO TO 20002
20004 IF(HMO.LT.0.28)20005,20006
20005 HMOIS(K) = 0.488 + 1.83 * HMO
      GO TO 20002
20006 IF(HMO.LT.0.45)20040,20041
20040 HMOIS(K) = 1.0
      GO TO 20002
20041 HMOIS(K) = 2.3725 - 3.05 * HMO
20002 CONTINUE
      HMOIS(1) = HMOIS(2)
      HMO = (SMOS(4) + SMOS(5) + SMOS(6)) / 45.
      IF(HMO.LT.0.093)20042,20044
20042 HMOIS(4) = 0.0
      GO TO 20046
20044 IF(HMO.LT.0.129)20048,20050
20048 HMOIS(4) = -1.7308 + 18.61111 * HMO
      GO TO 20046
20050 IF(HMO.LT.0.32)20052,20054
20052 HMOIS(4)=.447 + 1.73 * HMO
```

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      GO TO 20046
20054 IF(HMO.LT.0.45)20056,20058
20056 HMOIS(4) = 1.0
      GO TO 20046
20058 HMOIS(4) = 2.37 - 3.05 * HMO
20046 CONTINUE
C...CALCULATE THE EFFECT OF TEMPERATURE ON THE RATE OF DECOMPOSITION
      HETMP(1) = HEFT(TMAX)/4. + HEFT(SA)/2. + HEFT(TMIN)/4.
      HETMP(2) = HEFT(TMAX - SB/4.)/4. + HEFT(SA)/2.
     1 + HEFT(TMIN + SB/4.)/4.
      HETMP(3) = HEFT(SAVTP(2))
      HETMP(4) = HEFT(SAVTP(3))
C...COMPUTE NITROGEN TO CARBON RATIO FROM PHENOLOGICAL STAGE
C...AND SOFT COMPONENT FROM N/C FOR INPUTS TO LITTER FROM
C...ABOVEGROUND LIVE COMPARTMENTS
      HS1(1)= ATANF(1.5,0.035691,0.069032,-0.12,PHEN(1))
      HS1(2) = ATANF(3.0,0.03591,0.09663,-0.04,PHEN(2))
      HS1(3) = ATANF(5.0,0.03878,0.07268,-0.1,PHEN(3))
      HS1(4) = ATANF(5.0,0.03878,0.07268,-0.1,PHEN(4))
      HS1(5) = 0.0123 - 0.000664 * PHEN(5)
      DO 20074 K = 1,5
20074 HS1(K) = -0.0216 + 1.348 * HS1(K) ** 0.333
C...CALCULATE THE LOSSES OF THE HARD AND SOFT COMPONENTS FROM THE
C...BELOWGROUND DEAD AND LITTER COMPARTMENTS
      DO 20064 K=1,4
      K1 = 40 + K
      HSO40(K) = X(K1) * HETMP(K) * HMOIS(K) * HS40(K) * HKSP
20064 HHO40(K) = X(K1) * HETMP(K) * HMOIS(K) * (1.0 - HS40(K))*HKHP
      HSO40(5) = X(45) * HETMP(1) * HMOIS(1) * HS40(5) * HKSF
      HHO40(5) = X(45) * HETMP(1) * HMOIS(1) * (1.0 - HS40(5)) * HKHF
C...CALCULATE THE GAINS OF HARD AND SOFT MATERIALS TO THE LITTER AND BELOWGROUND
C...DEAD COMPARTMENTS
      HSI40(1) = H0241*HS1(1) + H0341*HS1(2) + H0441*HS1(3)
     1 + H0541*HS1(4) + H0641*HS1(5) + H2041*HS19(1)+H2141*HS19(2)
     1 + H2241*HS19(3) + H2341*HS19(4) + H2441*HS19(5) + H2541*HS19(6)
     2 + H3541 * 0.5
      HHI40(1) = H0241 + H0341 + H0441 + H0541 + H0641 + H2041 + H2141
     1 + H2241 + H2341 + H2441 + H2541 - HSI40(1)  + H3541
      HSI40(2) = H1242*HS11(1) + H1342*HS11(2) + H1442*HS11(3)
     1 + H1542*HS11(4) + H1642*HS11(5)   + H4042
      HHI40(2) = H1242 + H1342 + H1442 + H1542 + H1642 - HSI40(2)+H4042
      HSI40(3) = H1243*HS11(1) + H1343*HS11(2) + H1443*HS11(3)
     1 + H1543*HS11(4) + H1643*HS11(5)
      HHI40(3) = H1243 + H1343 + H1443 + H1543 + H1643 - HSI40(3)
      HSI40(4) = H1244*HS11(1) + H1344*HS11(2) + H1444*HS11(3)
     1 + H1544*HS11(4) + H1644*HS11(5)
      HHI40(4) = H1244 + H1344 + H1444 + H1544 + H1644 - HSI40(4)
      HSI40(5) = 0.08 * H4045          + 0.5*H3545
      HHI40(5) = 0.92 * H4045  + 0.5*H3545
      HLITI  = HLITI  + HHI40(1) + HSI40(1)
      HLITO    = HLITO    +(HHO40(1) + HSO40(1))*DT+H4142
      HBGDI  = HBGDI  + H4142 + HHI40(2) + HSI40(2) + HHI40(3)
     1 + HSI40(3) + HHI40(4) + HSI40(4)
```

```
      HBGDO    = HBGDO    +(HH040(2) + HS040(2) + HH040(3)
     1 + HS040(3) + HH040(4) + HS040(4))*DT
C        **************************************************************
C        *                CALCULATION BLOCK FOR STEER FLOWS          *
C        **************************************************************
      IF(ATIM .EQ. 1.) 61160, 61161
61160 IF(TIME .LT. 119.) GO TO 66001
      IF(ABS(TIME-119.) .GT. .01) GO TO 53000
      X(40)=(ATWT*ANUM*453.59)/(ACRES*4047.0)
      GO TO 53000
61161 IF (NDAY.LT.120.OR.NDAY.GT.300) GO TO 66001
      IF (NDAY.EQ.120) GO TO 53001
      GO TO 53000
53001 IF (TIME .LT.365.0) GO TO 53002
      IF (TIME.LT. 730.0) GO TO 53003
      IF (TIME.LT. 1095.0) GO TO 53002
      IF (TIME.LT. 1460.0) GO TO 53003
      GO TO 53000
53002 X(40)=(ATWT1*ANUM1*453.59)/(ACRE1*4047.0)
      GO TO 53000
53003 X(40)=(ATWT2*ANUM2*453.59)/(ACRE2*4047.0)
53000 CONTINUE
C
C     ******************************************************************
C     *      CALCULATE ANIMALS DIGESTIBLE ENERGY REQUIREMENTS(DIGNR)      *
C...DETERMINE ANIMALS ENERGY NEEDS IN KCAL(AENK)
C
      ATWT=(X(40)*ACRES*4047.)/(ANUM*453.59)
      IF (ATWT.LT.0.0)ATWT=HUNGR=0.0
      ATWK=ATWT/2.2046
      AENK=70.*(ATWK**.75)
C
C...CALCULATE TEMP(SA) EFFECT INCLUDING HEAT INCREMENT(KLEIBER)
C
      IF(SA. GT. 13.0) 67723, 67724
67723 AHEAT=1.42
      GO TO 67725
67724 AHEAT=CLI(0.0,13.0,2.10,1.42,SA)
67725 CONTINUE
      IF(AHEAT.GT. 2.4) AHEAT = 2.4
C
C...DIGNR = DIGESTIBLE ENERGY REQUIRED PER SQUARE METER
      DIGNR=(AENK*AHEAT*2.*ANUM)/(ACRES*4047.)
C
C*********************************************************************
C          CALCULATIONS FOR ANIMALS PREFERENCE TENDENCY(APTC)
C
C...CALCULATE ACCESSIBLE FORAGE
C
      AX(1)=AMAX1(X(2)-5.0,0.0)
      AX(2)=AMAX1(X(3)-5.0,0.0)
      AX(3)=AMAX1(X(4)-5.0,0.0)
      AX(4)=AMAX1(X(5)-1.2,0.0)
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      AX(5)=AMAX1(X(6)-24.0,0.0)
      AX(6)=AMAX1(X(20)-5.0,0.0)
      AX(7)=AMAX1(X(21)-5.0,0.0)
      AX(8)=AMAX1(X(22)-5.0,0.0)
      AX(9)=AMAX1(X(23)-1.0,0.0)
      AX(10)=AMAX1(X(24)-4.0,0.0)
      AX(11)=AMAX1(X(25)-20.0,0.0)
C
C...DETERMINE AMOUNT OF TOTAL AVAILABLE BIOMASS
      ATFB = 0.0
      DO 68808 I= 1,11
68808 ATFB = ATFB + AX(I)
C...DETERMINE IF ATFB IS ADEQUATE - IF NOT REMOVE COWS FOR SEASON
      IF(ATFB .LE. .0001) 68810, 68812
68810 ASTP=0.0
68812 CONTINUE
      IF(NDAY .EQ. 119.) ASTP = 1.0
      IF(ASTP .EQ. 0.0) GO TO 66001
C
C
C...DETERMINE DIGESTIBILITY OF FORAGE
      ADIG(1)=CLI(2.0,14.0,ADGVA,ADGVB,APHEN(1))
      ADIG(2)=CLI(2.0,14.0,ADGVA,ADGVB,APHEN(2))
      ADIG(3)=ATANF(17.0,0.4222,0.7157,-.2,APHEN(3))
      ADIG(4)=CLI(2.0,14.0,ADGVA,ADGVB,APHEN(4))
      ADIG(6)=CLI(14.0,16.0,ADGVB,ADGVC,APHEN(6))
      ADIG(7)=CLI(14.0,16.0,ADGVB,ADGVC,APHEN(7))
      ADIG(8)=CLI(14.0,16.0,ADGVB,ADGVF,APHEN(8))
      ADIG(9)=CLI(14.0,16.0,ADGVB,ADGVC,APHEN(9))
      DO 69810 I=1,11
      IF(ADIG(I) .GT. .80) ADIG(I) = .80
69810 IF(ADIG(I) .LT. .30) ADIG(I)=.30
C
C...CALCULATE AVERAGE DIGESTIBILITY (AVDIG)
      ADG = AQ = 0.0
      DO 69811 I=1,11
      ADG = ADG + (ADIG(I) * FINT(I))
      AQ = AQ + FINT(I)
69811 AVDIG = ADG/AQ
      IF(NDAY .EQ. 120) AVDIG = 0.6
C
C...DETERMINE APTC VALUES
C
      DO 60002 I=1,11
      APTC(I) = AX(I) * ADIG(I) * APAL(I)
60002 CONTINUE
C...SET APTC TO DECIMAL FRACTIONS
C
      SPTC=0.0
      DO 60003 I=1,11
60003 SPTC=SPTC+APTC(I)
      DO 60004 I=1,11
      APTC(I)=APTC(I)/SPTC
```

```
60004 CONTINUE
C
C***********************************************************************
C...CALCULATIONS FOR FORAGE INTAKE
C...HUNGR= HUNGER CARRIED OVER FROM PREVIOUS DAY
      HUNGR=ERR+HUNG
      AHU= .01*X(40)
      IF(HUNGR .GT. AHU) HUNGR = AHU
      IF(HUNGR .LT. 0.0) HUNGR = 0.0
C...INTAKE INCREASES PROPORTIONALLY AS DIGESTABILITY INCREASES
      AFX = CLI(.60,.45,1.40,0.70,AVDIG)
C
C...CALCULATE FORAGE INTAKE RATE (AFIN)
C
      AFIN = ((DIGNR/4./AVDIG)* AFX)+ HUNGR
C
      AMFIN=.04 *X(40)
      IF(AFIN. GT. AMFIN)  AFIN=AMFIN
C
C...CALCULATE FORAGE DESIRED PER CATEGORY
      DO 60005 I=1,11
60005 FINT(I)= APTC(I) * AFIN
C
C...ARRANGE DESIRED FORAGE INTAKE IN ORDER OF PREFERENCE
      CALL GETS(FINT,INDX)
C
C...COMPARE FORAGE INTAKE / AVAILABILITY IN ORDER OF PREFERENCE--
C...FILL UNAVAILABLE CAT. FROM MORE PREFERRED AVAILABLE CAT.
      ERR=0.0
      DO 67704 I=1,11
      J=INDX(I)
      IF(FINT(J).GT.AX(J)) 67703,67704
67703 ERR=ERR+(FINT(J)-AX(J))
      FINT(J)=AX(J)
67704 CONTINUE
      IF(ERR. EQ. 0.0) GO TO 67709
      DO 67706 I=1,11
      J=INDX(I)
      IF(FINT(J).LT.AX(J)) 67705,67706
67705 FINT(J)=FINT(J)+ERR
      IF(FINT(J).LT.AX(J)) 67709,67708
67708 ERR=FINT(J)-AX(J)
      FINT(J)=AX(J)
67706 CONTINUE
      GO TO 67710
67709 CONTINUE
      ERR=0.0
67710 CONTINUE
C
C...RINT=REAL FORAGE INTAKE
      RINT=AFIN-ERR
      APERN = RINT/X(40)
C***********************************************************************
```

```
C...STEER METABOLISM
C
      GAS = .07 * RINT * AVDIG
      AURIN = .07 * RINT * AVDIG
      AFECE=RINT-(AVDIG*RINT)
C...ACTIVITY INCREASES WITH DECREASED FORAGE BIOMASS
      ATX=CLI(150.,0.0,0.0,6.,ATFB)
      IF(ATX .LE. 0.0)ATX=0.0
      IF(ATX .GT. 6.0) ATX = 6.0
      ACT  = .00015  * X(40) * (1.8 + ATX)
C*********************************************************************
C           DETERMINE GAIN(AGAIN) AND CARRYOVER HUNGER(HUNG)
C
      IF(ATWT .LT. 600.) 68977, 68978
68977 AZT = 2.25
      GO TO 68979
68978 AZT = 1.75
68979 CONTINUE
      HUNG = 0.0
      ATGAN = (AZT * 453.59 * ANUM * 1.945)/(ACRES * 4047.)
      ADUM = RINT - AFECE- AURIN - ACT  - GAS - (DIGNR/8.)
      IF(ADUM .GT. 0.0) 68980, 68981
68980 AGAIN = ((ADUM/1.945)* ACRES * 4047.)/(ANUM * 453.59)
      ARESP=(DIGNR/8.)+GAS+ACT +ADUM-(ADUM/1.945)
      HUNG = ATGAN - ADUM
      GO TO 68982
68981 ARESP=(DIGNR/8.)+GAS+ACT -(ADUM/3.)
      AGAIN = ((ADUM*.66666) * ACRES * 4047.)/(ANUM * 453.59)
      HUNG = ABS(ADUM) + ATGAN
68982 CONTINUE
      IF(ADUM .GT. ATGAN) HUNG = 0.0
C
      GO TO 67712
66001 DO 60001 I=1,11
60001 FINT(I)=0.0
      ATWT = 486.
      AGAIN = 0.0
      AURIN=AFECE=ARESP=0.0
67712 CONTINUE
      RETURN
      END
C*********************************************************************

      SUBROUTINE CYCL2
C...UPDATE THE PROPORTION SOFT MATERIAL ACCORDING TO THE FLOWS
C...INTO AND OUT OF THE LITTER AND BELOWGROUND DEAD COMPARTMENTS
      HSI40(2) = HSI40(2) + H4142
      HSO40(1) = HSO40(1) + H4142
      DO 20066 K=1,5
      K2 = 40 + K
      IF(X(K2).EQ.0.0)20066,20067
20067 HS40(K)=((HSI40(K)-HSO40(K))*DT+HS40(K)*(X(K2)+(-HSI40(K)-
     1HHI40(K)+HSO40(K)+HHO40(K))*DT))/X(K2)
```

```
20066 CONTINUE
      HTOBL   = X(42) + X(43) + X(44)
      HTOMI   =          X(52) + X(53) + X(54)                + HTOCO
      HTOCO  = H5101 + H5201 + H5301 + H5401
      RETURN
      END
C*******************************************************************

      SUBROUTINE PENN
C...THIS SUBROUTINE CALCULATES THE POTENTIAL EVAPOTRANSPN RATE(PEVAP)
C...USING PENNMANS 1948 EQUATION.
      WDR=WSP*24.
      R=.20   $CL=1.-CLP/100.
      ZOO=ZZOO=PTEMP
      CALL CLASS(ZOO,ZO1)  $ZO8=RHP*ZOO/100.
      T2=(ZZOO+ 273.)*.01     $T2=T2*T2*T2*T2     $B1=.201*T2
      ME=ZZOO + 1.  $IF(ME.LE.1) ME=1.    $B=RADS(ME)
      E=.35*(ZOO-ZO8)*(1.+ .0098*WDR)
      H= SOLA1*(1.-R)*(.18+.55*CL)-B1*(.56-.092*SQRT(ZO8))*(.10+.90*CL)
      PEVAP=(B*H+.27*E)/(B+.27)    $PEVAP=PEVAP/10.
      IF(PEVAP.LE.0.0) PEVAP=0.01
      RETURN   $END
C*******************************************************************

      SUBROUTINE CLASS(ZOO,ZO1)
C...THIS SUBROUTINE CALCULATES THE SATURATION VAPOR PRESSURE OF WATER(ZO1-MB
C...,ZOO-MM OF HG) FOR AIR AT TEMPERATURE (ZOO)----------THE CLAUSIUS-
C...CLAPEYRON EQUATION (HESS,1959) IS USED TO CALCULATE THE SATURATION
C...VAPOR PRESSURE
      ZOO=ZOO+273.  $C=ALOG(6.11)    $X1=597.3*18.*4.19/8.314
      X2=1./273.    $X3=1./ZOO    $X4=X1*(X2-X3)   $D1=X4 + C
      ZO1=EXP(D1)   $ZOO=ZO1*25.4/33.87
      RETURN   $END
C*******************************************************************

      SUBROUTINE STCHP
C...THIS SUBROUTINE USES A STOCHASTIC PROCESS TO SIMULATE DAILY WEATHER
C...OBSERVATIONS---- THE AVERAGE DAILY CLOUD COVER(CLP), RELATIVE
C...HUMIDITY(RHP),RAINFALL(PRIP) AND MAXIMUM AND MINIMUM AIR TEMPERATURE
C...(TMP,TNP) ARE SIMULATED BY THE MODEL.
      DIMENSION A(2,5,12),B(12,10),C(10,2),RH(12,11),R1(12,11)
     1,WS(12,5,7),CL(12,5,11),TMX(12,5,23),TMN(12,5,23),R2(12,11)
       DATA A/
     10.000,0.000, .036,0.000, .110, .143, .375, .600, .667, .667,
     10.000,0.000, .029,0.000, .088, .188, .516, .550,1.000, .750,
     10.000,0.000, .058,0.000, .163, .267, .516, .593, .500, .800,
     10.000,0.000, .085,0.000, .226, .300, .909, .737, .500, .833,
     10.000,0.000, .031,0.000, .283, .357, .588, .743,1.000,1.000,
     10.000,0.000, .044, .125, .328, .343, .650, .600,1.000, .923,
     10.000,0.000, .075,0.000, .338, .367, .529, .474,0.000,0.000,
     10.000,0.000, .126, .125, .246, .259, .444, .467, .500,0.000,
     10.000,0.000, .045, .200, .241, .263, .750, .647, .800, .857,
     10.000,0.000, .023,0.000, .197, .083, .385, .667, .667,1.000,
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10.000,0.000,0.000,0.000, .117,0.000, .174, .533,1.000,1.000,
10.000,0.000,0.000,0.000, .059, .182, .424, .333, .667,1.000/
 DATA R/.587,.606,.449,.382,.322,.299,.311,.350,.349,.336,.487,.528
1,.839,.824,.678,.614,.548,.502,.527,.567,.579,.559,.744,.822,
1.915,.920,.830,.739,.669,.637,.668,.722,.671,.686,.856,.920,
1.964,.984,.943,.873,.808,.798,.813,.843,.841,.841,.944,.982,
1.978,1.00,.986,.941,.889,.885,.883,.915,.919,.914,.985,.988,
1.991,1.00,.997,.975,.938,.933,.935,.950,.965,.950,.995,.994,
11.00,1.00,1.00,.995,.990,.973,.980,.988,.997,.991,1.00,1.00,
11.00,1.00,1.00,1.00,1.00,1.00,.998,.998,1.00,1.00,1.00,1.00,
11.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,
11.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00,1.00/
 DATA C/0.0,.10,.20,.30,.50,.70,.90,1.5,2.5,4.5,.10,.10,.10,.20,.20
1,.20,.60,1.0,2.0,2.0/
 DATA RH/
10.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,
10.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,
10.000,0.000, .005, .012, .011, .017, .005,0.000, .005, .005,0.000,
1 .023, .005, .009, .075, .083, .124, .155, .129, .081, .115, .156,
1 .166, .182, .071, .122, .312, .231, .306, .387, .318, .252, .355,
1 .440, .392, .453, .290, .299, .575, .456, .527, .597, .571, .524,
1 .627, .729, .630, .682, .576, .543, .828, .663, .651, .790, .724,
1 .710, .834, .881, .796, .794, .795, .733, .919, .876, .817, .878,
1 .862, .838, .949, .968, .873, .893, .919, .887, .968, .964, .962,
1 .956, .963, .924,1.000, .991, .934, .953, .976, .950,1.000,1.000,
1 .995, .978,1.000, .986,1.000, .995, .989, .995,1.000, .991,1.000,
11.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000/
 DATA R1/
10.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,
10.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,
10.000,0.000,0.000, .006,0.000, .011,0.000,0.000,0.000,0.000,0.000,
1 .009,0.000, .005, .027, .059, .065, .077, .092, .024, .041, .078,
1 .050, .065, .033, .069, .118, .118, .199, .265, .221, .143, .207,
1 .271, .271, .307, .171, .185, .403, .308, .387, .453, .401, .357,
1 .479, .583, .475, .549, .429, .375, .640, .503, .543, .652, .631,
1 .571, .677, .761, .674, .721, .638, .620, .849, .692, .667, .796,
1 .733, .719, .853, .890, .807, .809, .810, .750, .919, .864, .812,
1 .878, .857, .829, .949, .959, .867, .893, .919, .898, .957, .941,
1 .957, .945, .949, .919,1.000, .982, .923, .953, .971, .944,1.000,
11.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000/
 DATA R2/
10.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,
10.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,
10.000,0.000, .016, .030, .038, .039, .028, .014, .018, .018, .028,
1 .056, .029, .042, .129, .118, .204, .265, .221, .148, .207, .294,
1 .287, .316, .181, .190, .489, .396, .462, .536, .493, .443, .567,
1 .674, .564, .623, .495, .495, .801, .627, .640, .757, .700, .700,
1 .825, .876, .779, .772, .771, .722, .919, .876, .828, .884, .866,
1 .848, .954, .968, .873, .898, .924, .912, .989, .976, .978, .972,
1 .963, .938,1.000, .995, .939, .972, .976, .977,1.000,1.000, .995,
1 .994,1.000,1.000,1.000, .995, .994,1.000,1.000,1.000,1.000,1.000,
11.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,
11.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000/
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C...CLD(I,J,K),WS(I,J,K),TMX(I,J,K),TMN(I,J,K) CONTAIN THE CUMULATIVE
C...FREQUENCY DISTRIBUTIONS FOR CLOUD COVER(K=1,2,.....,11--K=2 PROBABILITY
C...FOR CLOUD COVER LESS THAN OR EQUAL TO 10 PERCENT, K=3--PROBABILITY
C...FOR CLOUD COVER LESS THAN OR EQUAL TO 20 PERCENT, ETC----CL(I,J,1)=0.0),
C...WIND SPEED(K=1,2,..7, K=2--PROBABILITY FOR WIND SPEEDS LESS THAN OR
C...EQUAL TO 5 MPH, K=3 PROBABILITY FOR WIND SPEEDS LESS THAN OR EQUAL TO
C...10 MPH, ETC------WS(I,J,1)=0.0), MAXIMUM AIR TEMPERATURE(K=1,2,.....,23--
C...K=2 PROBABILITY FOR MAXIMUM AIR TEMPERATURES LESS THAN OR EQUAL TO 0
C...(FAHRENHEIT),K=3 IS THE PROBABILITY FOR MAXIMUM AIR TEMPERATURES LESS
C...THAN OR EQUAL TO 5(FAHRENHEIT)------TMX(I,J,1)=0.), AND THE MINIMUM
C...AIR TEMPERATURE (K=2 PROBABILITY FOR THE MINIMUM AIR TEMPERATURE LESS
C...THAN OR EQUAL TO -25(FAHRENHEIT),K=3 IS THE PROBABILITY FOR MINIMUM AIR
C...TEMPERATURE LESS THAN OR EQUAL TO -20(FAHRENHEIT), ETC----TMN(I,J,1)=0,
C...K=1,2,.......23) AS A FUNCTION OF THE MONTH OF THE YEAR(I=1,2,,12), AND
C...RELATIVE HUMIDITY (J=1,2,,5,J=1--RH 0-20 PERCENT, J=2--RH 21-40 PERCENT,
C...ETC)
C...RH(I,J),R1(I,J),R2(I,J) ARE CUMULATIVE FREQUENCY DISTRIBUTIONS FOR
C      RELATIVE HUMIDITY(J=1,2,....,11--J=2-PROBABILITY FOR RH LESS
C      THAN OR EQUAL TO 10 PERCENT -J=3-PROBABILITY FOR RH LESS
C      THAN OR EQUAL TO 20 PERCENT---RH(I,1)=R1(I,1)=R2(I,1)=0.0)
C      AS A FUNCTION OF THE MONTH OF THE YEAR(I=1,2,..,12), RH(I,J)
C      IS THE REGULAR RH FREQUENCY DISTRIBUTION, IN R1(I,J) THE
C      AVERAGE RELATIVE HUMIDITY HAS BEEN INCREASED BY 15 PERCENT
C      ,WHILE IN R2(I,J) THE AVERAGE RH HAS BEEN DECREASED BY
C      BY 15 PERCENT.
C...B(I,J) IS THE CUMULATIVE FREQUENCY DISTRIBUTION FOR RAINFALL AMOUNTS
C      (J=1,2,...,10-----J=1 IS THE PROBABILITY FOR RAINFALL AMOUNTS
C      LESS THAN OR EQUAL TO .10 INCHES, J=2 IS THE PROBABILITY FOR
C      RAINFALL AMOUNTS LESS THAN OR EQUAL TO .20 INCHES,.30,.50,
C      .70,.90,1.5,2.5,4.5,6.5) FOR THE I TH MONTH (I=1,2,...,12)
C...C(I,J) CONTAINS THE LOWEST AMOUNT OF RAINFALL IN THE I TH RAINFALL
C      CATAGORY(J=1) AND THE WIDTH OF THE I TH RAINFALL CATAGORY(J=2)
C...A(I,J,K) IS THE PROBABILITY FOR RAINFALL GIVEN THE OCCURANCE(I=2) OR NON
C      OCCURANCE (I=1) OF RAINFALL ON THE PREVIOUS DAY, THE MONTH OF
C      THE YEAR (K=1,2,...,12) AND THE AVERAGE RELATIVE HUMIDITY
C      FOR THE DAY (J=1,2,..5--J=-RH 0-20 PERCENT,J=2-RH 21-40 PERCENT
C      )


C...READ IN THE STATISTICAL RELATIONSHIPS THAT ARE USED BY THE
C...STOCHASTIC SIMULATION MODEL(READ THE DATA FROM A FILE THAT HAS BEEN
C...STORED IN THE COMPUTER)
C...----APPLICATION TO THE SITES---- THE STATISTICAL RELATIONSHIPS USED BY
C...THIS MODEL MUST BE CALCULATED FROM A TIME SERIES OF DAILY WEATHER
C...OBSERVATIONS AT THE PARTICULAR SITE(CL,WS,TMX,TMN,RH,R1,R2,A,B)
      IF(TIME.EQ.0.0) READ(7,200)CL
      IF(TIME.EQ.0.0) READ(7,200)WS
      IF(TIME.EQ.0.0) READ(7,200)TMX
      IF(TIME.EQ.0.0) READ(7,200)TMN
  200 FORMAT(1H ,13(F5.3,1X))
      RAN=RANF(0)
      NNO=MON
C...DETERMINE WHICH RELATIVE HUMIDITY FREQUENCY DISTRIBUTION IS
```

```
C...USED TO CALCULATE THE RELATIVE HUMIDITY(RHP)
      IF(PMOD(NNO).EQ.1.) GO TO 800    $IF(PMOD(NNO).EQ.2.) GO TO 600
      IF(PMOD(NNO).EQ.3.) GO TO 700
C...USE THE UNMODIFIED RELATIVE HUMIDITY DISTRIBUTION TO GENERATE THE
C...CLASS INTERVAL OF RELATIVE HUMIDITY
  800 DO  1  I=2,11
      IF(RAN.LE.RH(MON,I).AND.RAN.GT.RH(MON,I-1))GO TO 2
    1 CONTINUE
    2 RHI=I-2  $RAN=RANF(0)
      GO TO 605
C...USE THE THE FREQUENCY DISTRIBUTION IN WHICH THE AVERAGE RELATIVE
C...HUMIDITY HAS BEEN INCREASED BY 15 PERCENT.
  600 DO  601  I=2,11
      IF(RAN.LE.R1(MON,I).AND.RAN.GT.R1(MON,I-1))GO TO 602
  601 CONTINUE
  602 RHI=I-2   $RAN=RANF(0)
      GO TO 605
C...USE THE RELATIVE HUMIDITY FREQUENCY DISTRIBUTION IN WHICH THE AVERAGE
C...RELATIVE HUMIDITY HAS BEEN DECREASED BY 15 PERCENT
  700 DO  701  I=2,11
      IF(RAN.LE.R2(MON,I).AND.RAN.GT.R2(MON,I-1))GO TO 702
  701 CONTINUE
  702 RHI=I-2  $RAN=RANF(0)
  605 CONTINUE
      RHP=(RHI+ RAN*1.)*10.
      NRH=RHP/20. + 1.   $IF(NRH.GT.5) NRH=5.
C...SIMULATE THE DAILY AVERAGE WIND SPEED(WSP)
      RAN=RANF(0)       $DO  3  I=2,7
      IF(RAN.LE.WS(MON,NRH,I).AND.RAN.GT.WS(MON,NRH,I-1)) GO TO 4
    3 CONTINUE
    4 WSI=I-2    $RAN=RANF(0)
      WSP=(WSI + RAN*1.)*5.00
C...SIMULATE THE DAILY AVERAGE CLOUD COVER(CLP)
      RAN=RANF(0)   $DO  5  I=2,11
      IF(RAN.LE.CL(MON,NRH,I).AND.RAN.GT.CL(MON,NRH,I-1)) GO TO 6
    5 CONTINUE
    6 CLI=I-2   $RAN=RANF(0)
      CLP=(CLI + RAN*1.)*10.
C...SIMULATE THE MAXIMUM AIR TEMPERATURE(TMP)
      RAN=RANF(0)    $DO  7  I=2,23
      IF(RAN.LE.TMX(MON,NRH,I).AND.RAN.GT.TMX(MON,NRH,I-1)) GO TO 8
    7 CONTINUE
    8 TMI=I-2  $RAN=RANF(0)
      TMP=-5.  +(TMI+ RAN*1.)*5.
      IF(TMP.GT.100.) CALL PXT(1.,P9)
      IF(TMP.LT.0.0) CALL PXT(-1.,P9)
      IF(TMP.GT.100..OR.TMP.LT.0.0) TMP=TMP + P9
C...SIMULATE THE MINIMUM AIR TEMPERATURE(TNP)
      RAN=RANF(0)    $DO  9  I=2,23
      IF(RAN.LE.TMN(MON,NRH,I).AND.RAN.GT.TMN(MON,NRH,I-1)) GO TO 10
    9 CONTINUE
   10 TNI=I-2  $RAN=RANF(0)
      TNP=-35.  + (TNI + RAN*1.)*5.
```

```
      IF(TNP.GT.70.) CALL PXT(1.,P9)
      IF(TNP.LT.-30.) CALL PXT(-1.,P9)
      IF(TNP.GT.70..OR.TNP.LT.-30.)TNP=TNP + P9
  532 CONTINUE
      TNN=TMP    $IF(TMP.LT.TNP) TMP=TNP  $IF(TMP.LT.TNP)TNP=TNN
      RAN=RANF(0)   $I=1   $DRY=0.0    $IF(PRA.EQ.1.) I=2
C...DETERMINE IF RAINFALL WILL OCCUR
      IF(RAN.LE.A(I,NRH,MON)*PRF)  DRY=1.
      RHHH=0.0
      IF(DRY.EQ.1.)GO TO 60  $PRIP=0.0  $PRA=0.0  $GO TO 11
   60 RAN=RANF(0)      $IF=1.
C...CALCULATE THE RAINFALL AMOUNT
      IF(RAN.LT.B(NNO,1))GO TO 14
      DO  12  I=1,9
      IF(RAN.GT.B(NNO,I).AND.RAN.LE.B(NNO,I+1)) GO TO 15
   12 CONTINUE
   15 IF=I+1
   14 RAN=RANF(0)
      PRIP=          C(IF,1) + C(IF,2)*RAN  $PRA=1.0
   11 CONTINUE
      TMAX = (TMP-32.0)/1.84
      TMIN = (TNP-32.0)/1.84
      RETURN  $END
C*******************************************************************

      SUBROUTINE PXT(P8,P9)
C...THIS SUBROUTINE IS USED TO DETERMINE THE MAXIMUM AND MINIMUM TEMPERATURE
C...AT THE UPPER AND LOWER LIMITS OF THE FREQUENCY DISTRIBUTION(+10 OR-10
C...DEGREES FAHRENHEIT AT THE MOST CAN BE ADDED TO THE TEMPERATURE AT THE
C...EXTREMES)
C...THIS SUBROUTINE CALCULATES A CUMULATIVE FREQUENCY DISTREBUTION
C...FROM A FREQUENCY DISTREBUTION WHICH ASSUMES THAT THE PROBABILITY FOR
C...TEMPERATURES GREATER THAN THE END POINT VALUES DECREASES LINEARLY TO
C...ZERO AT 10 DEGREES BEYOND THE END POINT VALUES. THE NUMBER OF DEGREES
C...ADDED TO THE END POINT VALUE IS THEN CALCULATED BY THIS SUBROUTINE.
      DIMENSION PM(11)
      PM(1)=0.   $DO  1  I=2,11
      PQ=(I-1)
    1 PM(I)=PM(I-1) + 1.-.1*PQ
      DO  3  I=2,11
    3 PM(I)=PM(I)/PM(11)
      RAN=RANF(0)
      DO  2  I=1,10
      IF(RAN.GT.PM(I).AND.RAN.LE.PM(I+1)) GO TO 5
    2 CONTINUE
      I=10
    5 P9=P8*I
      RETURN   $END
C*******************************************************************

      SUBROUTINE START
C...THE WEIGHTING FACTORS WF1(I) TO WF6(I) ARE SUMMED HERE FOR USE IN CYCL1.
      DO 53333 JIT = 1,5
```

```
       SASM(JIT)=WF1(JIT)+WF2(JIT)+WF3(JIT)+WF4(JIT)+WF5(JIT)+WF6(JIT)
       SMFC=(WF1(JIT)*SFC1(JIT)+WF2(JIT)*SFC2(JIT)+WF3(JIT)*SFC3(JIT)+
      1WF4(JIT)*SFC4(JIT)+WF5(JIT)*SFC5(JIT)+WF6(JIT)*SFC6(JIT))
      2/SASM(JIT)
       SMWP=(WF1(JIT)*SWP1(JIT)+WF2(JIT)*SWP2(JIT)+WF3(JIT)*SWP3(JIT)+
      1WF4(JIT)*SWP4(JIT)+WF5(JIT)*SWP5(JIT)+WF6(JIT)*SWP6(JIT))
      2/SASM(JIT)
       SM2(JIT)=(SMFC-SMWP)/2.0
       SMR2(JIT)=SM2(JIT)
       SM1(JIT)=SMFC-SM2(JIT)
       SMR1(JIT)=SM1(JIT)+(0.1*SM1(JIT))
 53333 CONTINUE
       TEMP=X(2)+X(3)+X(4)+X(5)+X(6)
       X(62)=FNCIP*TEMP
       X(72) =FCPIP*TEMP
       TEMP=X(12)+X(13)+X(14)+X(15)+X(16)
       X(61)=FNCIP*TEMP
       X(71)=FCPIP*TEMP
       CALL RANSET(61)
       RETURN
       END
```

```
                                                                                         000100    017667    000000    000000
CORE MAP  17.12.44.  NORMAL            CONTROL
       ---TIME---LOAD MODE --L1--L2-----TYPE---------------USER----+----CALL------------FWA LOAD--LWA LOAD--BLNK COMN--LENGTH--
       FWA LOADER  064741  FWA TABLES  061657
       -PROGRAM----ADDRESS-                         --LABELED---COMMON--
       SIMCMP3     002242                                   STORAGF     000100
                                                            ROUTINS     002052
                                                            FLOWTBL     002224
                                                            OUTP        002226
                                                            UNITS       002232
                                                            OUTP        002226
       FMTPG       004355                                   UNITS       002232

       SKIPF       004412                                   ROUTINS     002052
       CARDTP      004460                                   OUTP        002226
                                                            UNITS       002232
                                                            STORAGE     000100
       STIDF       005410                                   UNITS       002232
                                                            FLOWTBL     002224
       FLIDF       006564                                   UNITS       002232

       IIZR        007517                                   ROUTINS     002052
       USIDF       007567                                   UNITS       002232
                                                            ROUTINS     002052
       TXIDF       010172                                   STORAGE     000100
                                                            FLOWTBL     002224
                                                            UNITS       002232

       NUM         010566
       CHARS       010672
       BYTES       011010
       GETBA       011111
       SIO$        011130
       ABORT$      012536
       SYSTEM$     012545
       ACGOER$     013553
       ENDFIL$     013566
       IFENDF$     013634
       INPUTC$     013713
       INPUTS$     014042
       KODER$      014117
       KRAKER$     015542
       OUTPTC$     017274
       OUTPTS$     017370
       REWINM$     017461
       ALNLOGE     017531
       ITOJE       017570
       REMARK$     017606
       TIME$       017636                                   REFERENCES
       ----UNSATISFIED EXTERNALS-----
```

```
SIMCOMP VERSION 3.0          PARAMETER VALUES

- SIMULATION CONTROL PARAMETERS -

TIME  = INDEFINITE
TSTRT =          0
TEND  =  730.000000
DT    =  1.00000000
DTPR  =  365.000000
DTPL  =          0
DTFL  =  100.000000

- STATE VARIABLES -

X(  1) = 800.000000
X(  5) = .500000000
X( 14) = 20.0200000
X( 21) = 30.0000000
X( 25) = 10.0000000
X( 43) = 162.000000
X( 52) = 4.00000000
X( 61) = 12.0000000
X( 65) = 100.000000
X( 72) = .500000000
X( 76) = 400.000000

X(  2) = .500000000
X(  6) = 14.8400000
X( 15) = 11.5200000
X( 22) = .500000000
X( 40) =          0
X( 44) = 100.000000
X( 53) = 9.00000000
X( 62) = 1.20000000
X( 66) = 100.000000
X( 73) = 80.0000000
X( 90) =          0

X(  3) = .500000000
X( 12) = 90.4000000
X( 16) = 24.0000000
X( 23) = 2.00000000
X( 41) = 150.000000
X( 45) =          0
X( 54) = 12.0000000
X( 63) = 150.000000
X( 70) = .100000000E-01
X( 74) = .120000000
X( 98) = 7.00000000

X(  4) = .500000000
X( 13) = 40.0000000
X( 20) = 50.0000000
X( 24) = 4.00000000
X( 42) = 100.000000
X( 51) = 17.0000000
X( 60) = .300000000
X( 64) =          0
X( 71) = .200000000
X( 75) = 20.0000000
X( 99) = 100.000000

- USER DEFINED VARIABLES -

ATWT = 486.000000
ANUM2 = 45.0000000
ACRES = 320.000000
FINT(4) =          0
FINT(8) =          0
AFECE =          0
APAL(2) = 1.00000000
APAL(6) = 1.00000000
APAL(10) =          0
TNDX(3) =          0
TNDX(7) =          0
TNDX(11) =          0
ADIG(3) = .600000000
ADIG(7) = .500000000
ADIG(11) = .300000000
APHEN(3) = 15.0000000
APHEN(7) = 15.0000000
APHEN(11) = 15.0000000
WETDY(3) = 1520.00000
AX(1) =          0
AX(5) =          0
AX(9) =          0
APTC(2) =          0
APTC(6) =          0
APTC(10) =          0
APP(3) = 2000.00000
APERN = .200000000E-01
ADGVA = .700000000
ATIM = 1.00000000
ST1(4) = 22.0000000
ST2(3) = 7.00000000
TR1(2) = .200000000E-01
TR2(1) = .155000000
TR2(5) = .150000000
TMAX =          0
SLA3(3) = .200000000
SHOT(2) = .100000000

ATWT1 = 486.000000
ACRE1 = 320.000000
FINT(1) =          0
FINT(5) =          0
FINT(9) =          0
AURIN =          0
APAL(3) = 1.00000000
APAL(7) = 1.00000000
APAL(11) =          0
TNDX(4) =          0
TNDX(8) =          0
HUNG = .100000000E-04
ADIG(4) = .600000000
ADIG(8) = .500000000
ASTP = 1.00000000
APHEN(4) = 15.0000000
APHEN(8) = 15.0000000
AVDIG = .600000000
WETDY(4) = 1520.00000
AX(2) =          0
AX(6) =          0
AX(10) =          0
APTC(3) =          0
APTC(7) =          0
APTC(11) =          0
APP(4) = 1900.00000
AFIN = .100000000E-04
ADGVB = .500000000
ST1(1) = 20.0000000
ST1(5) = 16.0000000
ST2(4) = 8.00000000
TR1(3) = .150000000E-01
TR2(2) = .160000000
SA =          0
TMIN =          0
SLA3(4) = 1.00000000
SHOT(3) = .100000000

ATWT2 = 460.000000
ACRE2 = 320.000000
FINT(2) =          0
FINT(6) =          0
FINT(10) =          0
ARESP =          0
APAL(4) = .130000000
APAL(8) = .800000000
TNDX(1) =          0
TNDX(5) =          0
TNDX(9) =          0
ADIG(1) = .600000000
ADIG(5) = .400000000
ADIG(9) = .500000000
APHEN(1) = 15.0000000
APHEN(5) = 15.0000000
APHEN(9) = 15.0000000
WETDY(1) = 1520.00000
WETDY(5) = 1520.00000
AX(3) =          0
AX(7) =          0
AX(11) =          0
APTC(4) =          0
APTC(8) =          0
APP(1) = 1900.00000
APP(5) = 1900.00000
RINT =          0
ADGVC = .350000000
ST1(2) = 15.0000000
ST2(1) = 8.00000000
ST2(5) = 7.00000000
TR1(4) = .100000000E-01
TR2(3) = .155000000
TCD =          0
SLA3(1) = .200000000
SLA3(5) = 1.00000000
SHOT(4) = .100000000

ANUM1 = 20.0000000
ANUM = 20.0000000
FINT(3) =          0
FINT(7) =          0
FINT(11) =          0
APAL(1) = 1.00000000
APAL(5) = .200000000E-03
APAL(9) = .550000000
TNDX(2) =          0
TNDX(6) =          0
TNDX(10) =          0
ADIG(2) = .600000000
ADIG(6) = .500000000
ADIG(10) = .300000000
APHEN(2) = 15.0000000
APHEN(6) = 15.0000000
APHEN(10) = 15.0000000
WETDY(2) = 1520.00000
WETDY(6) = 1520.00000
AX(4) =          0
AX(8) =          0
APTC(1) =          0
APTC(5) =          0
APTC(9) =          0
APP(2) = 2000.00000
AGAIN = .800000000
ERR =          0
ADGVF = .450000000
ST1(3) = 20.0000000
ST2(2) = 7.00000000
TR1(1) = .100000000E-01
TR1(5) = .200000000E-01
TR2(4) = .150000000
STEMP =          0
SLA3(2) = .200000000
SHOT(1) = .100000000
SHOT(5) = .100000000
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SDTH(1) =  .300000000E-01
SDTH(5) =  .400000000E-01
RTRS(2) =  .100000000E-03
RTDTH(1) =  .100000000E-01
RTDTH(5) =  .500000000E-02
TPRT(4) =  4.00000000
CRT(3) =              0
P6560 =  .600000000
FNNIP =  .500000000E-02
FNCIP =  .300000000E-01
FPSR =  .600000000E-02
WF1(2) =  3.00000000
WF2(1) =  2.00000000
WF2(5) =  6.00000000
WF3(4) =  1.00000000
WF4(3) =  4.00000000
WASM(2) =  1.60000000
SM1(1) =  1.70000000
SM1(5) =  1.02000000
SM2(4) =  .760000000
WF5(3) =  2.00000000
WF6(2) =  1.00000000
SASM(1) = INDEFINITE
SASM(5) = INDEFINITE
PS01(2,1) =  1.00000000
PS01(6,1) =  2.00000000
PS01(10,1) =  2.00000000
PS01(4,2) =              0
PS01(8,2) =              0
PS01(2,3) =  .200000000
PS01(6,3) =  .500000000E-01
PS01(10,3) =             0
PS01(4,4) =  13.0000000
PS01(8,4) =  13.0000000
PS01(2,5) =  5.00000000
PS01(6,5) =  15.0000000
PS01(10,5) =  15.0000000
PISC1 =              0
CLP =  20.0000000
CLD(2) =  20.0000000
CLD(6) =  20.0000000
CLD(10) =  20.0000000
PMOD(2) =  1.00000000
PMOD(6) =  1.00000000
PMOD(10) =  1.00000000
DAHOR =  15.0000000
RADS(4) =  .230000000
RADS(8) =  .290000000
RADS(12) =  .360000000
RADS(16) =  .460000000
RADS(20) =  .570000000
RADS(24) =  .720000000
RADS(28) =  .940000000
RADS(32) =  1.10000000
RADS(36) =  1.33000000
RADS(40) =  1.62000000
RADS(44) =  1.80000000
RADS(48) =  1.96000000
NLYA =              3
PILTT =              0
RAIN =              0
SAVTP(2) = -2.00000000
SAVTP(6) =  1.00000000
SAVTP(10) =  4.50000000
HEAT(1) = INDEFINITE
HEAT(5) = INDEFINITE
SDTH(2) =  .400000000E-01
SDTH(6) =  .200000000E-02
RTRS(3) =  .300000000E-04
RTDTH(2) =  .400000000E-02
TPRT(1) =  4.00000000
TPRT(5) =  .800000000
CRT(4) =              0
P6065 =  100.000000
RDR =              0
P7075 =  .600000000E-03
P7675 =  .518400000E-06
WF1(3) =  2.00000000
WF2(2) =  2.00000000
WF3(1) =  1.00000000
WF3(5) =  5.00000000
WF4(4) =  3.00000000
WASM(3) =  1.60000000
SM1(2) =  1.68000000
SM2(1) =  .650000000
SM2(5) =  .340000000
WF5(4) =  2.00000000
WF6(3) =  1.00000000
SASM(2) = INDEFINITE
PLAT = INDEFINITE
PS01(3,1) =  1.00000000
PS01(7,1) =  2.00000000
PS01(1,2) =              0
PS01(5,2) =              0
PS01(9,2) =              0
PS01(3,3) =  .100000000
PS01(7,3) =  .400000000E-01
PS01(1,4) =  8.00000000
PS01(5,4) =  13.0000000
PS01(9,4) =  13.0000000
PS01(3,5) =  5.00000000
PS01(7,5) =  15.0000000
PTA =              0
PILT1 =              0
TMP = INDEFINITE
CLD(3) =  20.0000000
CLD(7) =  20.0000000
CLD(11) =  20.0000000
PMOD(3) =  1.00000000
PMOD(7) =  1.00000000
PMOD(11) =  1.00000000
RADS(1) =  .190000000
RADS(5) =  .250000000
RADS(9) =  .300000000
RADS(13) =  .390000000
RADS(17) =  .490000000
RADS(21) =  .600000000
RADS(25) =  .780000000
RADS(29) =  .990000000
RADS(33) =  1.16000000
RADS(37) =  1.39000000
RADS(41) =  1.67000000
RADS(45) =  1.84000000
RADS(49) =  1.98000000
NLYS =              7
PEVAP =              0
PISCT =              0
SAVTP(3) = -1.00000000
SAVTP(7) =  1.50000000
SAVTP(11) =  5.50000000
HEAT(2) = INDEFINITE
HEAT(6) = INDEFINITE
SDTH(3) =  .400000000E-01
SPSX =  .200000000
RTRS(4) =  .500000000E-04
RTDTH(3) =  .100000000E-01
TPRT(2) =  4.00000000
CRT(1) =              0
CRT(5) =              0
P7370 =  .300000000E-04
TDR =              0
P7570 =  .450000000E-05
PHRI =  .100000000E-02
WF1(4) =  1.00000000
WF2(3) =  1.00000000
WF3(2) =  1.00000000
WF4(1) =  4.00000000
WF4(5) =  1.00000000
WASM(4) =  1.60000000
SM1(3) =  2.31000000
SM2(2) =  .560000000
WF5(1) =  1.00000000
WF5(5) =  1.00000000
WF6(4) =  1.00000000
SASM(3) = INDEFINITE
PRIP =              0
PS01(4,1) =  2.00000000
PS01(8,1) =  2.00000000
PS01(2,2) =              0
PS01(6,2) =              0
PS01(10,2) =             0
PS01(4,3) =  .120000000
PS01(8,3) =              0
PS01(2,4) =  8.00000000
PS01(6,4) =  13.0000000
PS01(10,4) =  13.0000000
PS01(4,5) =  15.0000000
PS01(8,5) =  15.0000000
PTF = INDEFINITE
PEVTT =              0
TNP = INDEFINITE
CLD(4) =  20.0000000
CLD(8) =  20.0000000
CLD(12) =  20.0000000
PMOD(4) =  1.00000000
PMOD(8) =  1.00000000
PMOD(12) =  1.00000000
RADS(2) =  .200000000
RADS(6) =  .260000000
RADS(10) =  .330000000
RADS(14) =  .410000000
RADS(18) =  .510000000
RADS(22) =  .620000000
RADS(26) =  .830000000
RADS(30) =  1.02000000
RADS(34) =  1.22000000
RADS(38) =  1.46000000
RADS(42) =  1.72000000
RADS(46) =  1.88000000
RADS(50) =  1.99000000
SOLA1 =              0
EVAST =              0
EVATT =              0
SAVTP(4) = -1.00000000
SAVTP(8) =  2.50000000
SAVTP(12) =  6.00000000
HEAT(3) = INDEFINITE
HEAT(7) = INDEFINITE
SDTH(4) =  .400000000E-01
RTRS(1) =  .350000000E-03
RTRS(5) =  .300000000E-05
RTDTH(4) =  .200000000E-01
TPRT(3) =  3.00000000
CRT(2) =              0
P6360 =  .200000000E-03
SMOGG =              0
FNSR =  .624000000E-01
FCPIP =  .105000000E-02
WF1(1) =  3.00000000
WF1(5) =  5.00000000
WF2(4) =  1.00000000
WF3(3) =  1.00000000
WF4(2) =  2.00000000
WASM(1) =  1.60000000
WASM(5) =  1.10000000
SM1(4) =  2.28000000
SM2(3) =  .770000000
WF5(2) =  1.00000000
WF6(1) =  1.00000000
WF6(5) =  1.00000000
SASM(4) = INDEFINITE
PS01(1,1) =  1.00000000
PS01(5,1) =  2.00000000
PS01(9,1) =  2.00000000
PS01(3,2) =              0
PS01(7,2) =              0
PS01(1,3) =  .420000000
PS01(5,3) =  .700000000E-01
PS01(9,3) =              0
PS01(3,4) =  8.00000000
PS01(7,4) =  13.0000000
PS01(1,5) =  5.00000000
PS01(5,5) =  15.0000000
PS01(9,5) =  15.0000000
PRA =              0
WSP = INDEFINITE
CLD(1) =  20.0000000
CLD(5) =  20.0000000
CLD(9) =  20.0000000
PMOD(1) =  1.00000000
PMOD(5) =  1.00000000
PMOD(9) =  1.00000000
DEPTH =  75.0000000
RADS(3) =  .220000000
RADS(7) =  .280000000
RADS(11) =  .350000000
RADS(15) =  .440000000
RADS(19) =  .540000000
RADS(23) =  .670000000
RADS(27) =  .880000000
RADS(31) =  1.05000000
RADS(35) =  1.27000000
RADS(39) =  1.54000000
RADS(43) =  1.76000000
RADS(47) =  1.92000000
NOBSD =              1
RHP = INDEFINITE
PRF =  .600000000
SAVTP(1) = -4.00000000
SAVTP(5) = -.500000000
SAVTP(9) =  3.50000000
SAVTP(13) =  6.50000000
HEAT(4) = INDEFINITE
HEAT(8) = INDEFINITE
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HEAT(9) = INDEFINITE
SBOT(1) =  7.00000000
SBOT(5) =  9.50000000
SBOT(9) =  14.0000000
ZMOND =           0
SMOS(1) =  .600000000
SMOS(5) =  2.00000000
SMOS(9) =  2.00000000
SWP1(1) =  .200000000
SWP1(5) =  .200000000
SWP2(4) =  .200000000
SWP3(3) =  .200000000
SWP4(2) =  2.00000000
SWP5(1) =  2.00000000
SWP5(5) =  2.00000000
SWP6(4) =  2.00000000
SFC1(3) =  .800000000
SFC2(2) =  .800000000
SFC3(1) =  .800000000
SFC3(5) =  .800000000
SFC4(4) =  4.20000000
SFC5(3) =  4.20000000
SFC6(2) =  4.20000000
SPROD =           0
SCRT =           0
TP(1) =  12.0000000
SUN =  100.000000
SP2(1) =  .400000000E-03
SP2(5) =  .400000000E-03
SP3(4) =  3.00000000
SP4(3) =  20.0000000
SP5(2) =  400000.000
SP6(1) =  400000.000
SP6(5) =  400000.000
PHEN(4) =  1.00000000
TMIS(3) =           0
EP(2) =  1.00000000
SRAC(1,1) =           0
SRAC(5,1) =           0
SRAC(9,1) =           0
SRAC(13,1) =           0
SRAC(17,1) =           0
SRAC(1,2) =           0
SRAC(5,2) =           0
SRAC(9,2) =           0
SRAC(13,2) =           0
SRAC(17,2) =           0
SRAC(1,3) =           0
SRAC(5,3) =           0
SRAC(9,3) =           0
SRAC(13,3) =           0
SRAC(17,3) =           0
SRAC(1,4) =           0
SRAC(5,4) =           0
SRAC(9,4) =           0
SRAC(13,4) =           0
SRAC(17,4) =           0
SRAC(1,5) =           0
SRAC(5,5) =           0
SRAC(9,5) =           0
SRAC(13,5) =           0
SRAC(17,5) =           0
SRACR(1) =           0
SRACR(5) =           0
SPTW(4,1) =           0
SPTW(8,1) =           0

HEAT(10) = INDEFINITE
SBOT(2) =  6.50000000
SBOT(6) =  12.5000000
SBOT(10) =  12.0000000
PRIPT =           0
SMOS(2) =  .600000000
SMOS(6) =  2.00000000
SMOS(10) =  2.00000000
SWP1(2) =  .200000000
SWP2(1) =  .200000000
SWP2(5) =  .200000000
SWP3(4) =  .200000000
SWP4(3) =  2.00000000
SWP5(2) =  2.00000000
SWP6(1) =  2.00000000
SWP6(5) =  2.00000000
SFC1(4) =  .800000000
SFC2(3) =  .800000000
SFC3(2) =  .800000000
SFC4(1) =  4.20000000
SFC4(5) =  4.20000000
SFC5(4) =  4.20000000
SFC6(3) =  4.20000000
SSDTH =           0
DELT =           0
TP(2) =  12.0000000
Y1 =  12.0000000
SP2(2) =  .500000000E-03
SP3(1) =  4.00000000
SP3(5) =  3.00000000
SP4(4) =  15.0000000
SP5(3) =  500000.000
SP6(2) =  400000.000
PHEN(1) =  1.00000000
PHEN(5) =  1.00000000
TMIS(4) =           0
EP(3) =  1.00000000
SRAC(2,1) =           0
SRAC(6,1) =           0
SRAC(10,1) =           0
SRAC(14,1) =           0
SRAC(18,1) =           0
SRAC(2,2) =           0
SRAC(6,2) =           0
SRAC(10,2) =           0
SRAC(14,2) =           0
SRAC(18,2) =           0
SRAC(2,3) =           0
SRAC(6,3) =           0
SRAC(10,3) =           0
SRAC(14,3) =           0
SRAC(18,3) =           0
SRAC(2,4) =           0
SRAC(6,4) =           0
SRAC(10,4) =           0
SRAC(14,4) =           0
SRAC(18,4) =           0
SRAC(2,5) =           0
SRAC(6,5) =           0
SRAC(10,5) =           0
SRAC(14,5) =           0
SRAC(18,5) =           0
SRACR(2) =           0
SPTW(1,1) =           0
SPTW(5,1) =           0
SPTW(9,1) =           0

HEAT(11) = INDEFINITE
SBOT(3) =  7.50000000
SBOT(7) =  13.0000000
SBOT(11) =  9.00000000
PISC =           0
SMOS(3) =  .600000000
SMOS(7) =  2.00000000
PTEMP =           0
SWP1(3) =  .200000000
SWP2(2) =  .200000000
SWP3(1) =  .200000000
SWP3(5) =  .200000000
SWP4(4) =  2.00000000
SWP5(3) =  2.00000000
SWP6(2) =  2.00000000
SFC1(1) =  .800000000
SFC1(5) =  .800000000
SFC2(4) =  .800000000
SFC3(3) =  .800000000
SFC4(2) =  4.20000000
SFC5(1) =  4.20000000
SFC5(5) =  4.20000000
SFC6(4) =  4.20000000
SRDTH =           0
H =           0
NWK =           0
Y2 =  12.0000000
SP2(3) =  .400000000E-03
SP3(2) =  3.00000000
SP4(1) =  28.0000000
SP4(5) =  15.0000000
SP5(4) =  700000.000
SP6(3) =  400000.000
PHEN(2) =  1.00000000
TMIS(1) =           0
TMIS(5) =           0
EP(4) =  1.00000000
SRAC(3,1) =           0
SRAC(7,1) =           0
SRAC(11,1) =           0
SRAC(15,1) =           0
SRAC(19,1) =           0
SRAC(3,2) =           0
SRAC(7,2) =           0
SRAC(11,2) =           0
SRAC(15,2) =           0
SRAC(19,2) =           0
SRAC(3,3) =           0
SRAC(7,3) =           0
SRAC(11,3) =           0
SRAC(15,3) =           0
SRAC(19,3) =           0
SRAC(3,4) =           0
SRAC(7,4) =           0
SRAC(11,4) =           0
SRAC(15,4) =           0
SRAC(19,4) =           0
SRAC(3,5) =           0
SRAC(7,5) =           0
SRAC(11,5) =           0
SRAC(15,5) =           0
SRAC(19,5) =           0
SRACR(3) =           0
SPTW(2,1) =           0
SPTW(6,1) =           0
SPTW(10,1) =           0

HEAT(12) = INDEFINITE
SBOT(4) =  8.50000000
SBOT(8) =  14.0000000
SBOT(12) =  8.00000000
PILT = INDEFINITE
SMOS(4) =  2.00000000
SMOS(8) =  2.00000000
PRD =  .200000000E-01
SWP1(4) =  .200000000
SWP2(3) =  .200000000
SWP3(2) =  .200000000
SWP4(1) =  2.00000000
SWP4(5) =  2.00000000
SWP5(4) =  2.00000000
SWP6(3) =  2.00000000
SFC1(2) =  .800000000
SFC2(1) =  .800000000
SFC2(5) =  .800000000
SFC3(4) =  .800000000
SFC4(3) =  4.20000000
SFC5(2) =  4.20000000
SFC6(1) =  4.20000000
SFC6(5) =  4.20000000
SRTRS =           0
PHI =  .733038300
NDAY =           0
MON =           0
SP2(4) =  .400000000E-03
SP3(3) =  2.00000000
SP4(2) =  30.0000000
SP5(1) =  750000.000
SP5(5) =  500000.000
SP6(4) =  400000.000
PHEN(3) =  1.00000000
TMIS(2) =           0
EP(1) =  1.00000000
EP(5) =  1.00000000
SRAC(4,1) =           0
SRAC(8,1) =           0
SRAC(12,1) =           0
SRAC(16,1) =           0
SRAC(20,1) =           0
SRAC(4,2) =           0
SRAC(8,2) =           0
SRAC(12,2) =           0
SRAC(16,2) =           0
SRAC(20,2) =           0
SRAC(4,3) =           0
SRAC(8,3) =           0
SRAC(12,3) =           0
SRAC(16,3) =           0
SRAC(20,3) =           0
SRAC(4,4) =           0
SRAC(8,4) =           0
SRAC(12,4) =           0
SRAC(16,4) =           0
SRAC(20,4) =           0
SRAC(4,5) =           0
SRAC(8,5) =           0
SRAC(12,5) =           0
SRAC(16,5) =           0
SRAC(20,5) =           0
SRACR(4) =           0
SPTW(3,1) =           0
SPTW(7,1) =           0
SPTW(11,1) =           0
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SPTW(12,1) =          0
SPTW(16,1) =          0
SPTW(20,1) =          0
SPTW(4,2) =           0
SPTW(8,2) =           0
SPTW(12,2) =          0
SPTW(16,2) =          0
SPTW(20,2) =          0
SPTW(4,3) =           0
SPTW(8,3) =           0
SPTW(12,3) =          0
SPTW(16,3) =          0
SPTW(20,3) =          0
SPTW(4,4) =           0
SPTW(8,4) =           0
SPTW(12,4) =          0
SPTW(16,4) =          0
SPTW(20,4) =          0
SPTW(4,5) =           0
SPTW(8,5) =           0
SPTW(12,5) =          0
SPTW(16,5) =          0
SPTW(20,5) =          0
SPTWR(4) =            0
SMR1(3) = INDEFINITE
SMR2(2) = INDEFINITE
CNET(1) =             0
CNET(5) =             0
COUT(4) =             0
CIN(3) =              0
PS(2) =  .550000000E-02
RS(1) =  .600000000E-01
RS(5) =  .400000000E-01
EBM(4) =  1.00000000
FSM(3) =  .180000000
EAT(2) =  .500000000E-01
EATR(1) =  .500000000E-01
EATR(5) =  .500000000E-01
ESMR(4) =  .180000000
ENS(3) =  1.00000000
SLA1(2) =  .800000000
SLA2(1) =  .300000000E-02
SLA2(5) =  .200000000E-01
H0541 =               0
H1244 =               0
H1442 =               0
H1543 =               0
H2141 =               0
H2541 =               0
H5401 = INDEFINITE
H1644 =               0
HS1(1) =  .150000000
HS1(5) =  .150000000
HS11(4) =  .800000000E-01
HS40(3) =  .600000000E-02
HS040(2) = INDEFINITE
HH040(1) =            0
HH040(5) = INDEFINITE
HSI40(4) = INDEFINITE
HHI40(3) = INDEFINITE
HS19(2) =  .210000000
HS19(6) =  .170000000
HMER(4) =             0
HMOIS(4) =            0
HETMP(4) =            0
SLOS(4) =  .100000000E-01

SPTW(13,1) =          0
SPTW(17,1) =          0
SPTW(1,2) =           0
SPTW(5,2) =           0
SPTW(9,2) =           0
SPTW(13,2) =          0
SPTW(17,2) =          0
SPTW(1,3) =           0
SPTW(5,3) =           0
SPTW(9,3) =           0
SPTW(13,3) =          0
SPTW(17,3) =          0
SPTW(1,4) =           0
SPTW(5,4) =           0
SPTW(9,4) =           0
SPTW(13,4) =          0
SPTW(17,4) =          0
SPTW(1,5) =           0
SPTW(5,5) =           0
SPTW(9,5) =           0
SPTW(13,5) =          0
SPTW(17,5) =          0
SPTWR(1) =            0
SPTWR(5) =            0
SMR1(4) = INDEFINITE
SMR2(3) = INDEFINITE
CNET(2) =             0
COUT(1) =             0
COUT(5) =             0
CIN(4) =              0
PS(3) =  .300000000E-02
RS(2) =  .600000000E-01
EBM(1) =  1.00000000
EBM(5) =  10.0000000
FSM(4) =  .200000000
EAT(3) =  .500000000E-01
EATR(2) =  .500000000E-01
ESMR(1) =  .300000000
ESMR(5) =  .350000000
ENS(4) =  1.00000000
SLA1(3) =  1.00000000
SLA2(2) =  .400000000E-02
H0241 =               0
H0641 =               0
H1342 =               0
H1443 =               0
H1544 =               0
H2241 =               0
H5101 = INDEFINITE
H4142 =               0
H4042 =               0
HS1(2) =  .150000000
HS11(1) =  .100000000
HS11(5) =  .800000000E-01
HS40(4) =  .600000000E-02
HS040(3) = INDEFINITE
HH040(2) = INDEFINITE
HSI40(1) = INDEFINITE
HSI40(5) = INDEFINITE
HHI40(4) = INDEFINITE
HS19(3) =  .250000000
HMER(1) =             0
HMOIS(1) =            0
HETMP(1) =            0
SLOS(1) =  .600000000E-02
SLOS(5) =  .100000000E-01

SPTW(14,1) =          0
SPTW(18,1) =          0
SPTW(2,2) =           0
SPTW(6,2) =           0
SPTW(10,2) =          0
SPTW(14,2) =          0
SPTW(18,2) =          0
SPTW(2,3) =           0
SPTW(6,3) =           0
SPTW(10,3) =          0
SPTW(14,3) =          0
SPTW(18,3) =          0
SPTW(2,4) =           0
SPTW(6,4) =           0
SPTW(10,4) =          0
SPTW(14,4) =          0
SPTW(18,4) =          0
SPTW(2,5) =           0
SPTW(6,5) =           0
SPTW(10,5) =          0
SPTW(14,5) =          0
SPTW(18,5) =          0
SPTWR(2) =            0
SMR1(1) = INDEFINITE
SMR1(5) = INDEFINITE
SMR2(4) = INDEFINITE
CNET(3) =             0
COUT(2) =             0
CIN(1) =              0
CIN(5) =              0
PS(4) =  .500000000E-02
RS(3) =  .600000000E-01
EBM(2) =  1.00000000
ESM(1) =  .180000000
ESM(5) =  .600000000
EAT(4) =  .500000000E-01
EATR(3) =  .500000000E-01
ESMR(2) =  .350000000
ENS(1) =  1.00000000
ENS(5) =  1.00000000
SLA1(4) =  1.00000000
SLA2(3) =  .150000000E-01
H0341 =               0
H1242 =               0
H1343 =               0
H1444 =               0
H1642 =               0
H2341 =               0
H5201 = INDEFINITE
H4045 =               0
H3541 =               0
HS1(3) =  .150000000
HS11(2) =  .100000000
HS40(1) =  .600000000E-01
HS40(5) =  .100000000E-01
HS040(4) = INDEFINITE
HH040(3) = INDEFINITE
HSI40(2) = INDEFINITE
HHI40(1) = INDEFINITE
HHI40(5) = INDEFINITE
HS19(4) =  .250000000
HMER(2) =             0
HMOIS(2) =            0
HETMP(2) =            0
SLOS(2) =  .300000000E-02
SLOS(6) =  .250000000E-02

SPTW(15,1) =          0
SPTW(19,1) =          0
SPTW(3,2) =           0
SPTW(7,2) =           0
SPTW(11,2) =          0
SPTW(15,2) =          0
SPTW(19,2) =          0
SPTW(3,3) =           0
SPTW(7,3) =           0
SPTW(11,3) =          0
SPTW(15,3) =          0
SPTW(19,3) =          0
SPTW(3,4) =           0
SPTW(7,4) =           0
SPTW(11,4) =          0
SPTW(15,4) =          0
SPTW(19,4) =          0
SPTW(3,5) =           0
SPTW(7,5) =           0
SPTW(11,5) =          0
SPTW(15,5) =          0
SPTW(19,5) =          0
SPTWR(3) =            0
SMR1(2) = INDEFINITE
SMR2(1) = INDEFINITE
SMR2(5) = INDEFINITE
CNET(4) =             0
COUT(3) =             0
CIN(2) =              0
PS(1) =  .700000000E-02
PS(5) =  .450000000E-03
RS(4) =  .600000000E-01
EBM(3) =  1.00000000
FSM(2) =  .360000000
EAT(1) =  .500000000E-01
EAT(5) =  .500000000E-01
EATR(4) =  .500000000E-01
ESMR(3) =  .190000000
ENS(2) =  1.00000000
SLA1(1) =  1.00000000
SLA1(5) =  1.00000000
SLA2(4) =  .250000000E-01
H0441 =               0
H1243 =               0
H1344 =               0
H1542 =               0
H2041 =               0
H2441 =               0
H5301 = INDEFINITE
H1643 =               0
H3545 =               0
HS1(4) =  .150000000
HS11(3) =  .800000000E-01
HS40(2) =  .600000000E-02
HS040(1) = INDEFINITE
HS040(5) = INDEFINITE
HH040(4) = INDEFINITE
HSI40(3) = INDEFINITE
HHI40(2) = INDEFINITE
HS19(1) =  .210000000
HS19(5) =             0
HMER(3) =             0
HMOIS(3) =            0
HETMP(3) =            0
SLOS(3) =  .120000000E-01
HTOBL =               0
```

```
HMOI(1) = INDEFINITE      HMOI(2) = INDEFINITE      HMOI(3) = INDEFINITE      HMOI(4) = INDEFINITE
HTOMI =              0    HTOCO =              0    HLITI =              0    HLITO =              0
HBGDI =              0    HBGDO =              0    HKSP =   .370000000      HKHP =   .670000000E-01
HKSF =   .250000000      HKHF =   .400000000E-01    HECFF =   .800000000     HMAXL =   .100000000E-03
```

SIMULATION RESULTS

```
TIME = 0.
        X(1)  =  800.000000     X(2)  =  .500000000      X(3)  =  .500000000      X(4)  =  .500000000
        X(5)  =  .500000000     X(6)  =  14.8400000      X(90) =           0      X(12) =  90.4000000
        X(13) =  40.0000000     X(14) =  20.0200000      X(15) =  11.5200000      X(16) =  24.0000000
        X(20) =  50.0000000     X(21) =  30.0000000      X(22) =  .500000000      X(23) =  2.00000000
        X(24) =  4.00000000     X(25) =  10.0000000      X(42) =  100.000000      X(43) =  162.000000
        X(44) =  100.000000     X(41) =  150.000000      X(40) =           0      X(45) =           0
        X(51) =  17.0000000     X(52) =  4.00000000      X(53) =  9.00000000      X(54) =  12.0000000
        X(60) =  .300000000     X(65) =  100.000000      X(61) =  5.57820000      X(62) =  .505200000
        X(63) =  150.000000     X(66) =  100.000000      X(70) =  .100000000E-01  X(75) =  20.0000000
        X(71) =  .195237000     X(72) =  .176820000E-01  X(73) =  80.0000000      X(76) =  400.000000
        X(98) =  7.00000000     X(99) =  100.000000

TIME = 365.000000
        X(1)  =  891.381749     X(2)  =  1.74577641      X(3)  =  .343249766      X(4)  =  .186946954
        X(5)  =  .425720901     X(6)  =  12.7135472      X(90) =           0      X(12) =  63.1450496
        X(13) =  32.1901984     X(14) =  10.5134166      X(15) =  5.03165441      X(16) =  20.1397310
        X(20) =  66.6539906     X(21) =  30.4649188      X(22) =  5.24952973      X(23) =  4.22540072
        X(24) =  3.37575944     X(25) =  11.1308204      X(42) =  88.1263194      X(43) =  122.431071
        X(44) =  74.4885074     X(41) =  154.573013      X(40) =  4.61536523      X(45) =  12.6225526
        X(51) =  16.3906577     X(52) =  4.27221679      X(53) =  8.67740701      X(54) =  11.5698760
        X(60) =  .729269877E-01 X(65) =  103.552962      X(61) = -1.27007030      X(62) =  .462457238
        X(63) =  153.801672     X(66) =  49.7640526      X(70) =  .177659760E-01  X(75) =  20.2293543
        X(71) = -.252463939     X(72) =  .161860033E-01  X(73) =  80.2131058      X(76) =  399.998971
        X(98) =  7.01591240     X(99) =  100.000000

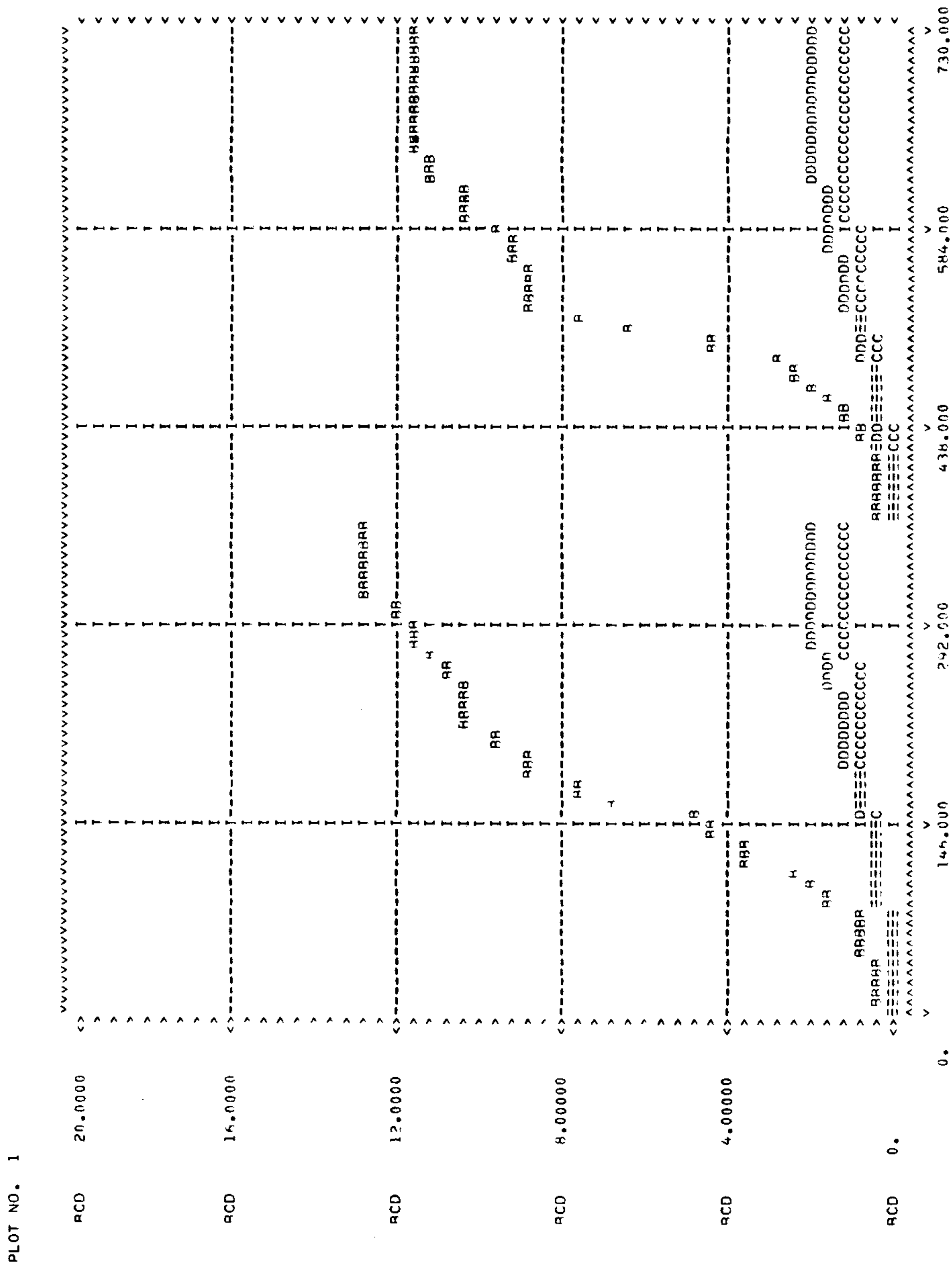
TIME = 730.000000
        X(1)  =  990.661654     X(2)  =  1.21900461      X(3)  =  .179917378      X(4)  =  .126370434
        X(5)  =  .197351884     X(6)  =  13.4435695      X(90) =  2.28544260      X(12) =  46.9531129
        X(13) =  30.1584201     X(14) =  5.33134837      X(15) =  3.69515161      X(16) =  18.2995699
        X(20) =  56.1314733     X(21) =  27.8035252      X(22) =  4.00449082      X(23) =  3.71919543
        X(24) =  2.90906204     X(25) =  12.8277588      X(42) =  72.1931877      X(43) =  100.925701
        X(44) =  52.6736967     X(41) =  140.382803      X(40) =  5.65841139      X(45) =  26.7058830
        X(51) =  15.8031564     X(52) =  4.11908488      X(53) =  8.36637693      X(54) =  11.1551692
        X(60) =  .713668211E-01 X(65) =  107.809385      X(61) = -7.03739033      X(62) =  .455421267
        X(63) =  155.520297     X(66) =  49.5643204      X(70) =  .168578003E-01  X(75) =  20.5391761
        X(71) = -.626266516     X(72) =  .159397443E-01  X(73) =  80.2791795      X(76) =  399.998032
        X(98) =  6.53237128     X(99) =  100.000000
```

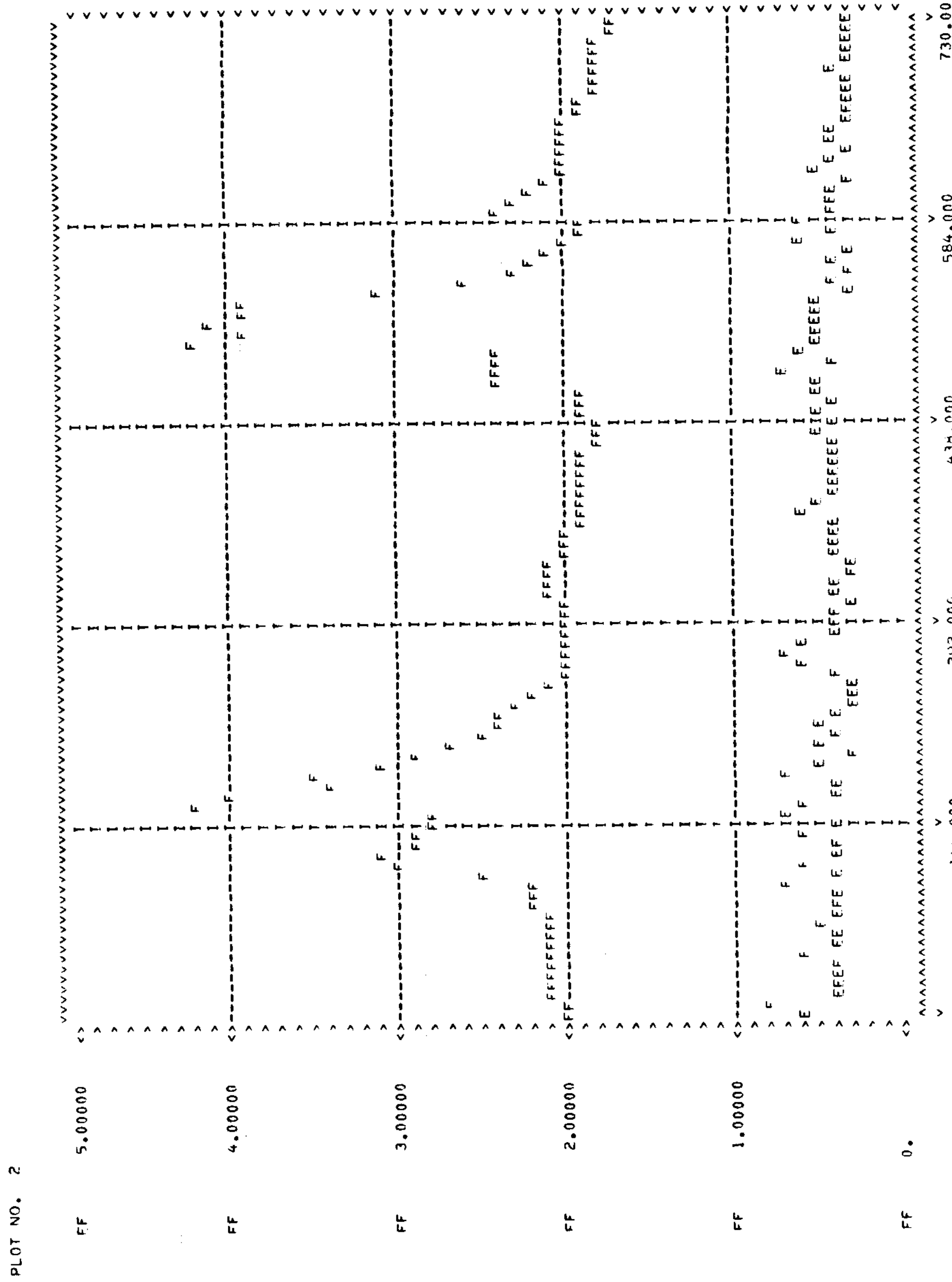
GRAPHICAL SIMULATION RESULTS 07/25/72 20.23.28.

GRAPH NO.	GROUP NO.	INDEPENDENT VARIABLE	DEPENDENT VARIABLE(S)	PLOTTED CHARACTER
1	1	TIME	PRIPT PILTT PISCT	B C D
2	1	TIME	SMOS(1) SMOS(4)	E F
3	1	TIME	EVAST EVATT	G H
4	1	TIME	SAVTP(1) SAVTP(3) SAVTP(5)	J K L
5	1	TIME	X(2)	M
5	2	TIME	X(20)	N
5	3	TIME	X(12)	O
5	4	TIME	PHEN(1)	P
6	1	TIME	X(3)	Q
6	2	TIME	X(21)	R
6	3	TIME	X(13)	S
6	4	TIME	PHEN(2)	T
7	1	TIME	X(4)	U
7	2	TIME	X(22)	V
7	3	TIME	X(14)	W
7	4	TIME	PHEN(3)	X
8	1	TIME	X(5)	Y
8	2	TIME	X(23)	Z

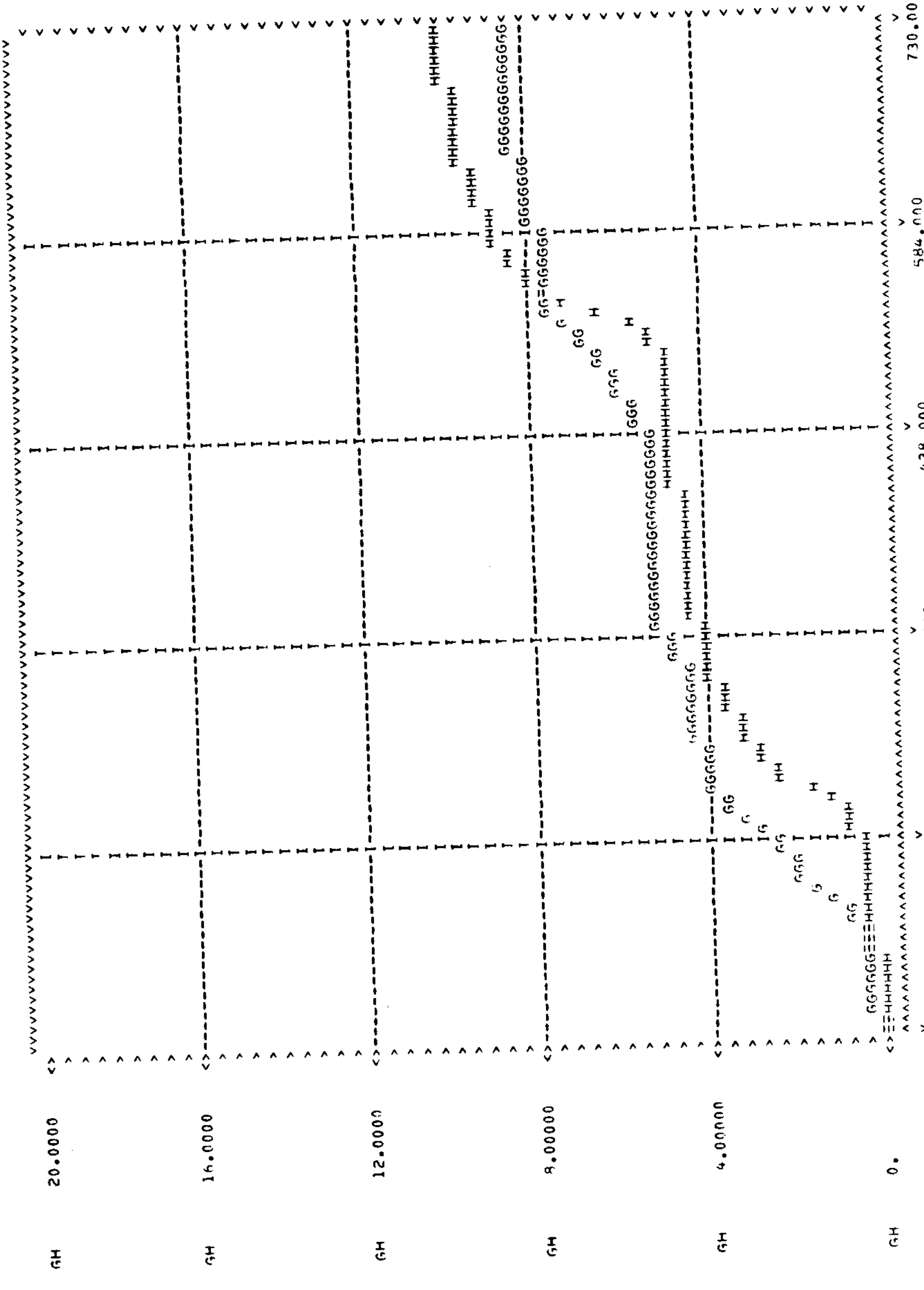
8	3	TIME	X(24)	0
8	4	TIME	X(15)	1
8	5	TIME	PHEN(4)	2
9	1	TIME	X(6)	3
9	2	TIME	X(25)	4
9	3	TIME	X(16)	5
9	4	TIME	PHEN(5)	6
10	1	TIME	APHEN(1) APHEN(2) APHEN(3) APHEN(4) APHEN(6)	7 8 9 + A
11	1	TIME	APHEN(7) APHEN(8) APHEN(9) APHEN(10) APHEN(11)	B C D E F
12	1	TIME	AVDIG	G
13	1	TIME	ATWT	H
13	2	TIME	AGAIN	J
14	1	TIME	X(51) HTOMI	K L
15	1	TIME	X(41) X(45)	M N
15	2	TIME	HTOBL	O
16	1	TIME	HTOCO SRTRS	P Q
17	1	TIME	X(60)	R
17	2	TIME	X(63)	S
17	3	TIME	X(65)	T

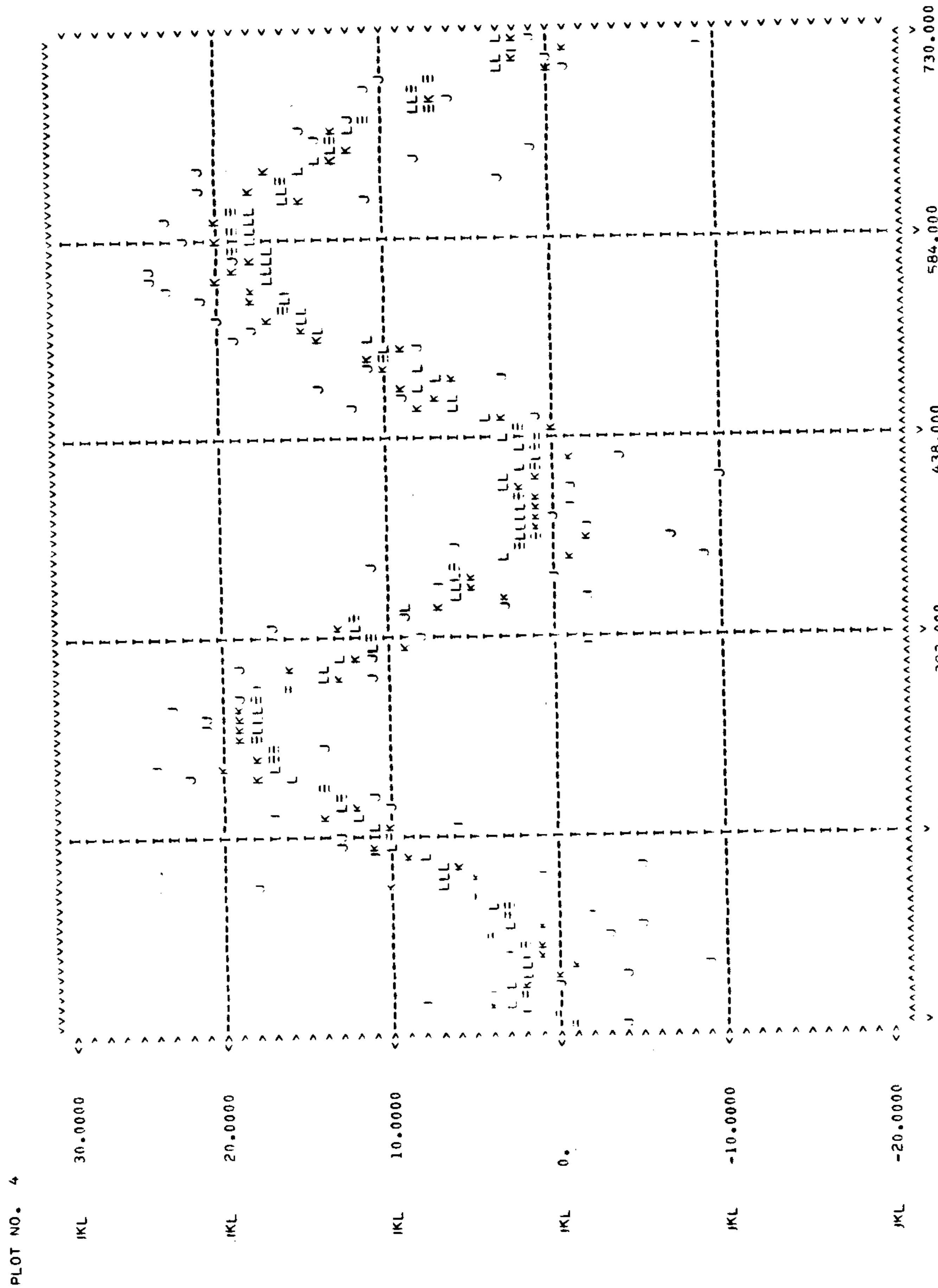
18	1	TIME	X(70)	U
18	2	TIME	X(73)	V
18	3	TIME	X(75)	W

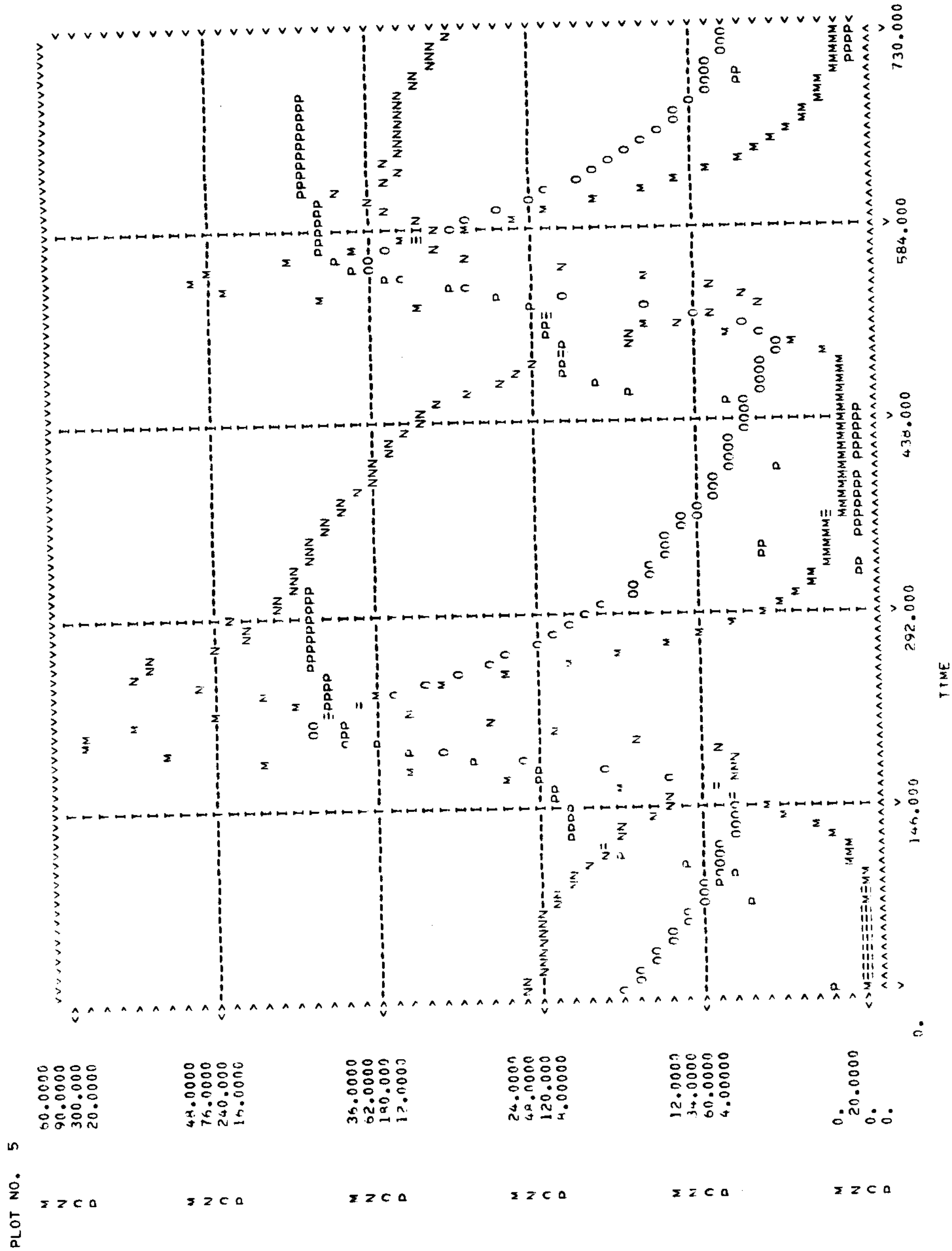

PLOT NO. 1
RCD 20.0000
RCD 16.0000
RCD 12.0000
RCD 8.00000
RCD 4.00000
RCD 0.
0.
146.000
292.000
438.000
584.000
730.000
TIME

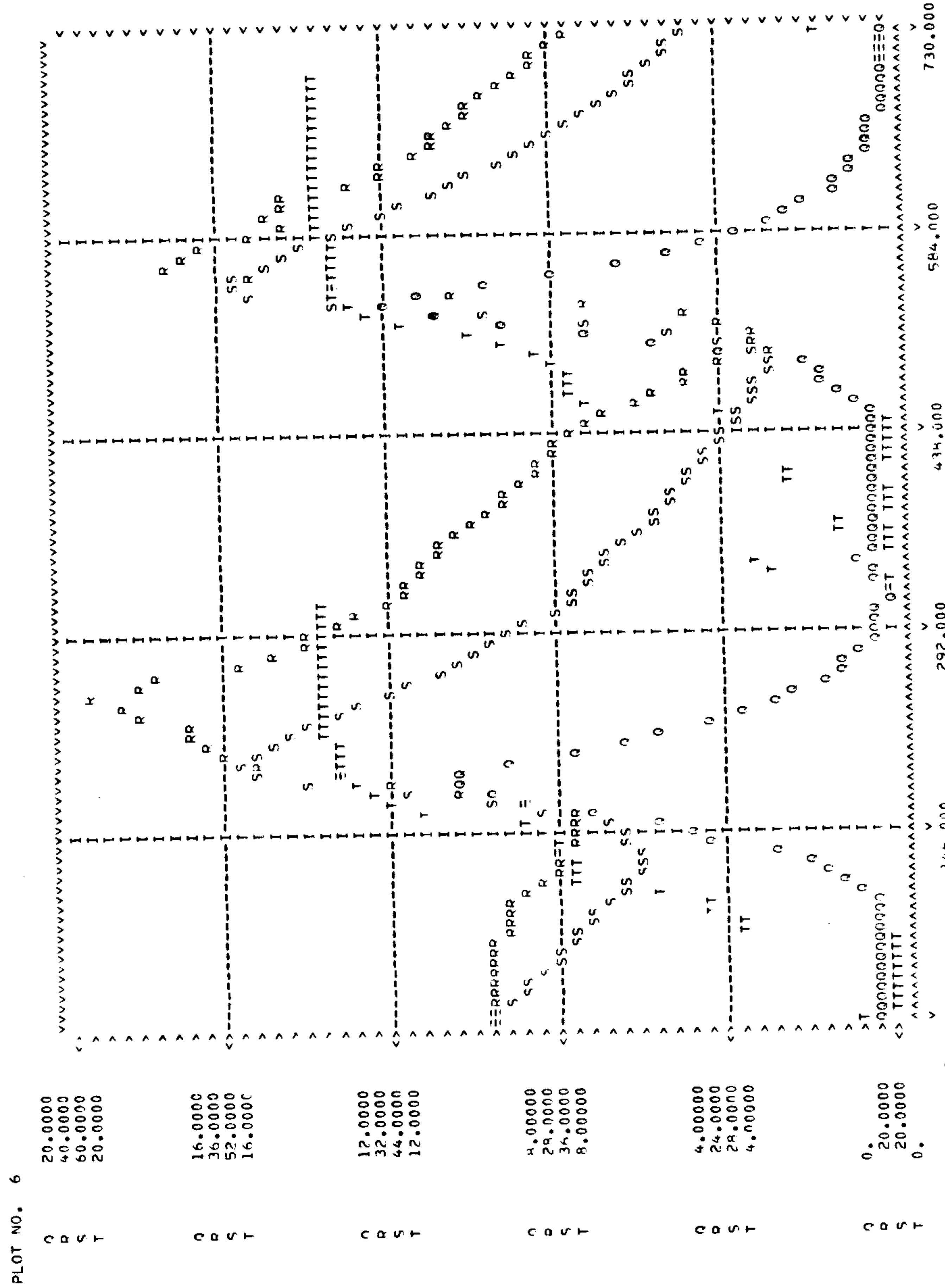

PLOT NO. 2
FF 5.00000
FF 4.00000
FF 3.00000
FF 2.00000
FF 1.00000
FF 0.
0.
146.000
292.000
438.000
584.000
730.000
TIME

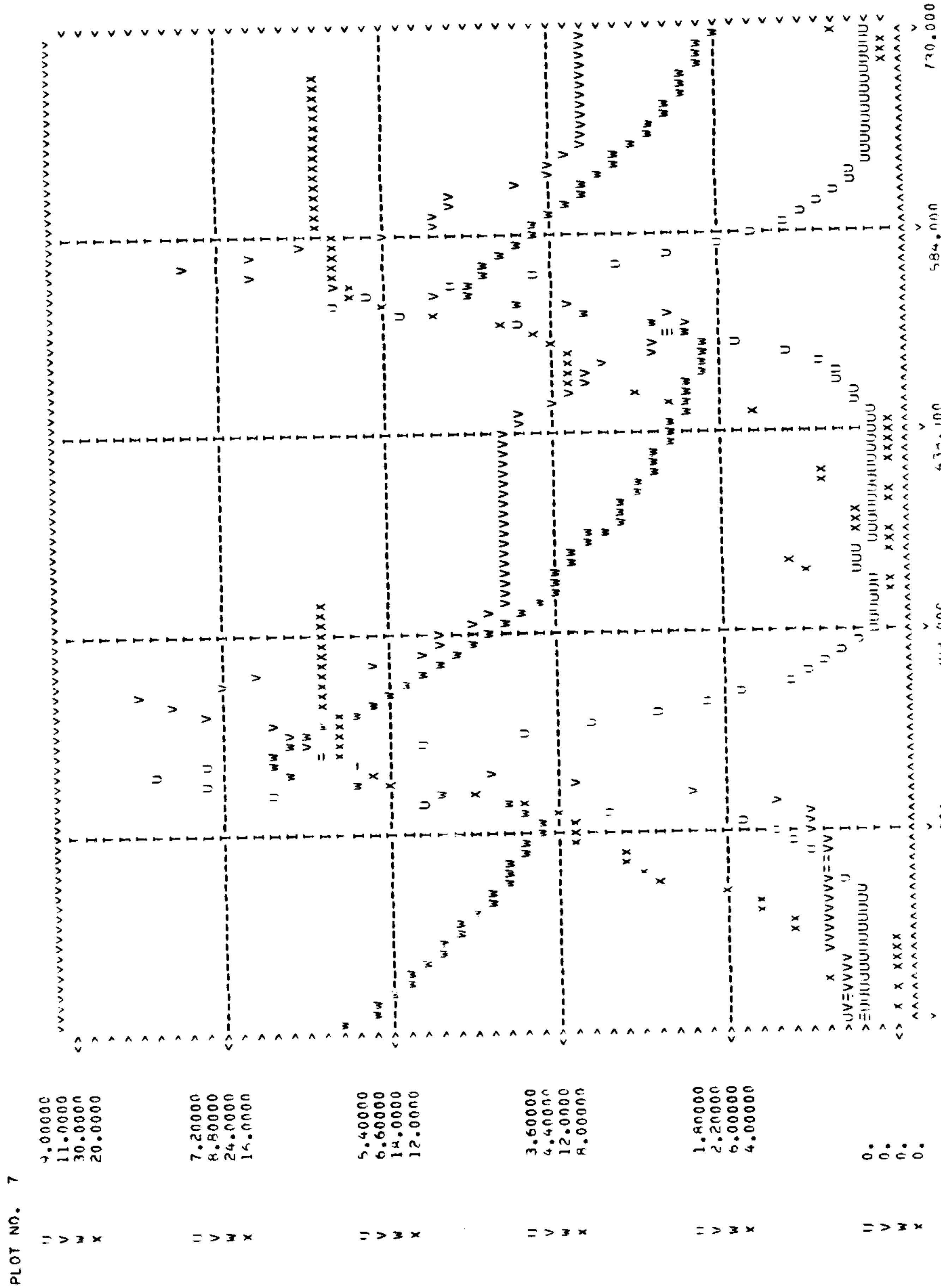
PLOT NO. 3


GH
20.0000
16.0000
12.0000
8.00000
4.00000
0.
TIME
0.
146.000
292.000
438.000
584.000
730.000

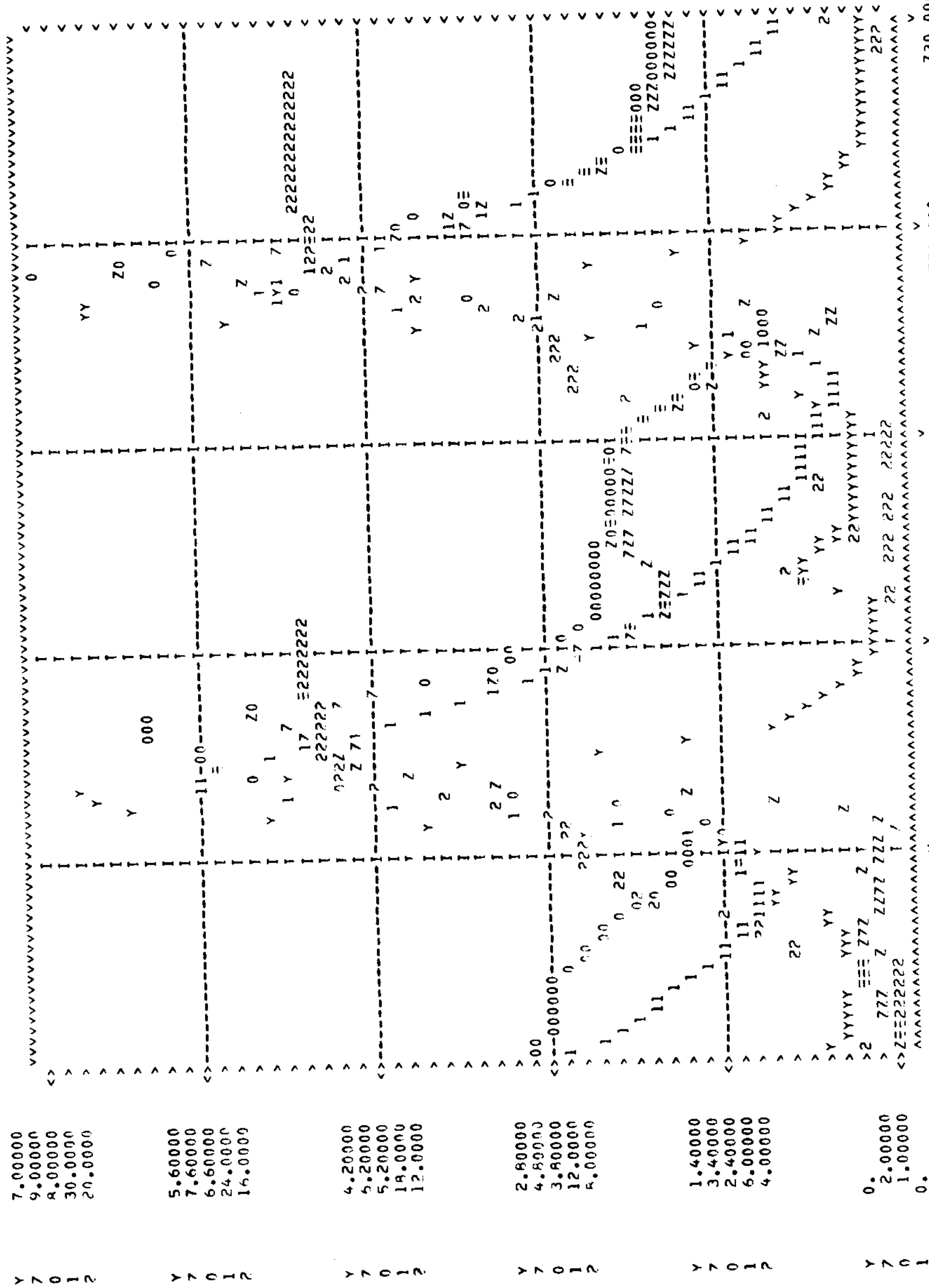

PLOT NO. 4
IKL 30.0000
IKL 20.0000
IKL 10.0000
IKL 0.
JKL -10.0000
JKL -20.0000
0.
146.000
292.000
438.000
584.000
730.000
TIME

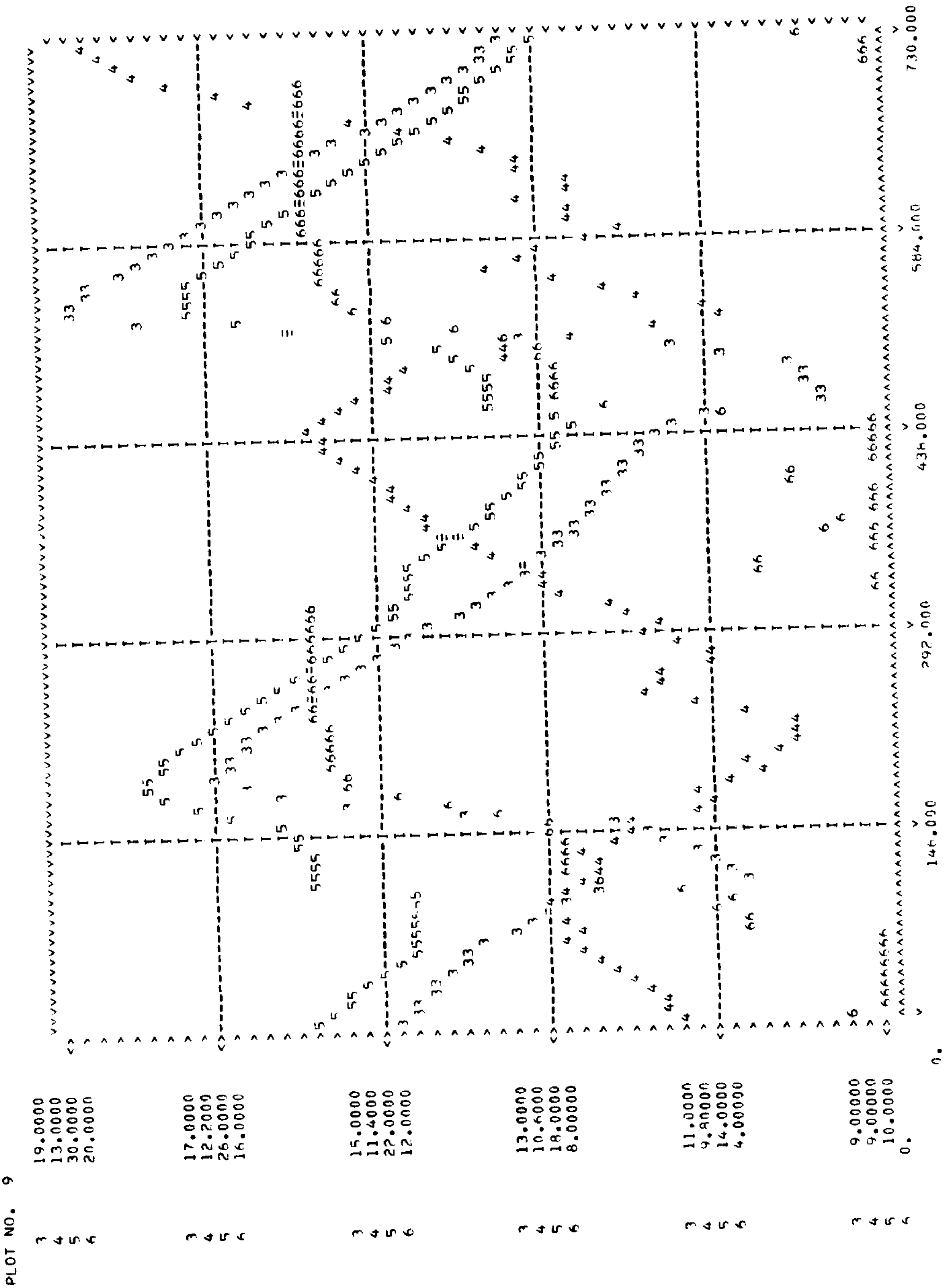

PLOT NO. 5
M N O P
60.0000 90.0000 300.000 20.0000
48.0000 76.0000 240.000 16.0000
36.0000 62.0000 180.000 12.0000
24.0000 48.0000 120.000 8.00000
12.0000 34.0000 60.0000 4.00000
0. 20.0000 0. 0.
0.
146.000
292.000
438.000
584.000
730.000
TIME

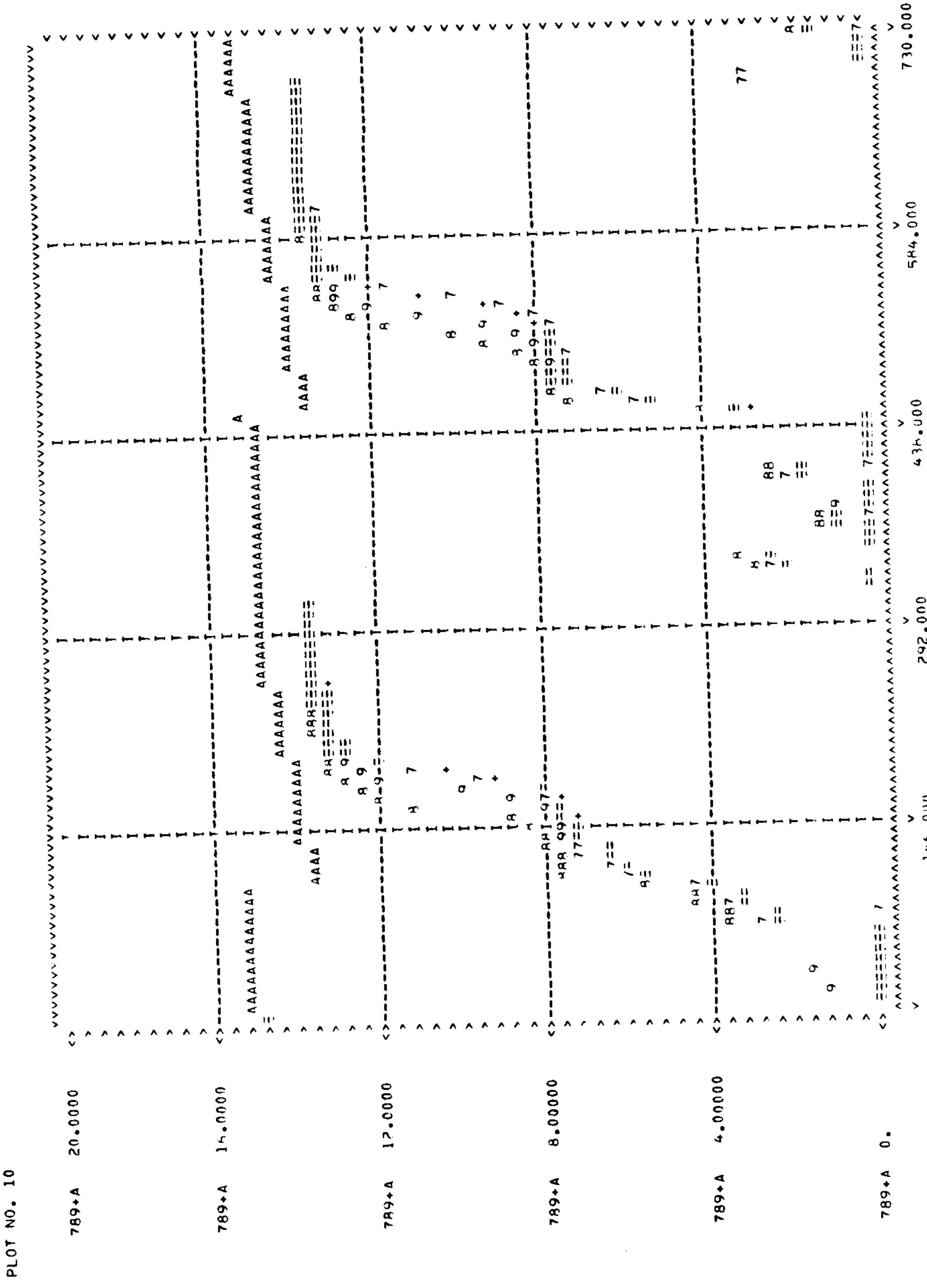

PLOT NO. 6
Q R S T
20.0000
40.0000
60.0000
20.0000
16.0000
36.0000
52.0000
16.0000
12.0000
32.0000
44.0000
12.0000
8.00000
28.0000
36.0000
8.00000
4.00000
24.0000
28.0000
4.00000
0.
20.0000
20.0000
0.
0.
146.000
292.000
438.000
584.000
730.000
TIME

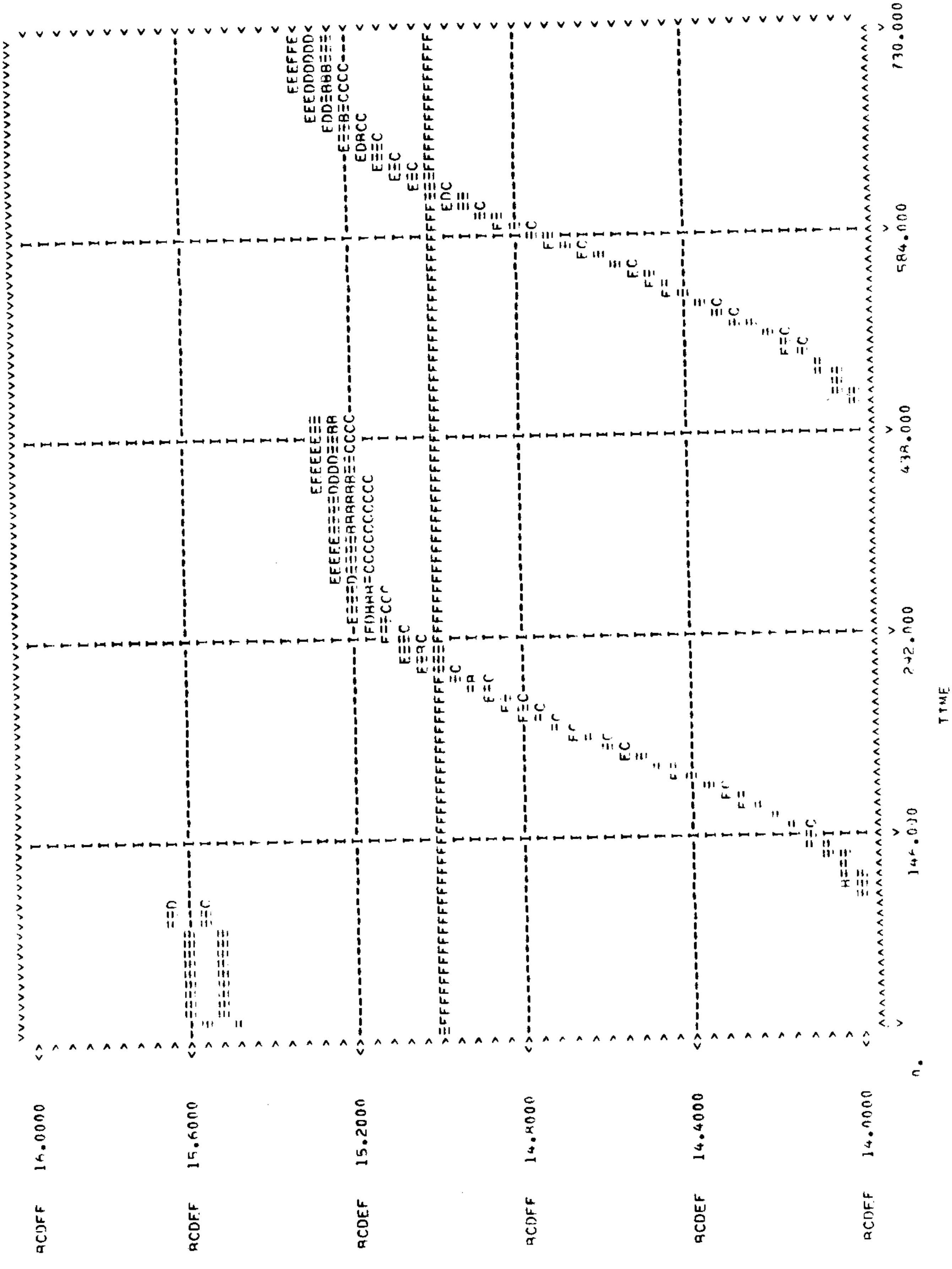

PLOT NO. 7
U 9.00000
V 11.0000
W 30.0000
X 20.0000
U 7.20000
V 8.80000
W 24.0000
X 16.0000
U 5.40000
V 6.60000
W 18.0000
X 12.0000
U 3.60000
V 4.40000
W 12.0000
X 8.00000
U 1.80000
V 2.20000
W 6.00000
X 4.00000
U 0.
V 0.
W 0.
X 0.
146.000
292.000
438.000
584.000
730.000
TIME

PLOT NO. 8


Y 7 0 1 2
7.00000
9.00000
8.00000
30.0000
20.0000
5.60000
7.60000
6.60000
24.0000
16.0000
4.20000
6.20000
5.20000
18.0000
12.0000
2.80000
4.80000
3.80000
12.0000
8.00000
1.40000
3.40000
2.40000
6.00000
4.00000
0.
2.00000
1.00000
0.
0.
0.
146.000
292.000
438.000
584.000
730.000
TIME

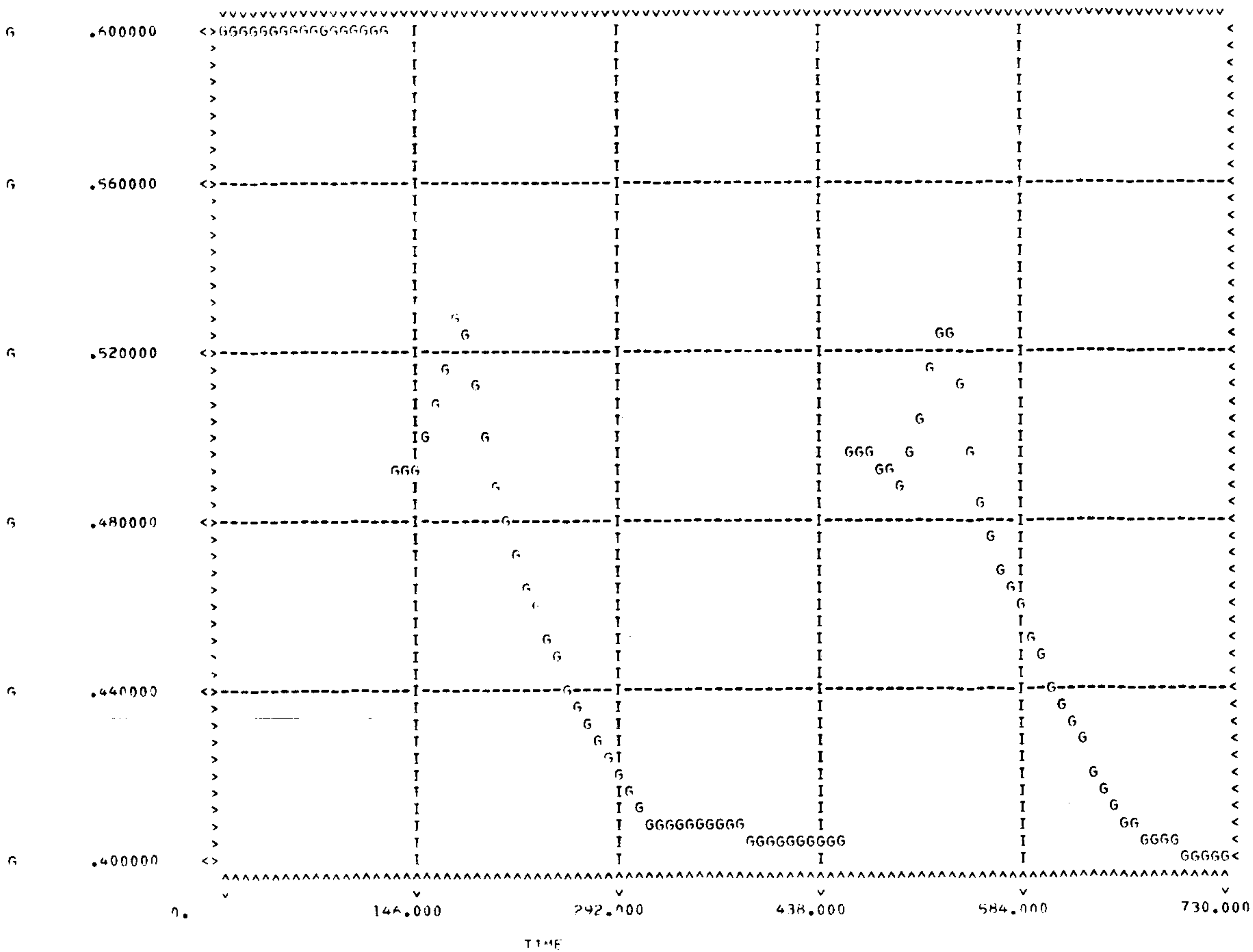

PLOT NO. 9
3 4 5 6
19.0000
13.0000
30.0000
20.0000
17.0000
12.2000
26.0000
16.0000
15.0000
11.4000
22.0000
12.0000
13.0000
10.6000
18.0000
8.00000
11.0000
9.80000
14.0000
4.00000
9.00000
9.00000
10.0000
0.
0.
146.000
292.000
438.000
584.000
730.000
TIME


PLOT NO. 10
789+A 20.0000
789+A 16.0000
789+A 12.0000
789+A 8.00000
789+A 4.00000
789+A 0.
0.
146.000
292.000
438.000
584.000
730.000
TIME

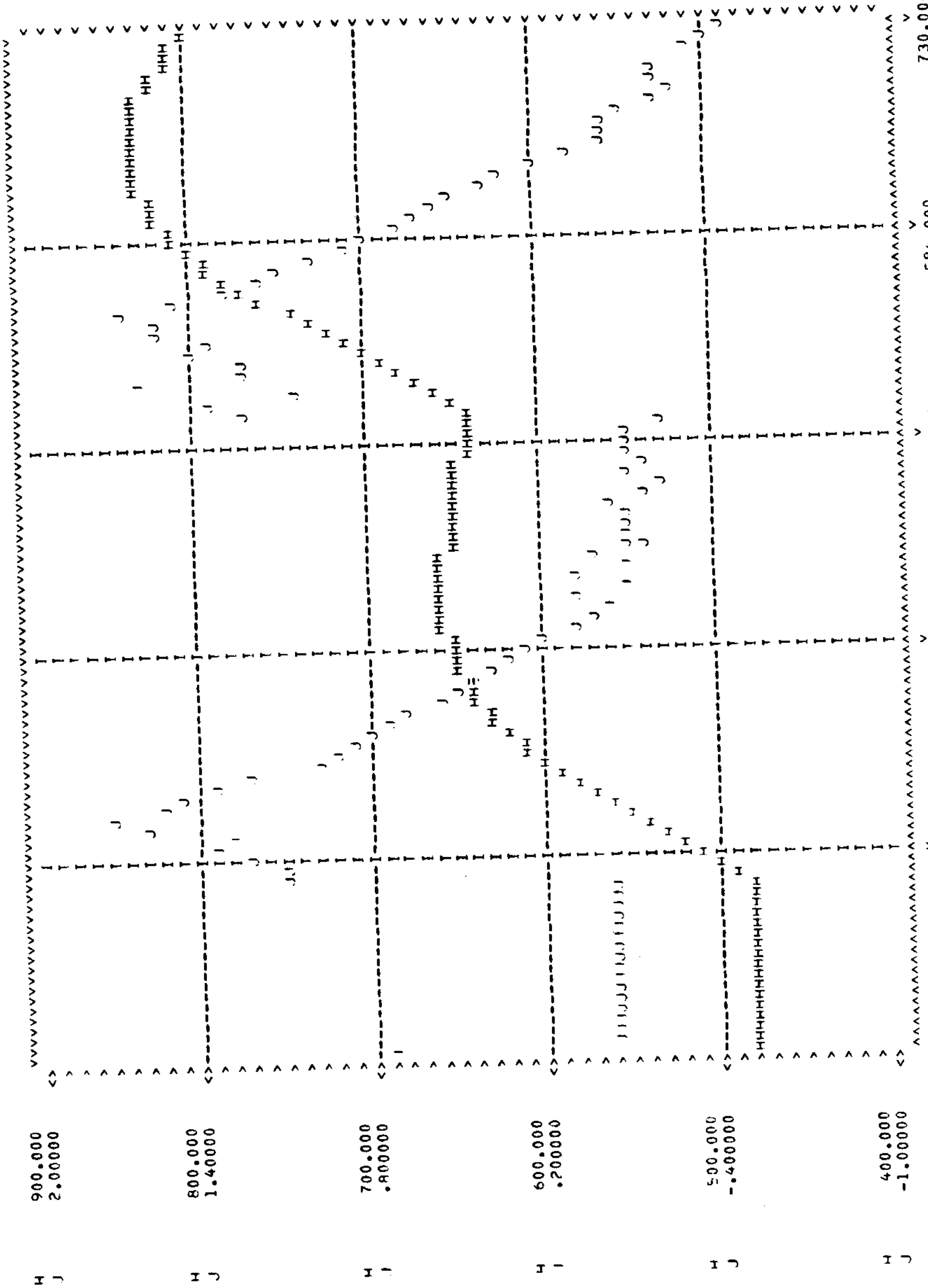

BCDEF 16.0000
BCDEF 15.6000
BCDEF 15.2000
BCDEF 14.8000
BCDEF 14.4000
BCDEF 14.0000
0.
146.000
292.000
438.000
584.000
730.000
TIME

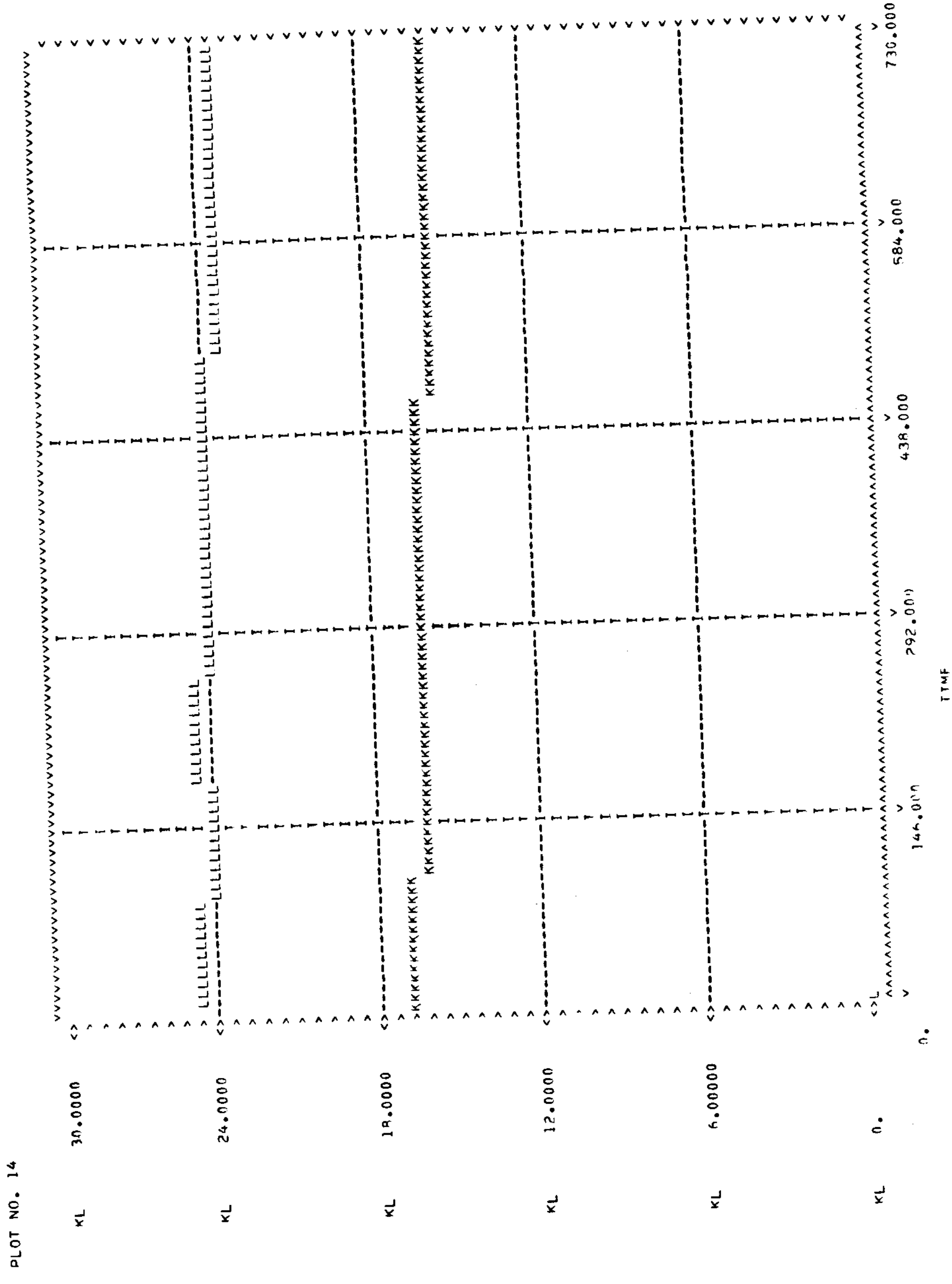
PLOT NO. 11

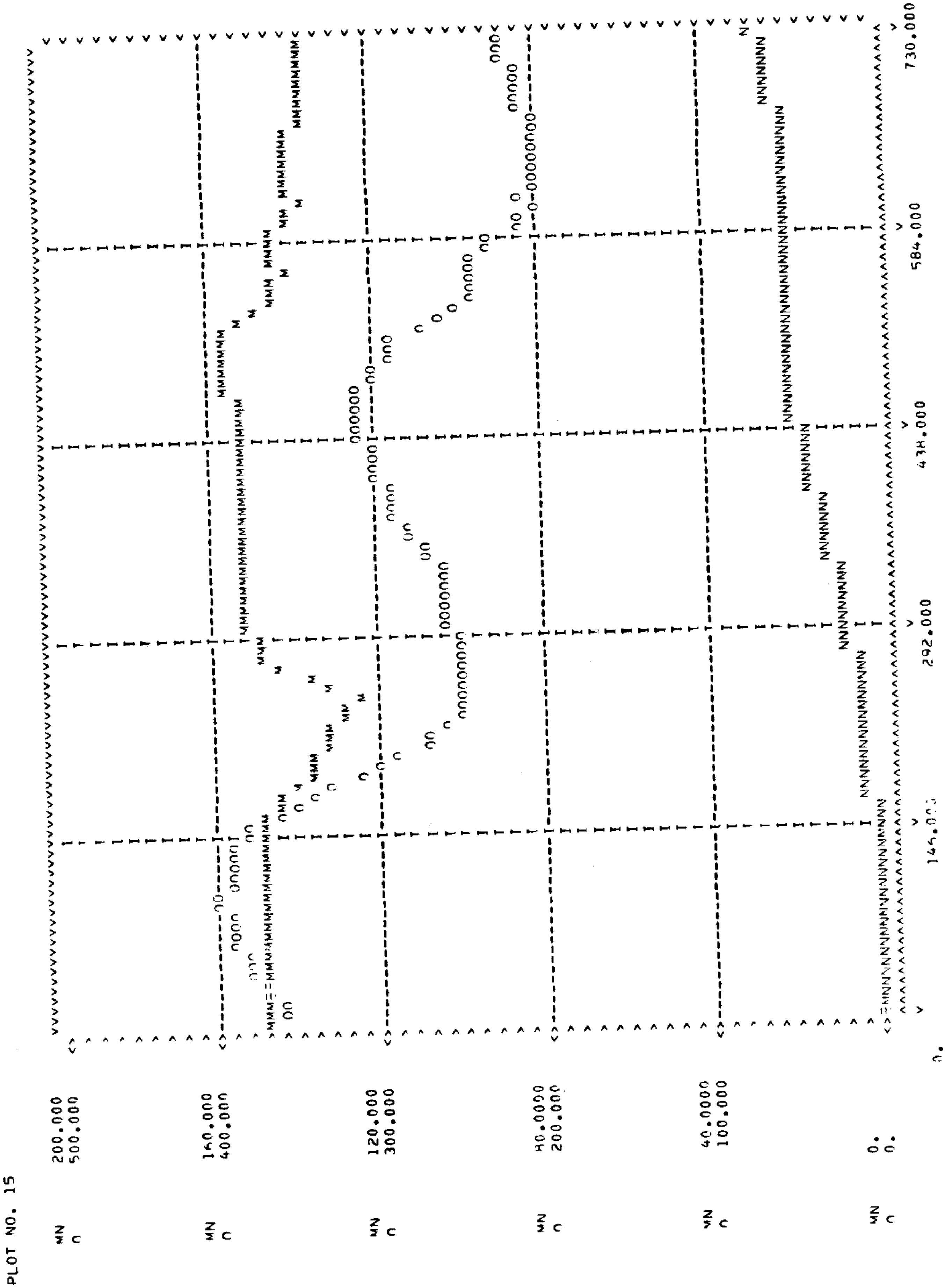
PLOT NO. 12

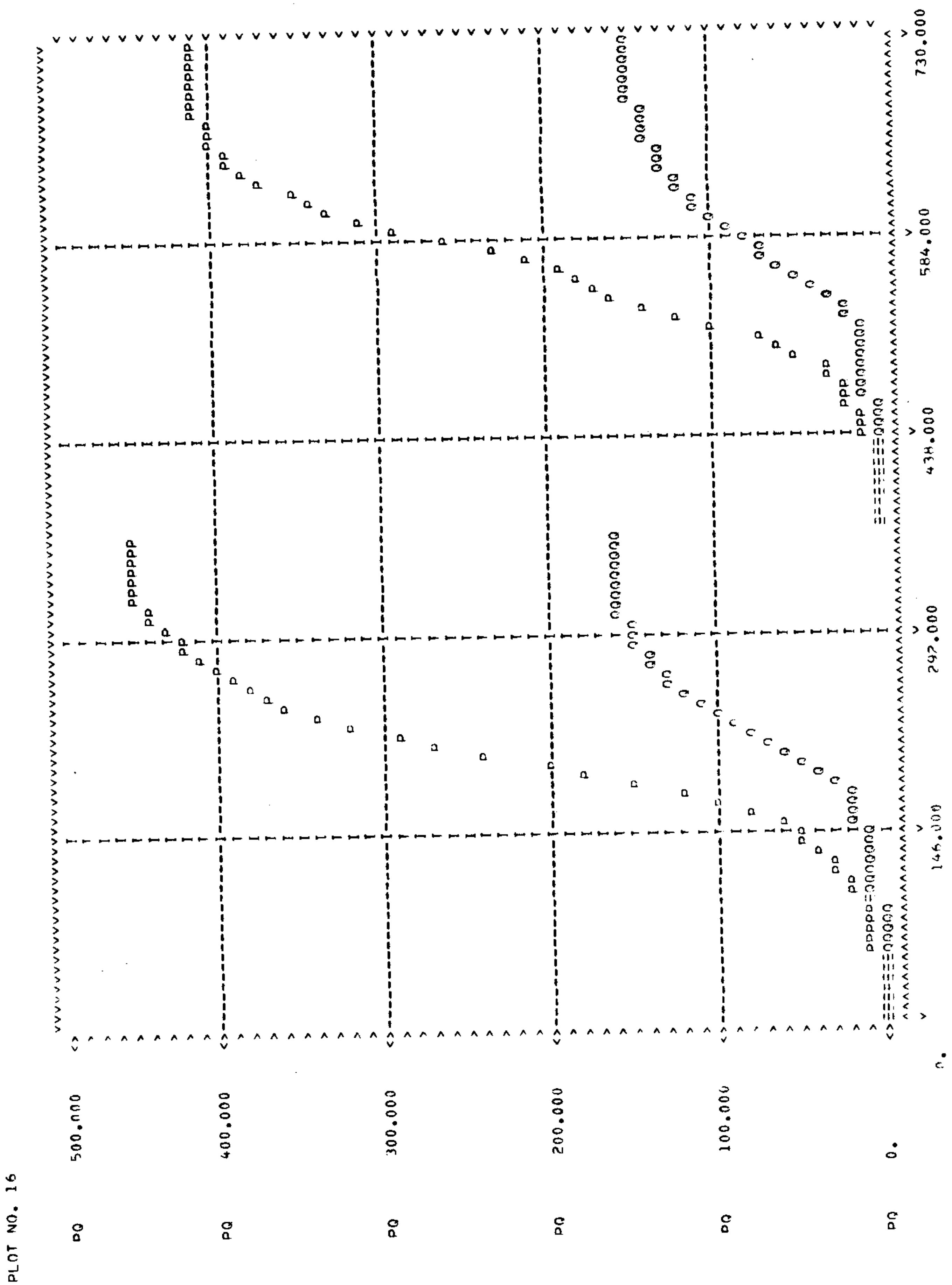

G .600000
G .560000
G .520000
G .480000
G .440000
G .400000
0.
146.000
292.000
438.000
584.000
730.000
TIME

PLOT NO. 13

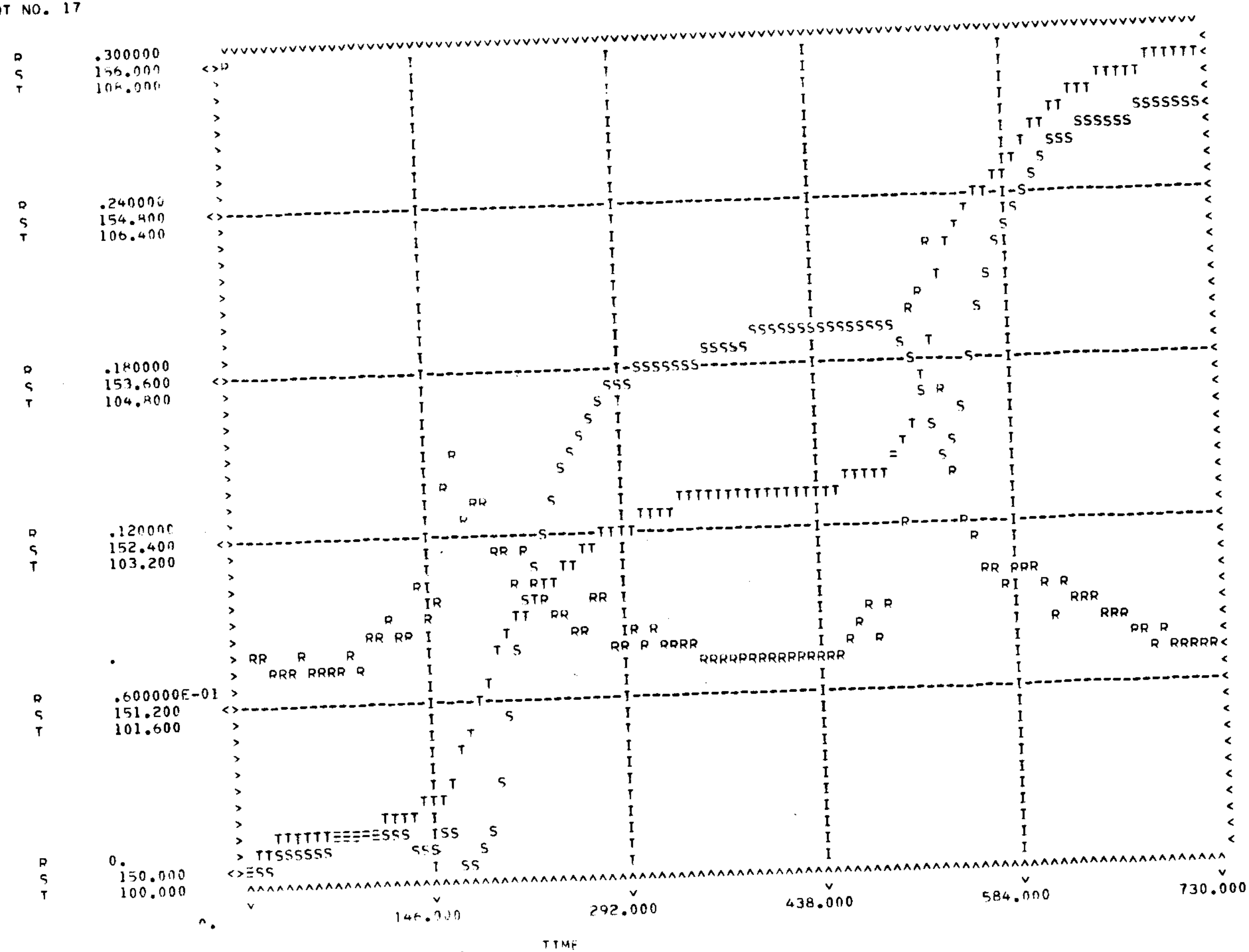

H J
900.000
2.00000
800.000
1.40000
700.000
.800000
600.000
.200000
500.000
-.400000
400.000
-1.00000
0.
146.000
292.000
438.000
584.000
730.000
TIME


PLOT NO. 14
KL 30.0000
KL 24.0000
KL 18.0000
KL 12.0000
KL 6.00000
KL 0.
0.
146.000
292.000
438.000
584.000
730.000
TIME


PLOT NO. 15
MN
C
200.000
500.000
160.000
400.000
120.000
300.000
80.0000
200.000
40.0000
100.000
0.
0.
146.000
292.000
438.000
584.000
730.000
TIME


PLOT NO. 16
PQ
PQ
PQ
PQ
PQ
PQ
500.000
400.000
300.000
200.000
100.000
0.
0.
146.000
292.000
438.000
584.000
730.000
TIME

PLOT NO. 17


R
S
T
.300000
156.000
108.000
.240000
154.800
106.400
.180000
153.600
104.800
.120000
152.400
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151.200
101.600
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150.000
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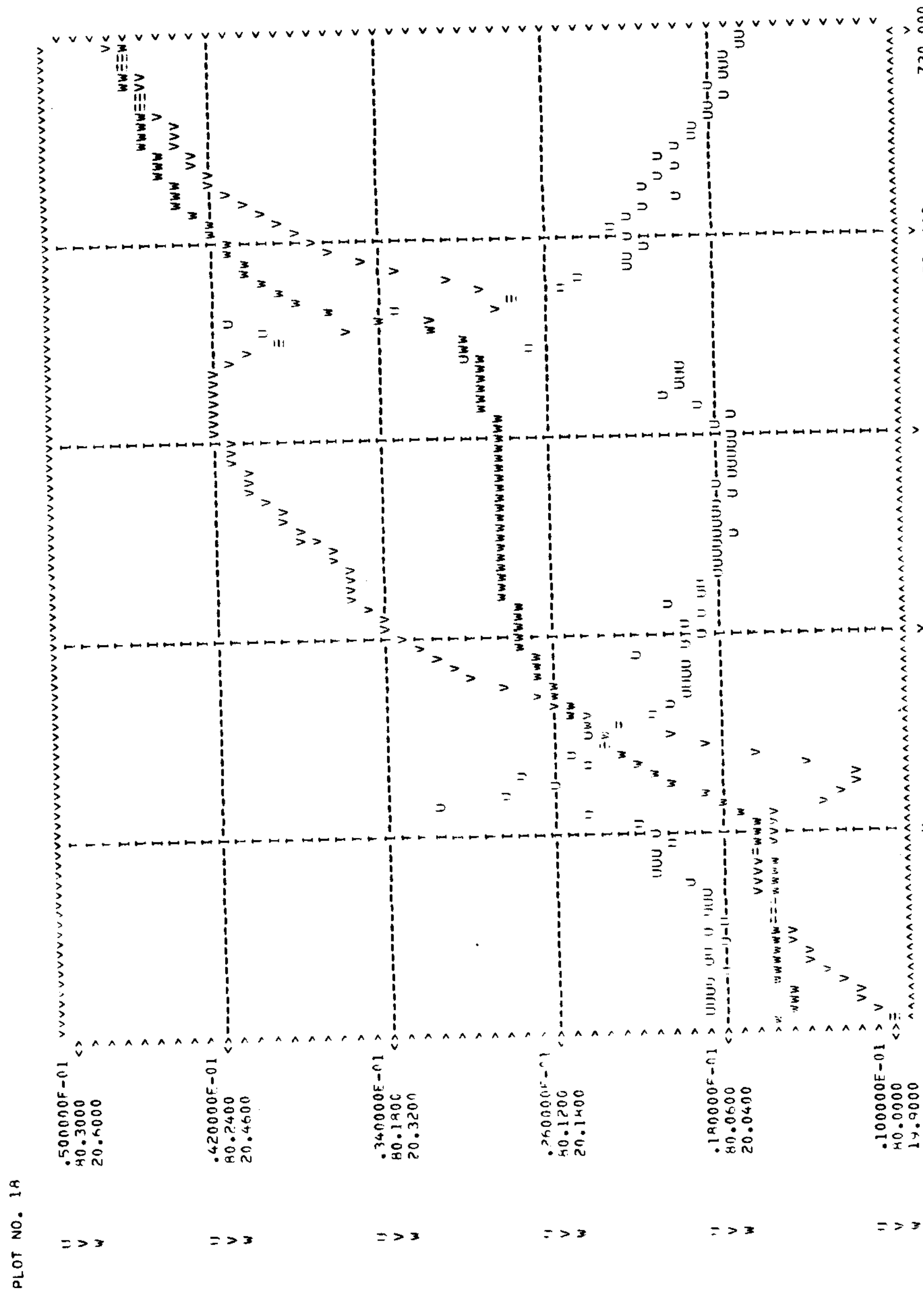
146.000
292.000
438.000
584.000
730.000
TIME

PLOT NO. 18


U V W
.500000E-01
80.3000
20.6000
.420000E-01
80.2400
20.4600
.340000E-01
80.1800
20.3200
.260000E-01
80.1200
20.1800
.180000E-01
80.0600
20.0400
.100000E-01
80.0000
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146.000
292.000
438.000
584.000
730.000
TIME

CHAPTER 10. CONCLUSIONS AND ANALYSIS OF STATUS OF THE MODEL

In the first chapter of this report we have discussed the philosophy of our modelling methods and outlined our objectives. Now that the model has been described, it remains to examine our efforts and to attempt to assess how far we have adhered to our philosophy and how well we have met our objectives.

The first part of this assessment may be answered positively in a simple pragmatic manner. The use throughout of the SIMCOMP precompiler guarantees that we will be oriented toward flows and that the system will deal with them by writing and solving difference equations. That is, the philosophy is built into the tool.

10.1 OBJECTIVES AND QUESTIONS

The objectives were more diverse. Among them, the requirement that there should be relatively easy interaction with the model is also provided by SIMCOMP. It is, in fact, our experience that small or moderate modifications to the model can be programmed under SIMCOMP and fresh output obtained within the time limits proposed, 30 min. Naturally there is a relationship between the size of the modification and the time required to implement it, but there is no doubt that this objective has been met at a satisfactory level.

That the model should represent a *total system* has been met, we believe, by the inclusion of those aspects of the ecosystem which we have called abiotic factors, production, consumption, and decomposition. Within these sections there could be room for doubt as to whether the total system is present. Possibly it would be more correct to say that the total system is indicated.

Examples of facets of the total ecosystem which are merely sketched, or which are even simplified out of the model, would not be hard to find. A specialist in the study of evapotranspiration might find fault with our handling of this topic, pointing out, perhaps, that stomatal behavior and water vapor profiles are not considered explicitly. Photosynthetic production is not as closely linked into the abiotic system as it might be, particularly with respect to available light and carbon dioxide. The consumer section deals with only one major consumer whereas there are many minor ones as well. There are many such instances, we admit. In some cases work is already well advanced on additions which will fill some of these gaps. It may be noticed that the reason for each page of this report bearing a date is that the work of development is still proceeding at a rapid rate, and it was necessary to set a time line at which this report would describe the model. It is expected that new developments will be added as they are completed and that updated materials will be issued to users of this report.

However, we wish to make the point that such additions tend to increase the level of complexity and that unrestricted addition of "improvements" would tend to subvert what is a basic requirement of any model. That is, it should represent the system with as few and as simple concepts as are necessary to predict the behavior of the system at the level of resolution chosen.

It is on this last ground that we believe our second stated objective is achieved. We are concerned primarily with carbon or energy flows. Flows of water and nutrients are secondary to this and so are dealt with in less detail.

The third stated objective, that the model should be representative of a grassland, is interpreted in the broad sense. Several of the authors are dispersed to sites where grasslands other than that which has been uppermost in our minds until now will be under study. We hope that the model has been structured in such a way that it can be adapted to these other sites by simple changes of parameter values, but this remains to be proven by experience.

In Chapter 1 after stating the principal objectives, we listed six specific questions to which ELM was to be addressed. It is appropriate to review these questions now and to examine how far we have succeeded in dealing with them.

The first two questions are related. One asks for the effects on primary productivity of perturbations in level and type of herbivory, water supply, temperature, nitrogen, and phosphorus; the other for carrying capacity of the grassland. With the exception of type of herbivory, all of these can now be answered with the present version of the model. These perturbations can be made, and the effects on primary productivity and carrying capacity resulting from them can be obtained by recording the amounts of the appropriate end products. The model deals with reasonable perturbations in a satisfactory manner and survives unreasonable ones. Here, of course, it is less easy to judge whether the responses are realistic since by definition they are of rare occurrence in the real system.

The results of appropriately driven runs are consistent with field data taken from the Grassland Biome program. This has been assured by using these data as guides while designing the model. It should be pointed out, however, that whenever a close check of performance is to be made, then the option in the abiotic section of using environmental data actually recorded at the site should be exercised. If the stochastic simulator is used to produce the driving variables, then one can expect that the output will only indicate the type of response to be expected, not a response agreeing in detail with results observed at any particular time. Failure to grasp this distinction can only lead to misunderstanding of the functioning of the model.

The fourth question concerned the composition of the plant community constituting the grassland. Insofar as the species composition has been restricted to five plant types (warm-season and cool-season grasses, forbs, shrubs, and cacti), an answer can only be given in terms of these. A detailed breakdown into species has not been attempted. Within this limitation the model can provide estimates of the amounts of these five plant types resulting from the perturbation.

Regarding qualitative differences in primary productivity and herbivory practice between Grassland Biome sites, we cannot yet provide an answer. These qualitative differences will be questions addressed in the near future by the liaison officers working at the various sites.

Validation of the model in the proper sense has not been attempted yet. Throughout the development, empirical data obtained by the experimental workers of the Grassland Biome program have been used extensively and their experience and advice have been drawn on freely. Our debt to them is acknowledged. The model has been designed with this data before us; one might say that we have used it as a yardstick by which to judge the output at each stage of development. Such activity, while perfectly legitimate in modelling, does not constitute validation. To think that it did would be to fall into the logical absurdity of the circular argument. Validation requires that the model as constituted should be run and its output compared with data which has not been used for its development. This validation remains to be done.

The work of the individual authors who will be acting as liaison officers at the various Grassland Biome sites to which they have dispersed will offer many opportunities for validation. If the model in its present form can predict the behavior of these grasslands merely by being given the parameter values appropriate to those sites, it will to that extent have been validated. This validation will, in fact, be an important part of the work at those sites. We recognize that once the model has been altered in structure to bring its output more closely into agreement with a given set of field data, those data are no longer available for validation.

Similarly, sensitivity analysis is an activity which remains to be done. Sensitivity analysis and the further improvement of SIMCOMP are activities which may best be undertaken at the central office with its greater computer capacity and permanent programming staff.

There are some areas in which gaps in the existing data are handicapping the modelling effort. Noticeable among these are our lack of information on belowground parts and on interchange of material between these and aboveground parts. Experimental work is in hand in the 1972 summer season, which hopefully will provide needed data on translocation between shoot and root systems. However, it seems that knowledge of the processes involved in the flows between belowground living parts, belowground dead parts, and microbes and their end products must wait for some later occasion since no work likely to produce useful results in this area has been put in hand to date. The experimental difficulties in this area are acknowledged to be very considerable and to be the real cause of the lack of data. It would be reasonable to suggest that intensive consultation between persons with expertise in that area should precede the planning of particular experimental work.

Compatibility of the various sections of the model with respect to time resolution has been achieved by the use of the same modelling system throughout. However, this does not mean that all sections of the model possess equal resolution with respect to the level of the detail which is represented. This is, of course, closely affected by the level of knowledge available in the various sections and the detail available in the data. This detail is probably greatest in the abiotic section. A conscious effort has been made there to maintain the resolution below that which could, in fact, be attained so as to make it more nearly compatible with some of the other sections. The level of detail available in the producer section and in the nutrient section is also greater than can be justified for inclusion while remaining compatible with other sections and under the overall aims. In the consumer section there is much detail available for a small number of consumers and less or none for a number of others. The decomposer section is perhaps the least well supplied with detailed data.

10.2 HOLISM VS. MECHANISM

We should, perhaps, digress here for a moment to describe our position on holism (coarse resolution) vs. mechanism (fine resolution) as a modelling philosophy. Models at the extremes of this scale are rare. Almost all useful models contain some mechanism (description of the physical processes operative in the system) and some holism (lumping of groups of processes and treating them as input/output systems). Our model is of this latter type. The greatest art in developing such models and interpreting their output is associated with the mixture of holism and mechanism. We strive toward mechanism because of the implication that cause-effect relationships are well represented. Such cause-effect relationships allow one to accept the model predictions even when the driving variables are significantly different from those used to develop the model. The holistic portions are paraphrased, "this input results in this output." Since physical mechanism and cause-effect relationships are not described, holistic portions of the model are valid only in the range of (in fact, only with) the input variables used to develop the model.

Typically, model sections contain both holistic and mechanistic segments. Many holistic portions are biologically based on the "mouse to elephant energy law" or the "Q_{10} temperature response," but still do not describe the mechanisms which underlie the law and thus fail to describe (or allow for discovery of) their limitations.

10.3 OUTPUT UTILITY

We feel that we should, at this stage, attempt to indicate what progress we have made toward obtaining output which may be useful scientifically or managerially. As to the first, we believe that we are already in a position to be able to carry out planned trials with the cooperation of the experimental staff. This type of activity will, in fact, be an important step toward the validation of the model. Similarly, our output could be used as a guide in the planning of experiments by suggesting possible outcomes. It would be another matter to claim that the output could substitute for experimental results. Such a stage can certainly not be approached before the widest and most thorough validation has been carried out. Even then there should always be clear reservations, and one might well hesitate to suggest the use of this method in lieu of experimentation except in those areas where experimentation is unduly difficult, costly, or slow.

In the matter of managerial use of the results of experimentation, it has been usual to delay practical application of results until they are deemed acceptable and reliable at the scientific level. There seems to be no good reason for reversing this policy in the present case. Modelling is properly to be regarded as a tool for gaining an understanding of problems. It is another method, perhaps one which may be regarded as additional to the experimental method. It certainly cannot claim to be a better method, nor is it conspicuously cheaper. It may sometimes be quicker. This is not a reason for allowing it to replace experimentation, nor for yielding to pressure to release the results for managerial purposes before they are scientifically acceptable.

ACKNOWLEDGMENTS

Many people have contributed time, effort, and ideas to this model. A complete list of contributors would be impossible to compile; however, the following individuals and groups certainly must be mentioned: George Van Dyne, Don Jameson, Mel Dyer, Norm French, John Marshall, Jim Ellis, Dave Coleman, Freeman Smith, Sam Bledsoe, Larry Harris, Alicja Breymeyer, Gordon Swartzman, Bob Francis, John Reuss, Vern Cole, Francis Clark, Phil Sims, A. J. Dye, Ken Addison, and Chuck Dickinson contributed scientific data and results and/or modelling expertise directly to the authors. Without their help and guidance the model could never have been brought to this level of development.

The programming and secretarial staff provided valuable support in the conduct of the work and the preparation of this (and other) reports.

Finally, Jon Gustafson provided major programming support in the development, implementation, and maintenance of SIMCOMP in its several versions.

The authors gratefully acknowledge the help of these contributors, apologize to those whose names did not appear here, and accept full responsibility for errors of interpretation, implementation, or use of contributed material.

APPENDIX I

ALPHABETICAL LIST OF VARIABLES, THEIR MEANINGS, AND UNITS

This appendix contains an alphabetical list of the variables used in the current version of the model. This list is incomplete in that a number of temporary variables, introduced to simplify coding a portion of the model, are omitted. The listed variables are defined, and their units are given.

The authors would appreciate having any errors in this appendix called to their attention.

```
C      A(I,J,K)  IS THE PROBABILITY FOR RAINFALL GIVEN THE OCCURRENCE
C                      (I=2) OR NONOCCURRENCE (I=1) OF RAINFALL ON THE
C                      PREVIOUS DAY.
C                      J=1,2,,,,5 - RELATIVE HUMIDITY FOR THE DAY.
C                      J=1 , R.H. IS 1 - 20 PER CENT.
C                      J=2 , R.H. IS 21 - 40 PER CENT.
C                      ...
C                      J=5 , R.H. IS 81 - 100 PER CENT.
C                      K=1,2,,,12 - MONTHS OF THE YEAR.
C       ABM       IS TOTAL ABOVE GROUND BIOMASS, G/M**2.
C       ACRES     IS ACRES OF AREA RELATIVE TO ANUM.
C       ACRE1     IS AMOUNT OF AREA STOCKED FOR YEARS 1 AND 3,
C                 ACRES.
C       ACRE2     IS AMOUNT OF AREA STOCKED FOR YEARS 2 AND 4,
C                 ACRES.
C       ACT       IS THE FOOD USED IN ACTIVITY, G.M**2.
C       ADGVA     ,
C       ADGVB     ,
C       ADGVC     ,AND
C       ADGVF     ARE INPUT PARAMETERS USED TO DETERMINE
C                 DIGESTIBILITY CURVES.
C       ADIG      IS DIGESTIBILITY OF FOOD INTAKE
C       ADIGR     IS DIGESTIBLE ENERGY REQUIREMENT. KCAL.
C       ADUM      IS A DUMMY VARIABLE USED TO CALCULATE AGAIN
C       AENK      IS ENERGY REQUIREMENT PER ANIMAL, KCAL.
C       AFECE     IS FECAL MATERIAL, G/M**2.
C       AFIN      IS AMOUNT OF FOOD INTAKE REQUIRED BY AN ANIMAL, G/M**2.
C       AFX       IS A MULTIPLYING FACTOR TO INCREASE AFIN AS AVDIG
C                       INCREASES.
C       AGAIN     IS AMOUNT OF GAIN , LB/ANIMAL.
C       AHEAT     IS TEMPERATURE EFFECT ON ENERGY REQUIREMENT.
C       AMFIN     IS TOTAL MAXIMUM POSSIBLE FOOD INTAKE, G/M**2.
C       ANUM      IS NUMBER OF ANIMALS PER UNIT AREA.
C       ANUM1     IS STOCKING RATE FOR YEARS 1 AND 3.
C       ANUM2     IS STOCKING RATE FOR YEARS 2 AND 4.
C       APAL(I)   IS THE PALABILITY INDEX FOR EACH FOOD CATEGORY
C                 I=1,11.
C       APERN     IS INTAKE AS PERCENT OF BODY WEIGHT.
C       APHEN(I)  IS ADJUSTED PHENOLOGY FOR EACH FOOD CATEGORY.
C       APP(5)    IS A VARIABLE USED TO ADJUST THE RATE AT WHICH
C                 THE STANDING DEAD PHEN PROGRESS.APP(1)
C                 CORRESPONDS TO APHEN(6).
C       APTC      IS FOOD PREFERENCE TENDENCY.
C       ARESP     IS RESPIRATION LOSS, G/M**2.
C       ASC       IS DAILY INTERCEPTION BY THE STANDING CROP, CM/DAY.
C       ASTP      IS A DUMMY VARIABLE TO REMOVE CATTLE IF ATFB IS LIMITING
C       ATFB      IS THE AMOUNT OF TOTAL FORAGE BIOMASS, G/M**2.
C       ATGAN     IS THE LEVEL OF GAIN CHOSEN TO DETERMINE HUNG, G/M**2.
C       ATWK      IS TOTAL WEIGHT OF ANIMALS, KG.
C       ATWT      IS TOTAL WEIGHT OF ANIMALS, POUNDS.
C       ATWT1     IS ANIMAL WEIGHT AT THE TIME OF STOCKING FOR
C                 YEARS 1 AND 3.
C       ATWT2     IS ANIMAL WEIGHT AT THE TIME OF STOCKING FOR
C                 YEARS 2 AND 4.
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C     ATX         IS A MULTIPLICATION FACTOR FOR TRAVEL
C     AURIN       IS MATERIAL LOST AS URINE, G/M**2.
C     AVAT        IS AVERAGE DAILY AIR TEMPERATURE, DEG.C.
C     AVDIG       IS AVERAGE DIGESTIBILITY OF FOODS.
C     AVTC        IS AVERAGE DAILY AIR TEMPERATURE IN THE CANOPY, DEG.C.
C     AX          IS ACCESSIBLE FOOD, G/M**2.
C     AZT         IS A DUMMY VARIABLE = MAXIMUM RATE OF GAIN,LB.
C     B(I,J)      IS THE CUMULATIVE FREQUENCY DISTRIBUTION FOR AMOUNT OF
C                       RAINFALL.
C                       I=1,2,,,12  - MONTHS OF THE YEAR
C                       J=1,2,,,10
C                       J=1, PROBABILITY FOR RAIN ≤0.1 IN.
C                       J=2,      DITTO              ≤0.2 IN.
C                       J=3       DITTO              ≤0.3 IN.
C                       J=4       DITTO              ≤0.5 IN.
C                       J=5       DITTO              ≤0.7 IN.
C                       J=5       DITTO              ≤0.7 IN.
C                       J=6       DITTO              ≤0.9 IN.
C                       J=7       DITTO              ≤1.5 IN.
C                       J=8       DITTO              ≤2.5 IN.
C                       J=9       DITTO              ≤4.5 IN.
C                       J=10      DITTO              +6.5 IN.
C     C(I,J)      CONTAINS THE LOWEST AMOUNT OF RAINFALL IN THE ITH
C                       RAINFALL CATEGORY (J=1) AND THE WIDTH OF THE ITH
C                       RAINFALL CATEGORY (J=2)
C     CIN         IS GROSS PHOTOSYNTHETIC RATE, G/M**2/DAY.
C     CLD(I)      IS THE AVERAGE CLOUD COVER FOR THE ITH MONTH, I=1-12.
C     CLD(I,J,K)        IS THE CUMULATIVE FREQUENCY DISTRIBUTION FOR CLOUD
C                       COVER.
C                       I=1,2,,,12 - MONTHS OF THE YEAR.
C                       J=1,2,,,5
C                       J=1 , R.H. IS 1 - 20 PER CENT.
C                       J=2 , R.H. IS 21 - 40 PER CENT.
C                       ...
C                       J=5 , R.H. IS 81 - 100 PER CENT.
C                       K=2 - 11.
C                       K=2,PROBABILITY THAT CLOUD COVER IS >0,≤10 PERCENT
C                       K=3       DITTO                     >10,≤20
C                       ...
C                       K=11,     DITTO                  >90,≤100 PER CENT
C     CLP         IS THE DAILY AVERAGE CLOUD COVER, PERCENT.
C     CNET        IS NET PHOTOSYNTHESIS, G/M**2/DAY.
C     CRT         IS THE TRANSFER OF CARBON FROM TOPS TO ROOTS, G/M**2/DAY
C     COUT        IS RESPIRATION RATE, G/M**2/DAY.
C     DAHOR       IS THE DEPTH OF THE A SOIL HORIZON, CM.
C     DELT        IS THE SOLAR DECLINATION IN RADIANS.
C     DEPTH       IS THE TOTAL DEPTH OF THE SOIL WATER LAYERS, CM.
C     DIGNR       IS THE DIGESTIBLE ENERGY REQUIRED PER METER SQUARED.
C     EAT         IS THE EFFECT OF AIR TEMPERATURE ON PHOTOSYNTHESIS.
C     EATR        IS THE EFFECT OF AIR TEMPERATURE ON RESPIRATION.
C     EBM         IS THE EFFECT OF BIOMASS ON PHOTOSYNTHESIS AND RESPN.
C     ENS         IS THE EFFECT OF NUTRIENT STRESS.
C     EP          IS THE EFFECT OF PHENOLOGY ON PHOTOSYNTHESIS AND RESPN.
C     ERR         IS AMOUNT OF DESIRED BUT NOT AVAILABLE INTAKE, G/M**2.
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C       ESM          IS THE EFFECT OF SOIL MOISTURE ON PHOTOSYNTHESIS.
C       ESMR         IS THE EFFECT OF SOIL MOISTURE ON RESPIRATION.
C       EVAP         IS THE ACTUAL EVAPORATION RATE, CM/DAY.
C       EVAST        IS THE YEARLY CUMULATIVE EVAPORATIVE WATER LOSS FROM
C                          BARE SOIL, IN.
C       EVATT        IS THE YEARLY CUMULATIVE TRANSPIRATIONAL WATER LOSS,IN.
C       FCPIP        IS THE RATIO OF PHOSPHORUS TO PLANT BIOMASS MAINTAINED
C                          IN LIVING PLANT TISSUE.
C       FNCIP        IS THE RATIO OF NITROGEN TO PLANT BIOMASS MAINTAINED IN
C                          LIVING PLANT TISSUE
C       FNNIP        ADJUSTS THE RATE AT WHICH ROOT NITROGEN MOVES TO SOIL
C                          NITROGEN.
C       FNSR         IS THE NITROGEN STARVATION LEVEL FOR THE PLANT, REPRES-
C                          ENTED BY THE RATIO OF PLANT NITROGEN TO PLANT
C                          BIOMASS.
C       FPSR         IS THE PHOSPHORUS STARVATION LEVEL FOR THE PLANT, REPRES
C                          ENTED BY THE RATIO OF PLANT PHOSPHORUS TO PLANT
C                          BIOMASS.
C       FINT         IS FOOD INTAKE PER FOOD CATEGORY, G/M**2.
C       GAS          IS FOOD LOST AS GAS, G/M**2.
C       HBGDI        IS THE ACCUMULATIVE FLOW INTO THE BELOWGROUND
C                    DEAD G/M**2.
C       HBGDO        IS THE ACCUMULATIVE FLOW OUT OF THE BELOWGROUND
C                    DEAD,G/M**2.
C       HEAT(I)      IS THE DAILY CHANGE OF TEMPERATURE FOR THE ITH POINT
C                          IN THE SOIL PROFILE.
C                          I=1 IS THE 15 CM LEVEL.
C                          I=2 IS THE 30 CM LEVEL.
C                          . . .
C                          I=11 IS THE 165 MM LEVEL.
C       HECEF        IS 1.0 MINUS THE ECOLOGICAL GROWTH EFFICIENCY OF
C                          MICROBES.
C       HFTMP(I)     IS THE EFFECT OF TEMPERATURE ON THE RATE OF DECOM-
C                          POSITION. I=1 FOR LITTER AND FECES . I=2-4 FOR THE
C                          0-5,5-15 AND 15-60 CM. SOIL LAYERS.
C       HHI40(I)     IS THE FLOW OF HARD MATERIAL INTO COMPARTMENT 40+I,
C                          I=1-5. G/M**2/DAY.
C       HHO40(I)     IS THE FLOW OF HARD MATERIAL FROM COMPARTMENT 40+I,
C                          I=1-5. G/M**2/DAY.
C       HKHF         IS A RATE CONSTANT FOR THE DECOMPOSITION OF THE HARD
C                          COMPONENT OF FECES. M**2/DAY.
C       HKHP         IS A RATE CONSTANT FOR THE DECOMPOSITION OF THE HARD
C                          COMPONENT OF PLANT MATERIAL. M**2/DAY.
C       HKSF         IS A RATE CONSTANT FOR THE DECOMPOSITION OF THE SOFT
C                          COMPONENT OF FECES M**2/DAY.
C       HKSP         IS A RATE CONSTANT FOR THE DECOMPOSITION OF THE
C                          SOFT COMPONENT OF PLANT MATERIAL. M**2/DAY.
C       HLITI        IS THE ACCUMULATIVE FLOW INTO THE LITTER G/M**2.
C       HLITO        IS THE ACCUMULATIVE FLOW OUT OF THE LITTER G/M**2.
C       HMAXL        IS THE MAXIMUM NET REDUCTION PER DAY OF MICROBIAL
C                          BIOMASS (PROPORTION OF TOTAL BIOMASS).
C
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C      HMER(I)    IS THE MAINTENANCE ENERGY REQUIREMENT FOR THE MICROBES
C                       OF COMPARTMENT 50+I, I=1-4. G/M**2/DAY.
C      HMOI(I)    IS THE VOLUMETRIC WATER CONTENT CM**3 OF WATER
C                 PER CM**3 OF SOIL
C      HMOIS(I)   IS THE EFFECT OF MOISTURE ON THE RATE OF DECOMPOSITION.
C                       I=1 FOR LITTER AND FECES.
C                       I=2-4 FOR THE SOIL LAYERS 0-5,5-15 AND 15-60 CM.
C      HS1(I)     IS THE PROPORTION OF SOFT MATERIAL IN  COMPARTMENT
C                       1+I, I=1-5.
C      HS11(I)    IS THE PROPORTION OF SOFT MATERIAL IN CPMPARTMENT
C                       11+I, I=1-5.
C      HS19(I)    IS THE PROPORTION OF SOFT MATERIAL IN COMPARTMENT
C                       19+I, I=1-6.
C      HS40(I)    IS THE PROPORTION OF SOFT MATERIAL IN COMPARTMENT
C                       40+I, I=1-5.
C      HSI40(I)   IS THE FLOW OF SOFT MATERIAL INTO COMPARTMENT 40+I,
C                       I=1-5. G/M**2/DAY.
C      HSO40(I)   IS THE FLOW OF SOFT MATERIAL FROM COMPARTMENT 40+I,
C                       I=1-5. G/M**2/DAY.
C      HTOBL      IS TOTAL BELOW GROUND DEAD MATERIAL,G/M**2.
C      HTOCO      IS CUMULATIVE CO2 OUTPUT FROM MICROBES,G/M**2.
C      HTOMI      IS BIOMASS OF SOIL MICROBES, G/M**2.
C      HUNG       IS DIFFERENCE BETWEEN REAL AND OPTIMUM GAIN.
C      HUNGR      IS HUNGER CARRIED OVER FROM THE PREVIOUS DAY, G/M**2.
C      HWXYZ      ARE VARIABLES USED TO DESIGNATE THE AMOUNT OF
C                 MATERIAL FLOWING FROM COMPARTMENT WX TO YZ. FOR
C                 EXAMPLE, H1242 IS THE AMOUNT FLOWING PER DT FROM
C                 COMPARTMENT 12 TO 42, G/M**2/DT
       INDX(I)    IS USED IN GETSET TO RANK PALABILITY (INTER-
C                 MEDIATE VARIABLE).
C      MON        IS THE MONTH OF THE YEAR.
C      NDAY       IS THE DAY OF THE YEAR (1,2,,,365)
C      NLYA       IS THE NUMBER OF SOIL WATER LAYERS IN THE A SOIL HORIZON
C      NLYS       IS THE NUMBER OF SOIL WATER LAYERS CONSIDERED.
C      NOBSD      NOBSD=1-SIMULATED WEATHER DATA WILL BE USED OR,
C                 NOBSD=2-OBSERVED WEATHER DATA WILL BE USED TO DRIVE THE
C                       MODEL.
C      NWK        IS THE WEEK OF THE YEAR (1,2,,,52)
C      P2041      AND
C      P4150      AND
C      P4250      ARE DECOMPOSITION RATE PARAMETERS, G/M**2/DAY.
C      P6065      IS THE TRANSFER COEFFICIENT FROM X(60) TO X(65).
C      P6360                THE SAME FOR       X(63) TO X(60).
C      P6560      IS THE TRANSFER COEFFICIENT FROM X(65) TO X(60)
C                 G/M**2/DAY.
C      P7075                THE SAME FOR       X(70) TO X(75).
C      P7370                THE SAME FOR       X(73) TO X(70).
C      P7570                THE SAME FOR       X(75) TO X(70).
C      P7675                THE SAME FOR       X(76) TO X(75).
C      PBM        IS PLANT BIOMASS, G/M**2.
C      PC         IS THE CONCENTRATION OF NITROGEN IN THE SOIL SOLUTION,
C                       G/M**2/CM. WATER.
C      PEA        IS AN EMPIRICAL COEFICIENT USED IN THORNTH-
C                 WAITE≠S EVAPOTRANSPIRATION EQUATION (SEE
C                 EQUATION 2.12)
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C      PEVAP       IS THE POTENTIAL EVAPOTRANSPIRATION RATE FOR A GIVEN
C                        DAY, CM/DAY.
C      PEVAS       IS EVAPORATION RATE FROM BARE SOIL, CM/DAY.
C      PEVAST      IS YEARLY CUMULATIVE WATER LOSS BY BARE SOIL EVAPORATION
C                        INCHES.
C      PEVAT       IS THE RATE OF TRANSPIRATION, CM/DAY.
C      PEVATT      IS YEARLY CUMULATIVE WATER LOSS BY TRANSPIRATION, IN.
C      PEVTT       IS THE YEARLY CUMULATIVE SUM OF THE DAILY POTENTIAL
C                        EVAPOTRANSPIRATION RATE, INCHES.
C      PHEN        IS THE PHENOLOGICAL STAGE OF PLANT DEVELOPMENT, VARIES
C                        FROM 1 TO 14 - EARLY VEGETATIVE TO DORMANCY.
C      PHI         IS THE LATITUDE OF THE PLACE, RADIANS
C      PHRI        IS THE AMOUNT OF PHOSPHORUS THAT WILL ENTER THE LABILE
C                        POOL AS THE RESULT OF DAILY RAINFALL, G/M**2.
C      PILT        IS DAILY INTERCEPTION BY THE LITTER,CM/DAY.
C      PILT1       IS THE WATER STORED BY THE LITTER ON A GIVEN DAY, CM.
C      PILTT       IS YEARLY CUMULATIVE INTERCEPTION BY LITTER.INCHES.
C      PISC        IS DAILY INTERCEPTION BY STANDING CROP, CM/DAY.
C      PISC1       IS THE WATER STORED BY THE STANDING CROP ON A GIVEN DAY,
C                        CM.
C      PISCT       IS THE YEARLY CUMULATIVE STANDING CROP INTERCEPTION,IN.
C      PLAI        IS LEAF AREA INDEX FOR STANDING CROP BIOMASS.
C      PLA2        IS LEAF AREA INDEX FOR LIVE BIOMASS
C      PMOD(I)     DETERMINES WHICH RELATIVE HUMIDITY FREQUENCY DISTRIBUT-
C                        ION IS USED TO DRIVE THE MODEL.
C                        PMOD(I)=1 -- REGULAR DISTRIBUTION.
C                        PMOD(I)=2 --15 PER CENT INCREASE.
C                        PMOD(I)=3 --15 PER CENT DECREASE,
C                          FOR THE ITH MONTH.
C      PRA         INDICATES WHETHER RAINFALL OCCURRED ON THE PREVIOUS DAY.
C                        PRA=1 MEANS RAIN.
C                        PRA=2 MEANS NO RAIN.
C      PRD         CONTROLS THE DRAINAGE OF WATER FROM THE SOIL LAYERS
C                        WHICH ARE BELOW FIELD CAPACITY.
C      PRF         CONTROLS THE OCCURENCE OF RAIN GENERATED BY THE MARKOV
C                        CHAINS.(PRF=0.60 FOR DATA FROM CHEYENE.)
C      PRIP        IS DAILY PRECIPITATION, CM.
C      PRIPT       IS CUMULATIVE RAINFALL FOR THE YEAR ,INCHES.
C      PS          IS THE BASIC RATE OF PHOTOSYNTHESIS,
C                        G.C/G DRY WT/M**2/DAY.
C      PS01(I)     IS THE ARRAY WHICH CONTAINS THE SOIL LAYER INDEX
C                        J = 1
C                        PS01=1,A HORIZON.
C                        PS01=2, B HORIZON.
C                        J=2, THE FIELD CAPACITY
C                        J=3, THE FRACTION OF ROOT BIOMASS.
C                        J=4, THE WILTING PPINT.
C                        J=5, THE DEPTH IN CM. OF THE ITH SOIL WATER LAYER
C      PTE         IS AN EMPERICAL COEFICIENT USED IN
C                  THORNTHWAITE*S EVAPOTRANSPIRATION EQUATION
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5/15/72


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C                     (SEE EQUATION 2.12)
C      PTEMP          IS THE AVERAGE DAILY AIR TEMPERATURE, DEG.C.
C      PTZP           IS TOTAL DAILY EVAPORATIIVE WATER LOSS, CM/DAY.
C      R1(I,J)        IS EQUIVALENT TO RH(I,J) INCREASED BY 15 PER CENT.
C      R2(I,J)        IS EQUIVALENT TO RH(I,J) DECREASED BY 15 PER CENT.
C      RADS(I)        IS THE SLOPE OF THE SATURATED VAPOR PRESSURE CURVE FOR
C                           AIR AT THE ITH TEMPERATURE, I=1,2,,,50 DEG.C.
C      RAIN           IS THE AMOUNT OF PRECIPATATION IN CM
C      RDR            IS DEATH RATE OF ROOTS, G/M**2/DAY.
C      RH(I,J)        IS THE CUMULATIVE FREQUENCY DISTRIBUTION FOR RELATIVE
C                           HUMIDITY
C                           I=1,2,,,12 - MONTHS OF THE YEAR.
C                           J=1,2,,,11
C                           J=2, PROBABILITY OF RH ≤ 10 PER CENT.
C                           J=3,      DITTO          ≤20
C                           ...
C                           J=11      DITTO          ≤100 PER CENT.
C      RHP            IS THE DAILY AVERAGE RELATIVE HUMIDITY, PERCENT.
C      RINT           IS REAL INTAKE, G/M**2.
C      RPU            IS THE RELATIVE NITROGEN UPTAKE AS A FUNCTION OF THETA.
C      RS             IS THE BASIC RATE OF RESPIRATION,G C/GM DRY WT/M**2/DAY.
C      RTDTH          IS ROOT DEATH RATE COEFFICIENT, G/M**2/DAY.
C      RTRS           IS THE ROOT RESPIRATION COEFFICIENT, G/M**2/DAY.
C      RU             IS ROOT UPTAKE OF NITROGEN, G/M**2/CM WATER.
C      SA             IS THE AVERAGE OF TMAX AND TMIN. DEG.C.
C      SA1            IS AN ARRAY WHICH CONTAINS THE SOIL CONDUCTIVITY AND
C                           SPECIFIC HEAT CAPACITY FOR THE SOIL MOISTURE
C                           LAYERS.
C      SASM(I)        IS THE SUM OF WFK(J),I=1,5,K=1,6 (SEE WFK(J)).
C      SAVTP(I)       IS THE AVERAGE DAILY SOIL TEMPERATURE FOR THE ITH LAYER
C                           DEG.C.
C      SBOT(I)        IS THE AVERAGE SOIL TEMPERATURE AT 180 CM AT THE BEGINN-
C                           ING OF THE ITH MONTH.
C      SCRT           IS THE CUMULATIVE YEARLY FLOW OF CARBON TO THE ROOT
C                           SYSTEMS OF ALL SPECIES.....UNITS NEEDED!
C      SDTH(6)        IS THE COEFFICIENT OF TRANSFER FROM LIVE SHOOT TO STAND-
C                           ING DEAD.
C      SFCJ(I)        IS SOIL FIELD CAPACITY IN CM OF WATER PER CM OF
C                     SOIL FOR EACH PLANT SPECIES I IN EACH SOIL STRATUM
C                     J.  I=1,5  J=1,6
C      SHOT(5)        IS GROWTH OF SHOOT SYSTEMS, CALCULATED IN CYCL1.
C      SLA2(5)        AND
C      SLA3(5)        ARE COEFFICIENTS IN THE EQUATION FOR THE PARABOLIC
C                           FUNCTION EBM.
C      SLOS           IS THE COEFFICIENT OF STANDING DEAD TO LITTER,G/M**2/DAY
C      SMAX(I)        IS THE OBSERVED MAXIMUM AIR TEMPERATURE FOR THE ITH DAY
C                           OF THE YEAR, DEG.C.
C      SMIN(I)              IS THE OBSERVED MINIMUM AIR TEMPERATURE FOR THE
C                           ITH DAY OF THE YEAR, DEG.C.
C      SM1            IS THE INFLECTION POINT AND
C      SM2            IS THE SPREAD OF ATAN WASM VS.PHOTOSYNTHESIS.
C      SMOGG          IS THE ACCUMULATIVE FLOW FROM X(63) TO X(60)
C                     G/M**2/DAY.
C      SMOS(I)        IS THE SOIL WATER IN THE ITH LAYER,CM.
C                           I=1,2,,,NLYS
C      SMR1(I)        IS THE MIDPOINT AND,
C      SMR2(I)        IS THE SPREAD OF THE SIGMOID CURVE OF THE EFFECT
C                     OF SOIL WATER ON PHOTOSYNTHESIS
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C     SOLA1      IS THE SOLAR RADIATION RECEIVED ABOVE THE ATMOSPHERE
C                      EXPRESSED AS MM WATER PER DAY WHICH COULD BE
C                      EVAPORATED BY THE ENERGY.
C     SP2(5)     ADJUSTS THE RATE OF CHANGE IN VEGETATIVE PHENOLOGY.
C     SP3(5)     IS THE MINIMUM SOIL TEMPERATURE FOR PLANT GROWTH TO
C                      OCCUR.
C     SP4(5)     IS THE VALUE OF SPTWR BELOW WHICH THE PHENOLOGICAL CYCLE
C                      IS RESTARTED.
C     SP5(5)     IS THE MID POINT OF THE SIGMOID CURVE OF REPRODUCTIVE
C                      PHENOLOGICAL PROGRESSION.
C     SP6(5)     IS THE SPREAD OF THE SIGMOID CURVE OF REPRODUCTIVE
C                      PHENOLOGICAL PROGRESSION.
C     SPROD      IS THE YEARLY CUMULATIVE NET CARBON ASSIMILATION FOR ALL
C                      PRODUCERS.
C     SPSX       DETERMINES THE MAXIMUM RATE OF NET PHOTOSYNTHESIS,
C                      CNET(I).
C     SPTW(20,5)IS THE PREVIOUS 20 DAYS PRODUCT OF TMAX AND (5.0 - WASM)
C                      USED TO DETERMINE SPTWR.
C     SPTWR(5)   IS THE 20 DAY RUNNING AVERAGE USED TO RESET PHENOLOGICAL
C                      STAGE FROM POST-FLOWERING DORMANCY TO EARLY
C                      VEGETATIVE STAGE.
C     SRAC(20,5)IS AVERAGE OF THE PREVIOUS 20 DAYS, FOR EACH OF THE 5
C                      PLANT TYPES,OF SUN*TMAX*(5.0-WASM), USED TO
C                      DETERMINE SRACR.
C     SRACR(5)   IS THE 20 DAY RUNNING AVERAGE, USED TO DETERMINE VEGET-
C                      ATIVE PHENOLOGICAL PROGRESSION.
C     SRDTH      IS THE YEARLY CUMULATIVE ROOT DEATH FOR ALL PRODUCERS.
C     SRIN(I)    IS THE OBSERVED RAINFALL FOR THE ITH DAY OF THE YEAR,IN.
C     SRTRS      IS THE YEARLY CUMULATIVE ROOT RESPIRATION OF ALL
C                      PRODUCERS.
C     SSDTH      ISTHE YEARLY CUMULATIVE SHOOT DEATH FOR ALL PRODUCERS.
C     ST1        IS THE INFLECTION POINT AND,
C     ST2        IS THE SPREAD OF ATAN TEMP. VS. PHOTOSYNTHESIS.
C     STEMP      IS AVERAGE OF MAX. AND MIN. TEMPERATURES GREATER THAN 0.
C                      DEG.C.
C     SUN        IS INSOLATION IN CAL/CM**2/DAY
C     SVRG       IS A VEGATIVE REGROWTH PARAMETER.
C     SWP1(I)    TO
C     SWP6(I)    IS THE WILTING POINT FOR THE TOP SIX SOIL STRATA FOR
C                      EACH SPECIES, CM. WATER.
C     SWSM(I)    IS THE SUM OF THE ROOT DENSITY WEIGHTING FACTORS WF1(I)
C                      TO WF6(I) FOR ITH SPECIES, USED IN CALCULATING
C                      WASM(I).
C     TCD        IS THE AVERAGE AIR TEMPERATURE DURING THE DAYLIGHT HOURS
C     TDR        IS DEATH RATE OF TOPS, G/M**2/DAY.
C     THETA      IS THE WATER CONTENT OF THE TOP 60 CM OF SOIL,CM.
C     TMAX       IS THE MAXIMIMUM AIR TEMPERATURE , DEG.C.
C     TMIS(5)    IS THE CUMULATIVE SUM OF ( INSOLATION * MAXIMUM AIR
C                      TEMPERATURE * RAIN OVER 1 CM.),STARTED WHEN PHEN =
C                      7.0, USED TO DETERMINE REPRODUCTIVE PHENOLOGICAL
C                      PROGRESSION.
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C     TMIN       IS THE MINIMUM AIR TEMPERATURE, DEG.C.
C     TMN(I,J,K)        IS THE CUMULATIVE FREQUENCY DISTRIBUTION FOR
C                       MINIMUM AIR TEMPERATURE.
C                       I=1,2,,,12 - MONTHS OF THE YEAR.
C                       J=1,2,,,5
C                       J=1 , R.H. IS 1 - 20 PER CENT.
C                       J=2 , R.H. IS 21 - 40 PER CENT.
C                       ...
C                       J=5 , R.H. IS 81 - 100 PER CENT.
C                       K=1,2,,,23
C                       K=2,PROBABILITY FOR MIN.AIR TEMP.≤-30 DEG.F.
C                       K=3       DITTO                  ≤-25 DEG.F.
C      TMX(I,J,K)       IS THE CUMULATIVE FREQUENCY DISTRIBUTION FOR
C                       MAXIMUM AIR TEMPERATURE
C                       I=1,2,,,12 - MONTHS OF THE YEAR.
C                       J=1,2,,,5
C                       J=1 , R.H. IS 1 - 20 PER CENT.
C                       J=2 , R.H. IS 21 - 40 PER CENT.
C                       ...
C                       J=5 , R.H. IS 81 - 100 PER CENT.
C                       K=1 - 23
C                       K=2,PROPABILITY OF MAX. AIR TEMP.≤0DEG.F.
C                       K=3       DITTO                  ≤5 DEG.F.
C
C      TMP         IS THE MAXIMUM AIR TEMPERATURE, DEG.F.
C      TNP         IS THE MINIMUM AIR TEMPERATURE, DEG.F.
C      TP(1)       IS THE FRACTION OF THE DAY WHICH IS LIGHT.
C      TP(2)       IS THE FRACTION OF THE DAY WHICH IS DARK.
C      TPRT        IS A COEFFICIENT FOR ABOVE TO BELOW GROUND TRANSFER,
C                       G/M**2/DAY.
C
C      TR1         AND
C      TR2         ARE COEFFICIENTS OF THE EXPONENTIAL CURVE OF TEMPERATURE
C                  VS.RESPIRATION.
C      WASM        IS THE WEIGHTED AVERAGE SOIL  MOISTURE.
C      WETDY       IS SMOS(1)*DAY TEMP. USED TO CALCULATE PHEN OF DEAD.
C      WF1         TO
C      WF6         ARE WEIGHTING FACTORS FOR THE FOUR SOIL STRATA.
C      WS(I,J,K) IS THE CUMULATIVE FREQUENCY DISTRIBUTION FOR WIND SPEED.
C                       I=1,2,,,12 - MONTHS OF THE YEAR.
C                       J=1,2,,,5
C                       J=1 , R.H. IS 1 - 20 PER CENT.
C                       J=2 , R.H. IS 21 - 40 PER CENT.
C                       ...
C                       J=5 , R.H. IS 81 - 100 PER CENT.
C                       K=1 - 7
C                       K=2,PROBABILITY OF WINDSPEED +0,≤5 M.P.H.
C                       K=3       DITTO              +5,≤10
C                       ...
C                       K=7       DITTO              +25,≤30 M.P.H.
C
C       WSP        IS THE AVERAGE WIND SPEED 2 METERS ABOVE THE
C                  GROUND. MILES/HOUR.
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C                        * STATE VARIABLES *
C                        ********************
C
C      X(1)          IS AIR CO2 (SOURCE AND SINK) G/M**2.
C      X(2)          IS ABOVEGROUND LIVE WARM SEASON GRASS G/M**2.
C      X(3)          IS ABOVEGROUND LIVE COOL SEASON GRASS G/M**2.
C      X(4)          IS ABOVEGROUND LIVE FORB G/M**2.
C      X(5)          IS ABOVEGROUND LIVE SHRUB G/M**2.
C      X(6)          IS ABOVEGROUND LIVE CACTI G/M**2.
C      X(12)         IS LIVE WARM SEASON GRASS ROOTS G/M**2.
C      X(13)         IS LIVE COOL SEASON GRASS ROOTS G/M**2.
C      X(14)         IS LIVE FORB ROOTS G/M**2.
C      X(15)         IS LIVE SHRUB ROOTS G/M**2.
C      X(16)         IS LIVE CACTI ROOTS G/M**2.
C      X(20)         IS STANDING DEAD WARM SEASON GRASS G/M**2.
C      X(21)         IS STANDING DEAD COOL SEASON GRASS G/M**2.
C      X(22)         IS STANDING DEAD FORBS G/M**2.
C      X(23)         IS STANDING DEAD SHRUB LEAVES G/M**2.
C      X(24)         IS STANDING DEAD SHRUB WOOD G/M**2.
C      X(25)         IS STANDING DEAD CACTI G/M**2.
C      X(40)         IS STEER BIOMASS G/M**2.
C      X(41)         IS LITTER BIOMASS G/M**2
C      X(42)         IS BELOWGROUND DEAD (0 TO 5 CM) G/M**2.
C      X(43)         IS BELOWGROUND DEAD (5 TO 15 CM) G/M**2.
C      X(44)         IS BELOWGROUND DEAD (15 TO 60 CM) G/M**2.
C      X(45)         IS FECES G/M**2.
C      X(51)         IS LITTER MICROBES G/M**2.
C      X(52)         IS BELOWGROUND MICROBES (0 TO 5 CM) G/M**2.
C      X(53)         IS BELOWGROUND MICROBES (5 TO 15 CM) G/M**2.
C      X(54)         IS BELOWGROUND MICROBES (15 TO 60 CM) G/M**2.
C      X(60)         IS SOIL AVAILABLE NITROGEN G/M**2.
C      X(61)         IS PLANT ROOT NITROGEN G/M**2.
C      X(62)         IS PLANT TOP NITROGEN G/M**2.
C      X(63)         IS SOIL ORGANIC NITROGEN G/M**2.
C      X(65)         IS NITROGEN LABILE POOL G/M**2.
C      X(66)         IS ATM SOURCE AND SOIL SINK FOR NITROGEN G/M**2.
C      X(70)         IS THE SOLN OF PHOSPHORUS IN THE SOIL G/M**2.
C      X(71)         IS PHOSPHORUS IN THE PLANT ROOTS G/M**2.
C      X(72)         IS PHOSPHORUS IN THE PLANT TOPS G/M**2.
C      X(73)         IS SOIL ORGANIC PHOSPHORUS G/M**2.
C      X(75)         IS THE LABILE POOL OF PHOSPHORUS G/M**2.
C      X(76)         IS ATM SOURCE AND SOIL SINK FOR PHOSPHORUS G/M**2.
C      X(90)         IS THE AVERAGE DAILY SOIL TEMPERATURE FROM 0-60
C                    CM. DEG. C.
C      X(98)         IS SOIL WATER IN THE TOP 60 CM OF SOIL.
C      X(99)         IS ATM MOISTURE (H2O) CM.
C*************************************************************************
C*************************************************************************
C      Y1            IS THE NUMBER OF DAYLIGHT HOURS.
C      Y2            IS THE NUMBER OF NIGHT HOURS.
C      ZMOND         IS THE DAY OF THE MONTH.
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