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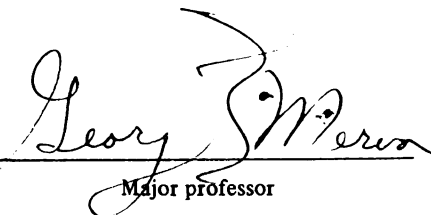
A WATER MANAGEMENT MODEL FOR PREDICTING THE
EFFECTS OF A DRAINAGE AND SUBIRRIGATION SYSTEM
ON CORN YIELDS

presented by

Philip Nathan Brink

has been accepted towards fulfillment
of the requirements for

M.S. degree in Agr. Engr.


Major professor

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A WATER MANAGEMENT MODEL FOR PREDICTING THE EFFECTS OF A
DRAINAGE AND SUBIRRIGATION SYSTEM ON CORN YIELDS

By

Philip Nathan Brink

A THESIS

Submitted to
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MASTER OF SCIENCE

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ABSTRACT

A WATER MANAGEMENT MODEL FOR PREDICTING THE EFFECTS OF A DRAINAGE AND SUBIRRIGATION SYSTEM ON CORN YIELDS

by

Philip Nathan Brink

An improved water management and crop growth model was sought by combining two existing computer models, a water management model, DRAINMOD, by Dr. Wayne Skaggs and a crop growth model, CERES, by Dr. Joe Ritchie. By having DRAINMOD evaluate the water balance and CERES calculate the crop growth, a model was obtained that capitalizes on the strengths of the component models.

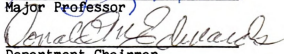
A procedure was developed to convert the soil water regime status calculated by DRAINMOD into soil water content by layers as required by CERES each day. CERES calculated crop growth and the crop's water use was transferred back to DRAINMOD for the next day's water balance.

Operation and behavior of the synthesized model was investigated by performing a 16 year simulation for a site in Michigan. Results show that the root zone depth responds realistically to soil water conditions existing in drainage. The root growth potential function was modified to account for wet stress. Crop stress factors that affect root water uptake, photosynthesis, and cell expansion require further modification as their relationships to wet stress are more clearly defined.

Approved:


Major Professor

Approved:


Department Chairman

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Thesis for the Degree of M.S.

MICHIGAN STATE UNIVERSITY

PHILIP NATHAN BRINK

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The Institute of Water Resource and the North Central Computer Institute (NCCI) deserve mention for the financial support they gave. The biannual meeting sponsored by NCCI for the DRAINMOD documentation was especially helpful in keeping me abreast of new DRAINMOD developments, and it was really good to meet and have the support of all those who came to the meetings.

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1. Introduction

In humid regions where organic soils require drainage during wet springs and irrigation during dry summers, interest in subirrigation has greatly increased in the last few years. Because a subirrigation system can meet both drainage and irrigation needs, it has an obvious economic edge over separate irrigation and drainage systems, requiring an investment in only one system (Worm, et al. 1982). In addition, because the water pressure needed for subirrigation is lower than those used for sprinkler irrigation systems, power requirements are less, resulting in operational energy savings. Though not appropriate everywhere, places that require drainage due to excess water often have an impermeable layer on which a water table can be perched for crop use. Follett et al. (1974) found maximum yields in plots where the water table was 0.60 to 0.90 m below the surface. Surface irrigation of the crops over the shallow water table resulted in no increase in yield.

Using drainage systems for applying water to the root zone is not a new idea, it has been in limited use for some time. Doty (1979) in his review of such systems said that French scientists, Bordas and Mathieu in 1931 reported higher yields from a controlled water table than from other irrigation systems, and Morris (1949), after considering some practical aspects of controlled subsurface drainage,

concluded that in the future all artificial drainage may be controlled drainage.

General adoption of this technology, however, has been quite slow despite its touted advantages. One reason for slow acceptance may be the complexity of designing and managing such a system. Better information about the response of a system and crops to various external factors and practices is needed. While a shallow water table can provide water in the root zone for the crop use, a heavy rain may inundate the field long enough to harm plants and reduce yield. Successful management requires a high level of skill and knowledge of the complex interactions of plant, soil, water, and climatic conditions.

Accounting for these variations and uncertainties has made it difficult to design an efficient water management system and manage it properly. Until 1940 the depth and spacing of drains in the United States were determined through empirical field observations (Ward 1972). Advances in flow theory lead to mathematical descriptions of water movement, giving rise to numerous methods to determine water table drawdown. The dynamic nature of the interaction between the moisture regime and plant system, however, involves more complicated mathematical relationships.

During the last 20 years rapid progress has been made in the simulation of agricultural processes. Models are now available to simulate discrete processes such as weather, water balance and movement in the soil, nutrient cycling and movement, tillage, erosion, soil temperature, and crop growth and development. Many of these models are quite restricted in purpose, others integrate several

processes such as weather, hydrology, tillage and crop growth and predict their interacting effects on crop growth and yield. The objective of this study was to use and modify existing computer models* to obtain an improved prediction of corn yields as a function of subirrigation water management system designs and practices.

*NOTE: ASAE standard of units have been used as much as possible, however, description of how certain models operated entailed the use of nonstandard units at times, most notably the length dimension of the centimeter (cm).

2. Literature Review

a. Drainage and subirrigation modeling

Modeling a soil water regime that includes a drainage system requires characterization of ground water flow. Many drainage models are available, ranging in complexity from the simple, steady state Hooghoudt model (1940), which deals only with saturated flow, to the complex numerical solution of the two-dimensional Richard equation for the analysis of combined saturated-unsaturated flow. Skaggs and Tang (1975) compared solutions of the Richard equation for drainage and subirrigation conditions to approximate drain spacing methods. While the numerical methods are more precise, he found the approximate methods to be as acceptable when the difficulty of determining field effective values of the soil properties was considered. Input and computational requirements of numerical methods also tend to prohibit their use for a field scale model.

Most models use approximate methods that are based on the Dupuit-Forchheimer (D-F) assumptions and ignore the water in the unsaturated zone (e.g. Kirkham, 1958, van Schilfgaarde 1963, Bouwer and van Schilfgaarde, 1963, Moody, 1966). The D-F assumptions state that, under the influence of gravity alone, all flow to the drain is horizontal and the velocity at each point is proportional to the slope

of the water table but independent of the depth (Forchheimer, 1930, as used by Hillel, 1982). In addition, these models assume a homogeneous soil with a constant hydraulic conductivity and a constant drainage flux (a steady-state condition).

Using these assumptions, Hooghoudt (1937, as used by Hillel, 1982) obtained an equation for the elliptical shape of the water table between the drains (Figure 1)

$$L^2 = (4Km/q)(2d + m) \quad (1)$$

where L is the distance between the drains, K is the saturated hydraulic conductivity, m is the midpoint water table height above the drain, q is the flux in $\text{cm}^3/\text{cm}^2/\text{hr}$ and d is the height of the drains above the impermeable layer. This equation has been widely used to determine the spacing and depth of drains necessary to maintain the water table at a certain level for a given flux, q.

Bouwer and van Schilfgaarde (1963) modified Hooghoudt's steady state equation by using a factor C to express the proportionality between the rate of fall of the water table between the drains and the flow rate into the tile line. This resulted in an equation which, when applied in finite time steps, could described transient-flow drainage. Van Schilfgaarde (1965), using their analysis, was able to developed a model to predict the water table depth as a function of precipitation. He accounted for evapotranspiration and soil moisture storage but ignored surface runoff.

Skaggs (1980) used their equation in a computer model, DRAINMOD, to estimate drainage flux in the following form:

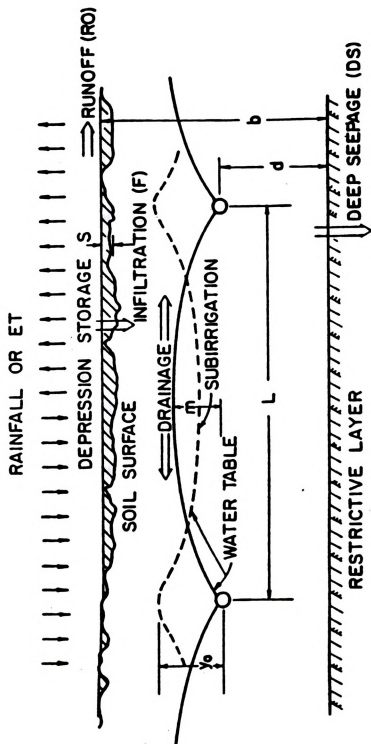


Figure 1. Schematic of water management system

$$q = \frac{8K_e d_e + 4K_e m^2}{C L^2} \quad (2)$$

where q , m and L are as defined before, K_e is the equivalent saturated lateral hydraulic conductivity and d_e is the equivalent depth from the drains to the impermeable layer. The constant C , though it can be varied depending on the water table elevation, is assumed to be unity. The equivalent depth, d_e corrects error in the drainage fluxes caused by applying the D-F assumptions at the drains where convergence occurs. The equivalent saturated hydraulic conductivity corrects the assumption of a homogeneous soil. Prior to every flux calculation, DRAINMOD calculates the equivalent conductivity by using a weighted average of the values of K for the layers that are saturated. This enables simulation of layered soils where each layer has a different K value. A modified form of Equation 2 is also used to predict subirrigation flux.

DRAINMOD accounts not only for drainage and subirrigation flux, but all the components of the water balance equation. It is a computer simulation model that characterizes the response of the soil water regime to various combinations of surface and subsurface water management. It predicts the response of the water table and the soil water above the water table to rainfall, evapotranspiration, given degrees of surface and subsurface drainage, and the use of watertable control or subirrigation practices. A water management system is simulated over a long period of time using climatological data to evaluate its performance allowing an optimum water management system

to be designed on a probabilistic basis as van Schilfgaarde (1965) proposed.

DRAINMOD has been widely accepted, used by the SCS and others for the design of subirrigation systems. It is reviewed in some detail here.

The model is based on the water balance for a thin vertical slice of a soil profile from the surface to the impermeable layer midway between the drain tiles as

$$\Delta V_a = D + ET + DS - F \quad (3)$$

where ΔV_a is the change in air volume in the soil profile, D is the drainage, ET is the evapotranspiration, DS is the deep seepage and F is the infiltration, all for a time increment Δt .

The amount of runoff and surface storage is computed from a water balance at the soil surface for each time increment which may be written as

$$P = F + \Delta S + RO \quad (4)$$

where P is the precipitation, F is the infiltration, ΔS is the change in volume of water stored on the surface, and RO is the runoff during time Δt .

The model includes methods to independently evaluate infiltration, subsurface drainage, surface drainage, potential and actual evapotranspiration, subirrigation and the soil water distribution in terms of the water table elevation, soil water

content, soil properties, site and drainage system parameters, crop type and stage of growth, and atmospheric conditions. In order to simplify the required inputs and to allow use of available data, approximate methods are used for each component.

Precipitation is one of the major inputs to DRAINMOD. The accuracy of the model's prediction for infiltration, runoff and surface storage is dependent on the complete description of rainfall intensity, duration and time distribution. The shorter the time increment for the rainfall input data, the better the estimates of these components will be. A basic time increment of one hour is used in the model because of the availability of hourly rainfall data for many locations in the U.S.

The infiltration component is important in predicting the rate of water flow into the soil, and whether storage of water at the surface and subsequently runoff will occur. The model uses the Green and Ampt's (1911) approximate equation to characterize infiltration as

$$f = A/F + B \quad (5)$$

where f is the infiltration rate, F is the accumulative infiltration and A and B are parameters that depend on soil properties, initial water content, and surface conditions such as cover or crusting.

Surface drainage is characterized by the average depth of depression storage that must be satisfied before runoff can begin. In most cases it is assumed that depression storage is evenly distributed over the field. A value for the maximum storage depth is required as input to the model. When the surface storage depth as determined by

Equation 4 exceeds this value, the additional excess is allotted to surface runoff. The model assumes that water available for runoff moves immediately from the surface to the outlet.

The evapotranspiration component of the model accounts for water loss by evaporation from the soil surface or by transpiration from the plants. Daily potential evapotranspiration (PET) is calculated from recorded daily maximum and minimum temperature values using the empirical methods developed by Thornthwaite (1948) and Thornthwaite and Mather (1957). Adjustments for day length and number of days in the month are made in the model based on latitude and date. After PET is calculated, checks are made to determine if ET is limited by the soil water conditions. When the ET demand can not be satisfied directly from the water table by an upward flux of water to the root zone, water is extracted from the root zone down to a lower limit water content, usually the wilting point. This creates a dry zone at the surface with a maximum depth equal to the rooting depth. If enough water is available, ET is set equal to PET, otherwise ET is set equal to the limiting amount supplied from the soil system (see Figure 2).

The relationship between maximum rate of upward flux and water table depth need to be estimated for a soil and entered into the model in tabular form. The relationship is approximate because it is defined for steady state conditions while the actual upward water movement process is transient. Generally, upward flux relationships must be calculated from basic soil properties, using numerical procedures.

Knowledge of the soil water distribution in the soil profile is

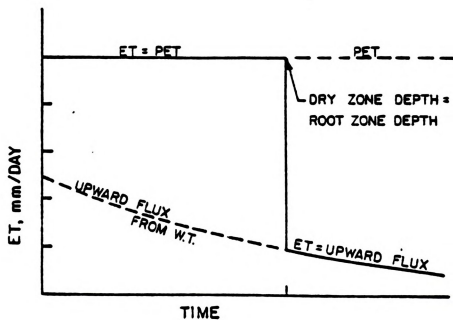


Figure 2. Schematic of the change in ET with time for a constant PET as treated in the model. When the dry zone depth reaches the bottom of the root zone ET is assumed to decline to the rate of upward flux.

Source: Skaggs (1980)

needed to evaluate individual components such as drainage and ET which depend on the position of the water table and the soil water distribution in the unsaturated zone. The water table depth is a key variable that is determined at the end of every water balance calculation. The soil water distribution above the water table is assumed to be in equilibrium with the water table up to the surface or to the bottom of the dry zone if one exists (Figure 3), and independent of the means by which water was removed from the profile, whether by ET or drainage (Figure 4). With this assumption, the air volume is related to the water table depth through the soil water characteristic curve, and, assuming hysteresis can be neglected, the water table depth can then be determined from the volume of water that enters or is removed from the profile over an arbitrary period of time.

An effective rooting depth is used in the model to define the zone from which water can be removed as necessary to supply ET demands. The rooting depth also gives the distance from the bottom of the root zone to the water table which is used to determine the upflux available from the water table. Since the simulation process is usually continuous for several years, an effective depth is defined for all periods. When the soil is fallow, the effective depth is defined as the depth of the thin layer that will dry out at the surface. A table of effective rooting depth versus the date is required as input. Generally, the depth above which 60% of the total root length exists is used as shown for corn in Figure 5. This method of treating the rooting depth is an approximation at best as the depth and distribution of plant roots are affected by many factors including

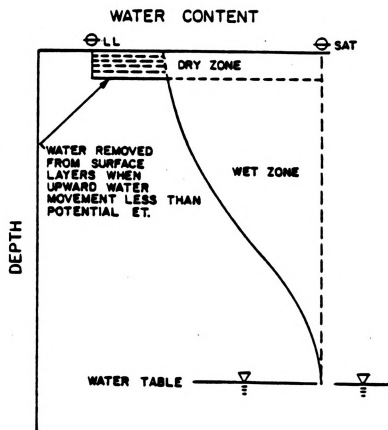


Figure 3. Soil water distribution and dry zone when a dry zone is created near the surface.

Source: Skaggs (1980)

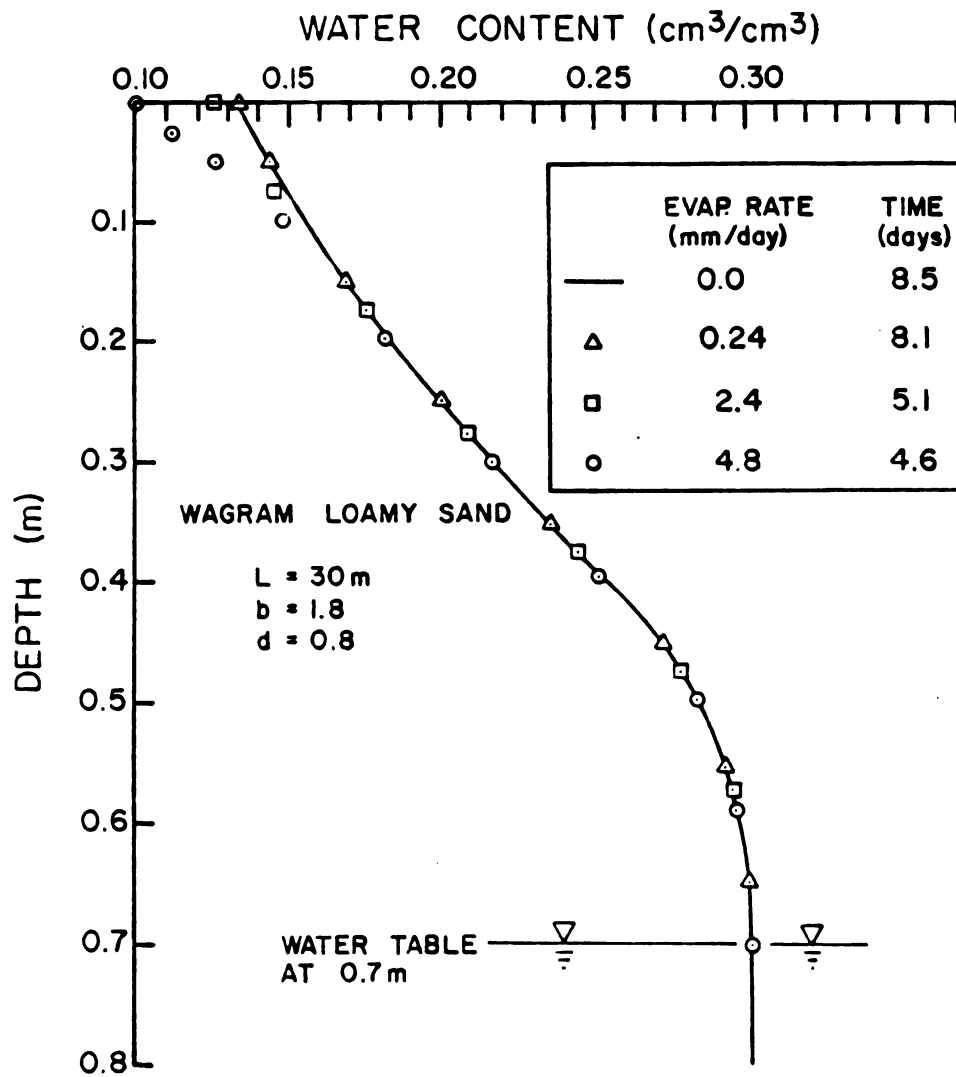


Figure 4. Soil water distribution for a water table depth of .7m for various drainage and evaporation rates.

Source: Skaggs (1980)

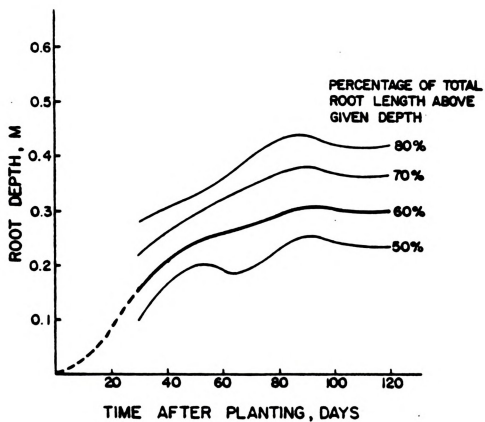


Figure 5. Relationships for corn root distribution with time.

Source: Mengel and Barber (1974).

hardpans and fertilizer distribution, but especially soil water. While the variation of the root zone depth with time may be approximated for some crops from experimental data reported in the literature, the model presently ignores the effect of the depth and fluctuation of the water table on the effective rooting zone.

The model can be used to analyze a broad range of drainage, subirrigation, and waste water application problems. DRAINMOD was developed and tested, however, for use in humid regions, and its application is presently limited to these regions. The methods were developed for field-sized units with parallel subsurface drains. Lateral seepage due to a sloping landscape was not considered, which limits application of the model to fields with slopes of less than about 5 percent. Deep seepage is site dependent and is not currently considered. Freezing conditions were not considered in the model, confining its application to periods when the soil is not frozen. The model simulation includes the whole year, so when the model is used where freezing conditions exist for part of the year, the results for that part of the year are generally ignored.

b. Crop response modeling

Quantifying the effect of drainage or subirrigation on crop yield is of vital importance in optimizing a system design. Steady state and non steady state equations for drainage design are numerous, yet little data on crop drainage requirements exists (Hiler et al. 1971). The water table must be maintained at a depth shallow enough for the crop roots to reach the water, yet deep enough to avoid root

zone aeration problems (Benz, 1983). Hedstrom et al. (1971) states there have been four approaches to the determination of drainage requirements for design purposes:

1. Drainage coefficient, which is the depth of water to be removed in a 24-hour period.
2. Optimum water table depth, which is highly dependent on the type of crop and the type soil as well as other factors.
3. Falling water table, drain depth and spacing which would cause the water table to fall a specified distance within a certain length of time.
4. Fluctuating water table, similar to the falling water table model; used to more effectively represent drainage with rainfall or subirrigation.

These four approaches deal either with the removal of a specified volume of water or with the location of the water table. Although the depth of water table has no direct influence on crop growth, it provides an indication of the prevailing soil water conditions, water supply, aeration and thermal properties of the soil (Wesseling, 1974). Shih (1983), for instance, found sweet corn had its best yields when the water table was at 0.60-0.90 m depth. Ward (1972) states that one method of incorporating the plant requirements into the design is to relate plant response to the water table depth, but then adds "The results of many studies generally agree upon the ideal water table height, but very little has been established for determining the permitted deviation from the ideal."

- i. Crop response to excessive soil water conditions

Sieben in 1964 (Wesseling, 1974) introduced a stress factor to

evaluate the influence of fluctuating high water tables during the winter on cereal crops. He figured that yield reductions caused by excessive soil water conditions could be related to the integral of elevation and time that the water table remained in the root zone taken to a depth of 30 cm. It is defined as

$$SEW_{30} = \sum_{i=1}^n (30 - y_i) \text{ cm-days} \quad (6)$$

where y_i is the water table depth on day i , with $i = 1$ being the first day and n being the number of days in the growing season. SEW_{30} is the sum of excess water above a 30 cm datum below the ground surface. For example, if the water table depth is at 28 cm depth for 1 day, then SEW would have a value of 2 cm-day ($30 - 28\text{cm} \times 1 \text{ day}$). Negative terms inside the summation are neglected. Using this technique he found a significant correlation between SEW_{30} values and yields (Nibler and Brooks, 1975).

The SEW_{30} concept was included in the formulation of DRAINMOD as an objective criterion on which to quantify excessive soil water conditions during the growing season. As the water table depth may vary significantly during the day, SEW_{30} is calculated in DRAINMOD on an hourly interval to better define the time that the water table remains in the root zone. Although the SEW_{30} concept has some weaknesses, it still provides a convenient method of approximating the quality of drainage. One problem is knowing what value of SEW_{30} is a threshold value of an adequate drainage system. Generally it is assumed that drainage is adequate to protect crops from excess water

if the SEW_{30} value totals less than 100 cm-days. Obviously, with crops which are more susceptible to poor drainage, it may be necessary to adjust the critical SEW_{30} value to fit the crop to be grown.

Hiler (1969) refined this idea by incorporating the fact that crops are more susceptible to damage at certain stages of development. He defined a stress day index (SDI) that is determined from a stress day factor and a crop susceptibility factor. The stress day (SD) factor is a measure of the degree of stress caused by excessive soil water conditions. The crop susceptibility (CS) factor is an experimentally determined parameter which reflects variations in susceptibility to stress according to the stage of growth. Its equation form is

$$SDI = \sum_{i=1}^N (SD_i \times CS_i) \quad (7)$$

where N represents the number of growing periods considered and SD_i and CS_i are the stress day and crop susceptibility factors respectively for period i.

Ravelo (1978) incorporated Hiler's method in DRAINMOD, using the SEW_{30} as the stress day factor, SD. He determined crop susceptibility factors for four growth stages of grain sorghum from experimental results presented in the literature. He then related the effects of excessive soil water to grain sorghum yield by assuming a linear relationship between SDI and the reduction in yield. Hardjoamidjojo and Skaggs (1982) applied the same approach to characterize the effects of excessive soil water on corn yields from Ohio. Their

analysis of the results showed a strong relationship between corn yield and SDI.

ii. Crop response to deficient soil water conditions

The stress day index method was also used to quantify the effects of deficient soil water during different crop growth stages on yields (Hiler et al., 1974; Shaw, 1978; Sudar et al., 1979). For drought conditions the stress day factor, SDd, was defined by Sudar (1979) as

$$SDd = 1 - AT/PT \quad (8)$$

where AT and PT are the actual and potential transpiration, respectively. Multiplying this by a yield susceptibility factor gives the stress day index for drought stress, SDID, as

$$SDID = \sum_{j=1}^N SDd_j \times CSd_j \quad (9)$$

where CSd_j is the crop susceptibility factors for growth period j , and N is the number of periods in the growing season. A correlation he found between SDID (labeled water stress index) and observed yield of corn is shown in Figure 6. This method of calculating the SDID for deficient soil water stress was incorporated into DRAINMOD by estimating the AT/PT ratio as ET/PET where ET is actual evapotranspiration and PET is potential evapotranspiration (Ravelo, 1978; Skaggs et al., 1982). This estimate was made because DRAINMOD does not

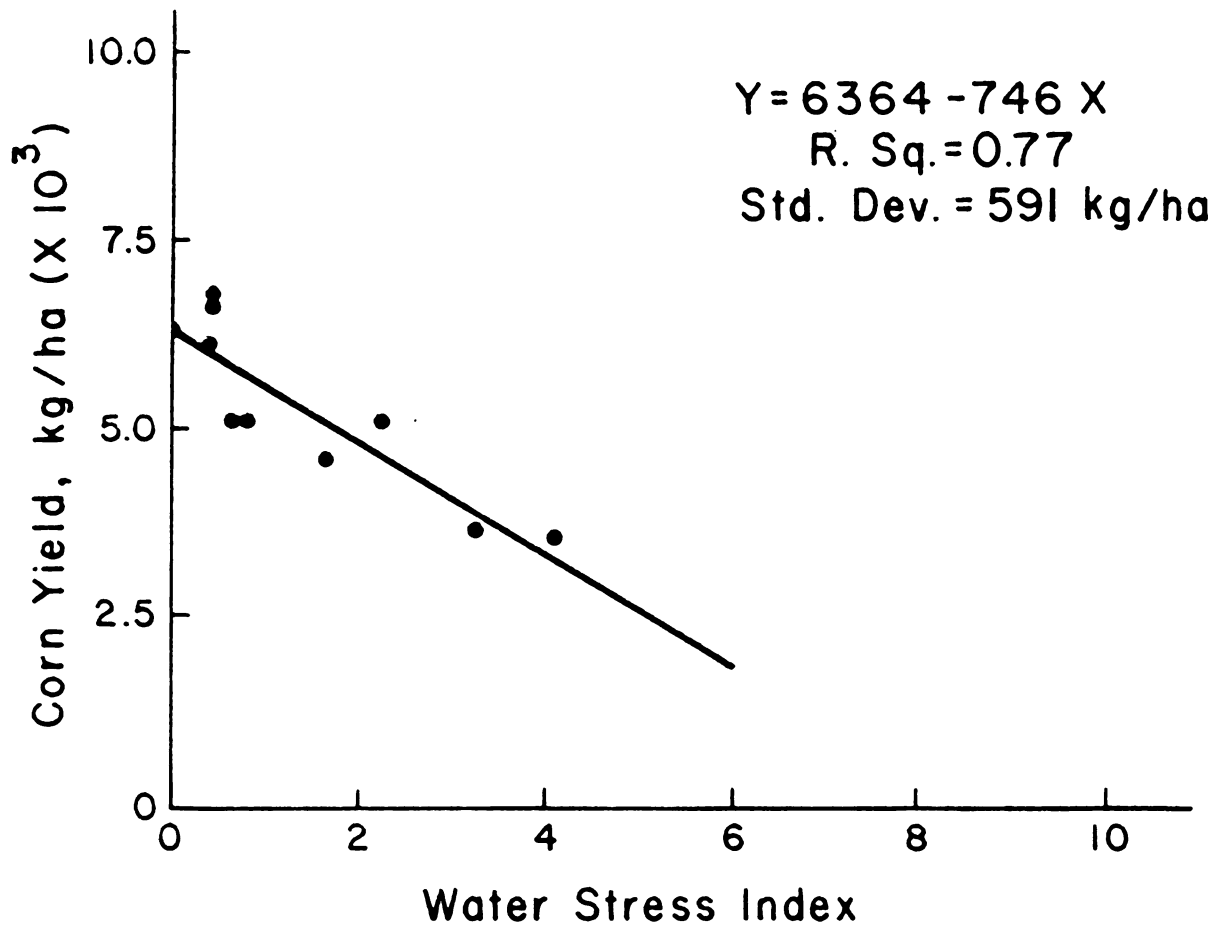


Figure 6. Correlation between stress day index for deficient water conditions (SDID, labeled Water Stress Index) and observed yields of corn for Grundy County, Missouri.

Source: Sudar (1974)

calculate transpiration and evaporation separately. Use of this method is an extension of the dry day count DRAINMOD performs, where a dry day is counted when ET is limited by soil water conditions.

iii. Crop response to delayed planting date

Crop yields are significantly reduced if the planting date is delayed beyond an optimum period. Another method of quantifying the influence of the water management design and practice in DRAINMOD on crop yields has been determining whether soil conditions cause a planting delay. Inputs to DRAINMOD to calculate this yield reduction include the date to begin seedbed preparation and planting, the number of days needed to complete this task, and the date beyond which yield reduction occurs if the crop is not yet planted. The model determines whether trafficable conditions exist for each day and keeps a running total of suitable working days during the planting period. When enough working days have occurred to complete planting, the model fixes the planting date and determines the length of planting date delay beyond the optimum.

The relative yield, YR_p , is estimated from the following equations:

if $PDELAY < DELAY1$,

$$YR_p = 100 - PDRF \times PDELAY \quad (10a)$$

if $PDELAY > DELAY1$,

$$YR_p = 100 - PDRF \times PDELAY - PDRF2 \times (PDELAY - DELAY1) \quad (10b)$$

where DELAY1 is a breakpoint past which the yields decrease at a faster rate, and PDRF and PDRF2 are the slopes before and after the breakpoint. The values of PDRF, PDRF2 and DELAY1 are inputs that need to be determined for the crop to be modeled. The last day planting can be completed without yields being reduced, JLAST, the required number of working days for seedbed preparation and planting, REQWRK, and the number of days in the growing season, IGROW, are also model inputs.

These equations are the general form of a relationship determined from the results of field tests conducted near Plymouth, N.C. which were presented in an Extension Corn Production Guide by Krenzer and Fike (1977). Similar results have been obtained for Ohio conditions (Nolte, 1976). Use of these data to estimate the effect of delay in planting on yield assumes that the observed effects are due to factors such as temperature and day length and not to deficient or excessive soil water conditions.

iv. Overall Crop Response Model

The yield version of DRAINMOD was programmed so that the time-varying root depth function and the computation of the stress-day indices are initiated after the required number of working days is satisfied and the planting date established. The stress-day factors are calculated for each day and stored. At the end of the year's simulation, the stress-day factors are multiplied by the appropriate crop susceptibility factors and the stress-day indices determined.

The relative yields as affected by excessive soil water conditions, deficient soil water conditions and delay in planting date are determined, and overall relative yields are calculated as a product of the three. A basic assumption in the use of these methods is that the three factors are independent; interactive effects are neglected. This approach was shown to be valid by Hardjoamidjojo and Skaggs (1982) for a Portsmouth sandy loam in Eastern N.C.

c. Crop Growth Modeling

Crop yields depend on soil, crop management, and climatological factors and involve complex relationships. The methods discussed above show attempts to correlate crop response to various water management practices and designs by determining a relationship between crop yields and soil water conditions. Determination of this relationship requires statistical analysis of field data such as is shown in Figure 6. While using these methods helps DRAINMOD to optimize a water management system design, DRAINMOD's strength lies in characterizing the soil water regime, not crop growth and development. In contrast, crop growth models focus more on the physiology of the plant and its relationships to the environment, incorporating factors such as CO_2 availability and photosynthetic rate to predict yields. Such models actually simulate the plant growth. Examples of this modeling genre are the work of Childs et al. (1977) and Duncan et al. (1971).

McMahon (1983) in an excellent review of a number of crop models identified two main approaches to modeling crops. The first is a

transpiration ratio approach that developed from the work of de Wit (1958). The second is essentially a photosynthetic approach of which the work of Ritchie (1984) is representative.

Although a water balance is not the main emphasis of a crop model, simulating actual field situations of crop growth requires knowledge of the soil water regime. Sometimes the water supply is considered non-limiting (e.g. Dayan et al, 1981). Generally the water balance is based on soil water content by layers, not on the water table depth (e.g. White et al, 1980, Saxton and Bluhm, 1982). Having a soil water content for each layer enables calculating water availability for root uptake in terms of the soil water content or pressure head (e.g. Feddes, 1976). Anderson et al. (1976), for instance, developed a model to simulate the water balance for deep, well-drained soils where the water table is considered deep enough to prevent having any influence. The soil is divided into layers to a depth of 9 feet. Any water infiltrating into the profile fills each layer to 80% of saturation before being added to the next layer down. Any water that flows below 9 feet is accumulated as deep seepage. Singh and Young (1984) also ignored the presence of a water table in their simulation of the soil water regime.

Ignoring the water table prevents the capability of modeling a water management system, which generally requires knowledge of the water table depth to solve for flow to the drains. Belmans et al. (1983) states that very few soil water, root uptake models treat the unsaturated-saturated system as an integrated zone. He developed a transient one-dimensional finite-difference soil water, root uptake model, SWARTE, that applies different types of conditions at the

bottom of the system. One bottom boundary condition includes the flux from the saturated zone, thus offering possibility of linking it to a watertable model. The flux can be entered or calculated from a flux-groundwater level relationship or combination of fluxes that include drainage or subirrigation and deep seepage. The pressure head is taken to be in equilibrium with the groundwater level. Water uptake by the roots is prescribed as a function of the soil water pressure head. Roots are considered concentrated to an effective depth which is required as input.

One of the more recently developed crop growth model is CERES (Ritchie and Otter, 1984; Jones, 1985). This model was developed by a team of interdisciplinary scientists coordinated by Dr. J. T. Ritchie at the Grassland, Soil and Water Research laboratory of the USDA, ARS. CERES is a comprehensive model of maize growth and development which considers the independent and interacting effects of genotype, weather, hydrology and nitrogen nutrition. CERES is a daily incrementing model and several empiricisms were developed to integrate minute by minute variations in factors like solar radiation, air temperature and rainfall into daily functions.

To accurately simulate maize growth, development and yield, CERES considers the following processes:

- phenological development, especially as it is affected by genetics and weather;
- extension growth of leaves, stems and roots;
- biomass accumulation and partitioning, especially as phenological development affects the development and growth of vegetative and reproductive organs;
- soil water balance and water use by the crop;

--soil nitrogen transformation, uptake by the crop and partitioning among the plant parts.

The last item mention is an option available in the nitrogen version of CERES. The version reviewed here is the non-nitrogen version. The model requires daily weather data of rain, minimum and maximum air temperatures, solar radiation and soil information available from standard soil classification data. The model calculates the soil water balance in order to evaluate possible growth stress caused by soil and plant water deficits using the equation

$$S = P + I - EP - ES - R - D \quad (11)$$

where S is the quantity of soil water resulting from the addition of precipitation (P) and irrigation (I), and the subtraction of evaporation from plants (EP) and soils (ES), runoff (R) and drainage from the profile (D). The soil water is distributed as water content in up to 10 layers of variable depth. The water content in any soil layer can change due to soil evaporation, root absorption, or flow to an adjacent layer. The field saturated water content, the field drained upper limit water content and the lower limit of plant water availability are the entered limits among which the water content can vary.

CERES uses the curve number procedure of the USDA-Soil Conservation Service (SCS, 1972) to calculate runoff from daily precipitation input. The technique was modified to account for the use of layered soils with the wetness of the soil in the layers near the surface replacing the antecedent rainfall condition, shown in

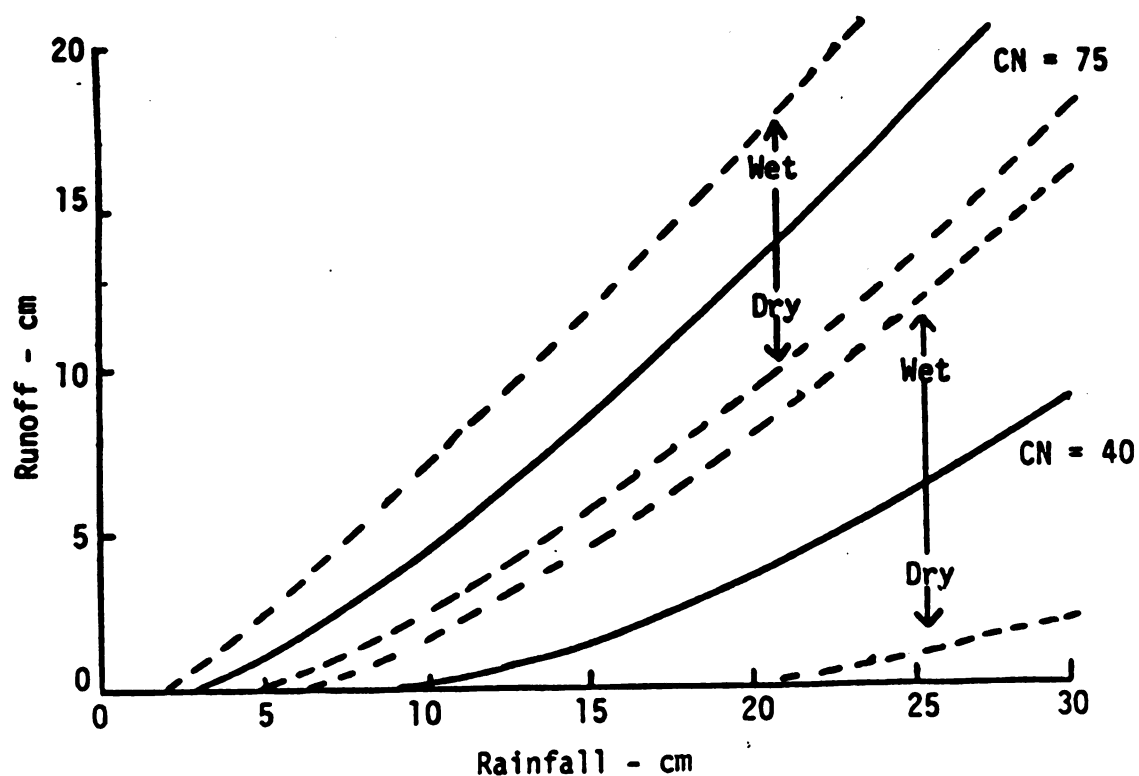


Figure 7. Soil Conservation Service curve number relationship used to calculate runoff from rainfall. The values shown for CN refer to the curve number associated with the solid line and the dashed lines represent the alterations made for a particular curve number when the soil is wet or dry at the time of rainfall.

Source: Ritchie (1984)

Figure 7. Any precipitation that is not estimated as runoff is considered to infiltrate into the soil. All irrigation water is automatically assumed to infiltrate.

CERES calculates water movement in the soil with an empirical relation. Drainage occurs when the water content at any time, θ_t , is between the field saturated water content, θ_o , and a drained upper limit water content, θ_u . The drainage rate (D) from a given layer is:

$$D = -K_d(\theta_t - \theta_u) z \quad (12)$$

where K_d is the conductance parameter and z is the thickness of the soil layer. The value of K_d can vary between 0 for no drainage and 1 for instantaneous drainage and represents the fraction of water between θ_u and θ_t that drains in one day. The most limiting layer to water flow sets the value of K_d used for the whole profile since that layer dominates the drainage rate in the soil profile. The soil water content for all the layers is updated daily to account for any infiltration, water flow, or root uptake.

CERES uses an equilibrium evaporation concept as modified by Priestly and Taylor (1972) to calculate potential evapotranspiration (ET). Then using procedures from an ET model (Ritchie, 1972), soil evaporation (ES) is separated from plant transpiration (EP) primarily using information on the leaf area index (LAI) and wetness of the soil surface.

Root length density and distribution in the soil are estimated in CERES and are required for calculating root water absorption. A flow rate of $0.03 \text{ cm}^3/\text{cm}$ root per day was chosen as an approximate maximum

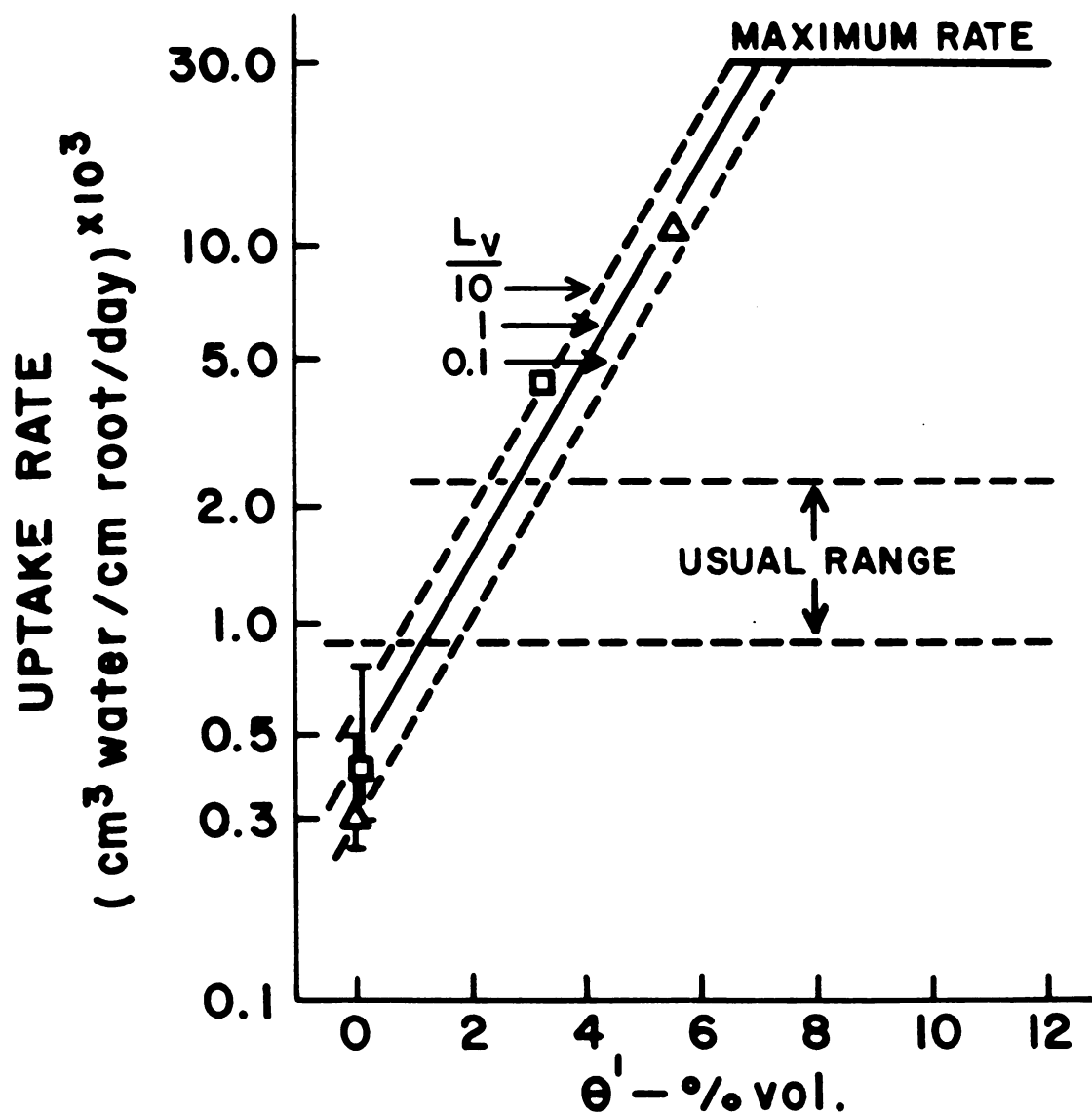


Figure 8. Maximum root water absorption as related to θ' (the water content above the lower limit) and the root length density. Also shown is the assumed maximum possible rate and the usual range of absorption when all the soil profile is at an optimum water content.

Source: Ritchie (1984)

plant limited flow rate (Figure 8). The calculated maximum possible root absorption rate is not allowed to exceed the plant limited flow rate or the maximum calculated transpiration rate. The absorption model was tested for a maize crop at Temple, Texas, in a study where root length density, transpiration and soil water were measured. The results show that the absorption model provides a reasonable evaluation of the water content distribution during a season.

CERES calculates the water balance components using empirical relationships that have been made as general as possible to avoid using regionally fitted parameters. The model was tested with about 300 data sets from several countries to demonstrate its generality for wheat (Ritchie and Otter, 1984). For a few cases where the soil water was measured throughout the season, the model values of the soil water were in reasonable agreement with measured values. When the agreement was poor, lack of root depth and root density data prevented determination of the cause.

Because the model was developed for regions where the influence of the water table could be ignored, the CERES water balance model does not account for the presence of a shallow water table or a drainage and subirrigation system. Thus, the model is not well suited for use in areas with these conditions.

3. Procedure

The objective of this study was to use and modify existing computer models to improve prediction of corn yields as a function of water management system design and practice. The water management model, DRAINMOD, by Skaggs (1980) was selected for the simulation of a water management system; the non-nitrogen version of the crop growth model, CERES, by Ritchie (Jones, 1984) was selected for the prediction of crop growth and yield. Both models have been tested and proven for the areas of application that they were developed, both in location and in type of modeling--DRAINMOD as a water management model for artificially drained soils in humid regions, CERES as a crop growth model for non artificially drained soils in sub-humid and humid regions. Though both DRAINMOD and CERES have the ability to conduct a water balance and calculate crop yields, it was decided that a merger of the two would capitalize on the strengths of each model, producing a better model with an extended range of application.

Both models were modified to transfer information to and from each other, making the simulation integrated. Information on the soil water regime calculated by DRAINMOD was transferred to CERES, while information on crop growth calculated by CERES was transferred to DRAINMOD. When any processes such as infiltration or evaporation were present in both models, the method considered to be superior was

utilized.

Since DRAINMOD keeps track of the water balance via a water table level, and CERES requires knowledge of the water content of the soil layers, a subroutine, HYDRO, was added to convert the soil water status into the soil water content by layers required by CERES. A basic and necessary assumption used in HYDRO is that the soil water above the watertable is in hydrostatic equilibrium with the watertable. When this is true, the pressure head and water content distribution in the wet zone can be determined from the soil water characteristic curve. For example, the soil water content 0.1 m above the water table corresponds to a -0.1 m pressure head.

This assumption is used by DRAINMOD for the rooting zone as mentioned earlier (see Figure 4), and it is generally found to hold for conditions in which the D-F assumptions are valid (Skaggs, 1980). However, HYDRO is needed because DRAINMOD does not calculate the water content of the soil above the water table directly.

HYDRO determines the water content for each 0.01 m increment above the water table. It then sums the water contents of the 0.01 m increments for each layer defined by CERES and divides by the thickness of the layer to obtain the layer's average weighted soil water content. With this information, CERES can determine root growth and evapotranspiration. HYDRO performs this function for each day based on the water table depth calculated for that day. If a dry zone exists (as defined by DRAINMOD, see Figure 3), it sets the water content of the dry zone to be equal to that at the wilting point plus the upflux from the water table.

A soil water characteristic curve for the rooting zone relating

pressure head and soil water content is required input to DRAINMOD. This curve is used to calculate the depth of a dry zone created when moisture is removed from the rooting zone. Presently, the same curve is used in HYDRO to calculate the water content above the water table for the whole profile.

While the hydrostatic distribution accounts for the soil water conditions as mentioned, the upflux from the water table to the roots also needs to be described. In DRAINMOD, the upflux from the water table that is available for plant use is calculated as a function of the distance between the bottom of the root zone and the water table. While the effective depth of the rooting zone as a function of time is an input to DRAINMOD, in CERES, the root growth is simulated over the season and is accounted for by root length and density, not just an effective rooting depth. To make use of the upflux information as DRAINMOD calculates it, it was necessary to transfer to DRAINMOD an effective depth of the roots from CERES daily. The root length density is summed over the whole profile to obtain a total, then the depth which contains 90% of the root's total volume is found. This depth is transferred to DRAINMOD for calculating the upflux. This upflux is then added to the soil water content of the dry zone, if one exists, in HYDRO. In this way, water available from the water table for crop use is transferred to CERES via a soil water content increase. By accounting for both a dry zone and upflux from the water table, HYDRO describes the dynamics of the water movement and the soil water regime more realistically than just using a hydrostatic distribution.

CERES accounts for dry stress, but not wet stress, so its root

growth routine had to be modified for use in the combined model. CERES calculates a soil water deficit factor, SWDF, each day to determine if the root growth should be reduced due to deficit soil water conditions. SWDF is a function of the amount of soil water between the LL and the DUL, that is, the extractable soil water, ESW. For each layer, SWDF is 1.0 unless the volumetric soil water, SW, falls below 0.25 of the ESW. In that case, SWDF varies linearly from 0 at LL to 1 at $ESW = 0.25$. The product of SWDF and new root growth calculated for the day gives the amount the roots grew that day. When the water content is greater than the DUL, the SWDF is undefined in CERES, that is, it is left to be unity; in the synthesized model, it should reflect stress due to excess water. Figure 9a shows the root growth potential function, SWDF, before being modified to account for wet stress.

Though the SWDF function needs to be defined above the DUL, its definition eludes easy delineation. Feddes (1976) states "a fixed 'anaerobiosis point' at which deficient aeration conditions exist and root growth is seriously hampered, is hard to define." He determined a suitable oxygen diffusion rate from literature for a sandy loam to be at a soil water pressure head of -0.5 m. He cautions, however, that relationships between ODR and soil water pressure heads vary for different soils.

A root upper limit, RUL, of soil water content was defined to be the limit above which wet stress would limit root growth and cause senescence. Above this limit, the root growth potential, SWDF, is assumed to be linear between 1 at the RUL and 0 at the SAT. Presently, the RUL is arbitrarily taken to be the soil water content

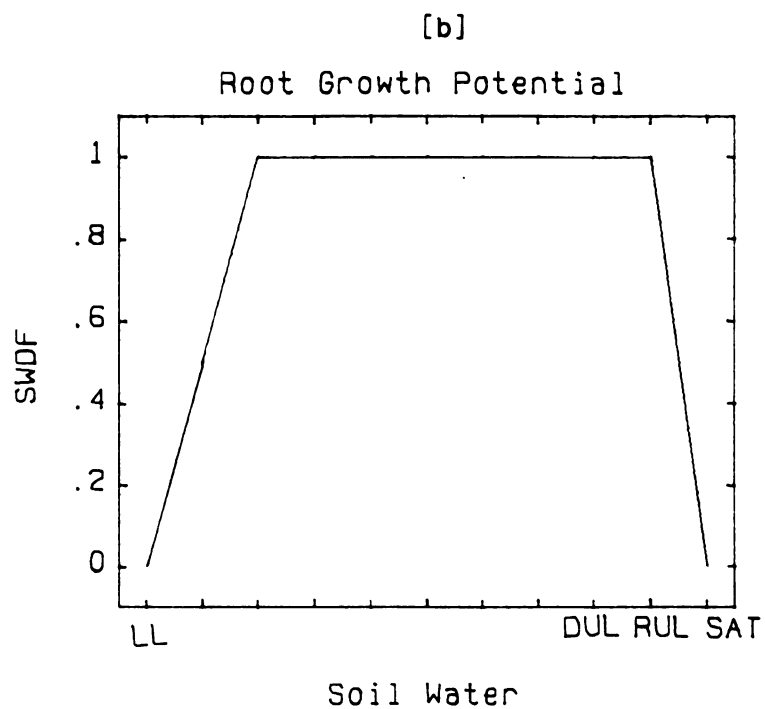
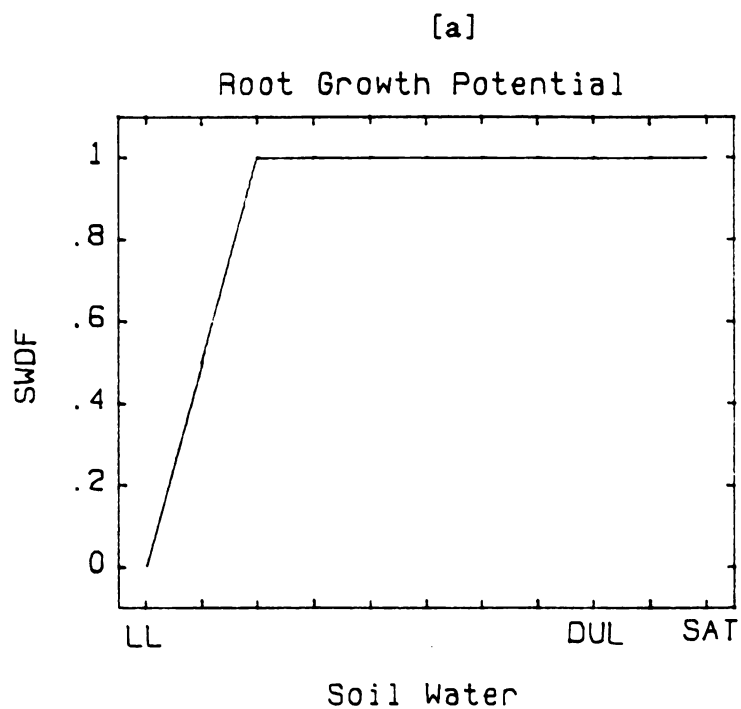


Figure 9. Root growth potential before [a] and after [b] being modified to account for wet stress.

midway between the DUL and SAT.

$$RUL = DUL + .5(SAT - DUL) \quad (13)$$

This linear relationship, shown in Figure 9b, appears to be adequate at present, but is subject to change as more becomes known about the limiting conditions for root growth.

The SWDF factor was also made to cause root senescence by reducing the root length volume, RLV, of a layer if the soil water content is above RUL for more than two days in succession.

$$RLV = RLV \times SWDF \quad (14)$$

This equation is used for each succeeding day that the water content is above RUL. The root growth function has now been modified so that when the soil water content is above the RUL for a given layer, it reduces root growth, prevents roots growing deeper, and finally causes complete senescence.

CERES calculates two other zero to unity soil water deficit factors. The less sensitive (SWDF1) is used to affect photosynthesis. The more sensitive factor (SWDF2) affects plant cell expansion. These factors account for deficient water stress during the various growth stages of corn. Like the root stress factor was before being modified, they do not account for excessive soil water conditions. These factors, or ones similarly defined, are needed to affect photosynthesis and plant cell expansion for excessive soil water

conditions. In the present stage of development of the merger, these factors have not been modified.

The CERES model was used to determine evaporation and transpiration, as its methods were considered superior to the Thornthwaite method used by DRAINMOD, both in better estimates on a daily basis and in determining evaporation separate from transpiration. An accurate estimate of these values is important in simulating plant growth.

The calculation of actual soil evaporation required a supplemental method since CERES does not account for upflux from a water table. CERES's prediction is primarily a function of the time since the last infiltration event; the soil continually dries until the next rainfall or irrigation. But in reality, the surface soil layer, as well as those below, may stay "wetter" than predicted because of the water provided by a water table. An empirical equation based on the relationship shown in Figure 10 (Ritchie and Burnett, 1971) was added to calculate evaporation due to the water content in the surface 0.03 m layer. If the evaporation predicted using this equation is greater than that predicted by CERES, it is used. This equation was added to the model and is valid for a Houston Black clay. Adjustments may be necessary for different soil types.

The infiltration calculations used in the synthesized model are those of DRAINMOD, based on the Green and Ampt methods, instead of the SCS curve numbers method of CERES. When an infiltration event occurs in DRAINMOD, the amount of infiltrated water is transferred to CERES for its calculation of the soil evaporation.

Figure 11 shows a generalized flow chart of how the models were

linked together. After CERES is initialized, a subroutine, CDMOD, checks to see if it is the first day of the month. If so, DRAINMOD's main program reads the weather data for the month, otherwise, DRAINMOD's main subroutine, FORSUB, conducts the water balance for one day. HYDRO then determines the water content of the soil layers for use in CERES using the the soil water regime information calculated by DRAINMOD. Next, CERES calculates evaporation, root growth, and plant growth. Both the actual ET and the root depth calculated are used in DRAINMOD the next day when the cycle is repeated. The models exchange information on a daily basis. In this way, actual water use and plant growth information are kept in balance between the two models.

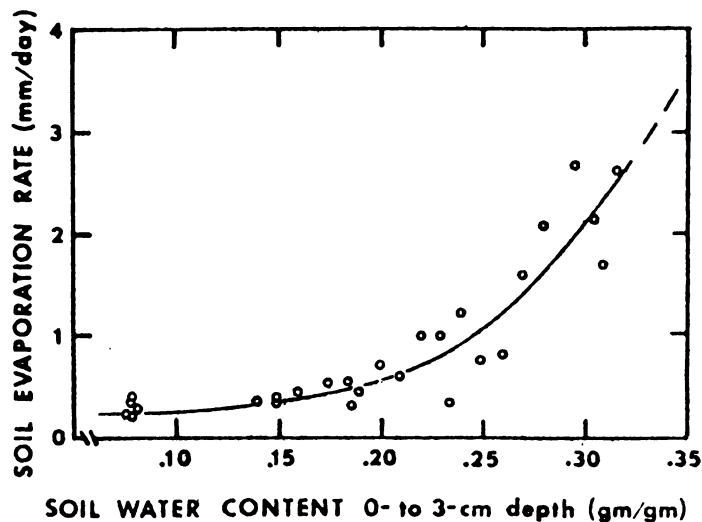


Figure 10. The influence of the surface soil water content on the water evaporation rate from bare soil.

Source: Ritchie and Burnett (1971)

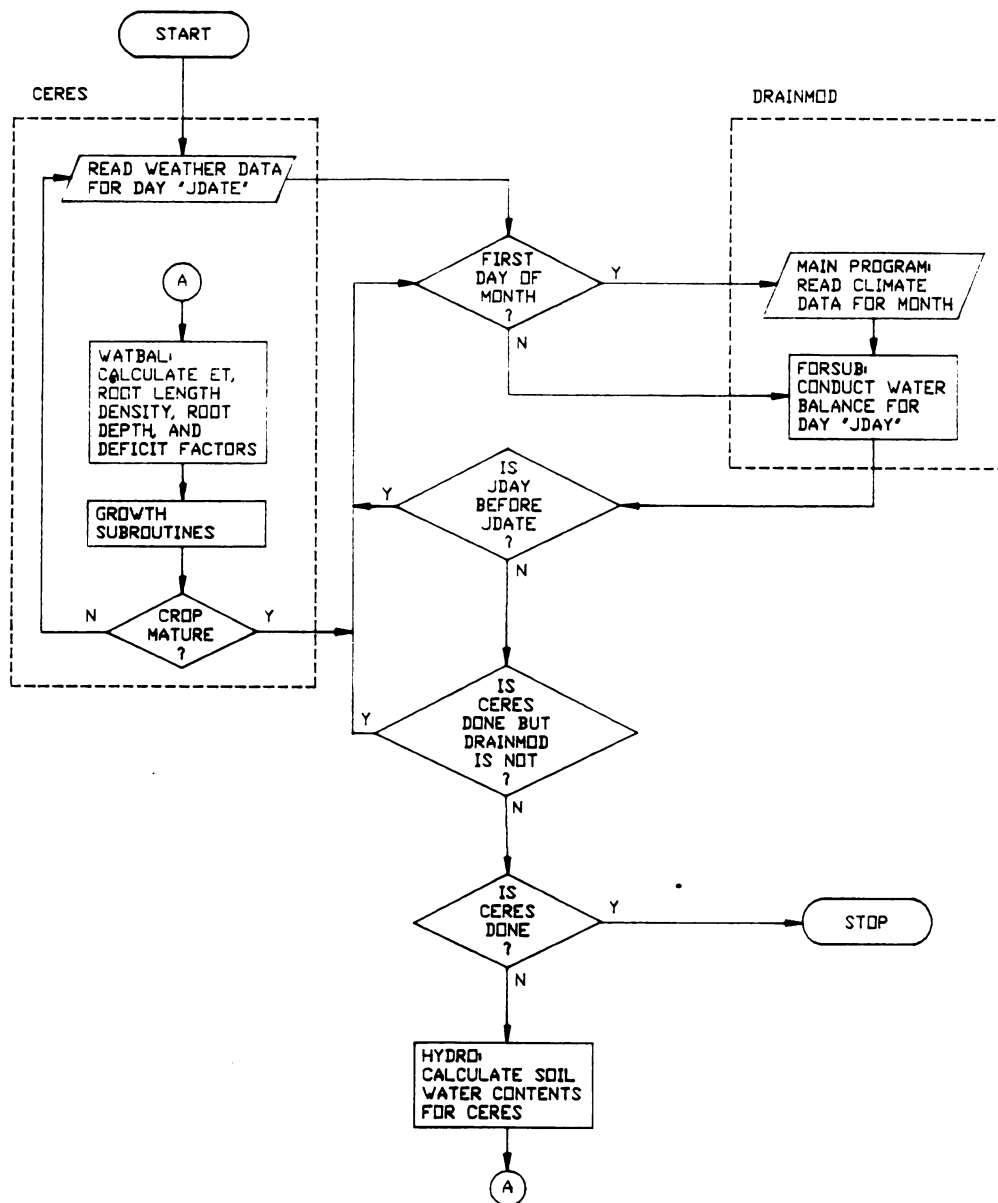


Figure 11. An Abbreviated Flow Chart of the Synthesized Models

4. Results and Discussion

The models DRAINMOD and CERES were linked together as explained in the preceding chapter. Operation and behavior of the synthesized model was investigated by performing a 16 year simulation for a site in Tuscola county, Michigan. Most of the soil information was obtained from literature. Hydraulic conductivities for some layers were obtained from field measurements. Nearby weather stations provided the climate data. A complete listing of the data used can be found in Appendix A. No actual yield data or measured water table levels for the years simulated were available for comparison with the model results. Much was learned, however, about the feasibility of the two models working together, what aspects need improvement, and what additional data are required.

In spite of the intrinsic difference between the two models in the way in which they handle the soil water information, HYDRO proved to be an adequate means of transferring this information between DRAINMOD and CERES. Given a water table depth, a dry zone depth, and the upflux from the water table from DRAINMOD, HYDRO calculated an average soil water content for each layer in CERES each day.

The adequacy of HYDRO as a link between the two models depends upon how well the soil water curve is defined for the soil profile, since HYDRO uses that curve to calculate water content in terms of a

hydrostatic pressure head. The better the soil water curve is defined, the more accurately HYDRO will be able to predict soil water contents.

Another factor that influences the accuracy of HYDRO is the thickness of the layers defined for CERES. The thicker the user has defined a layer, the greater the error in using an average soil water content for the whole layer. Each layer needs to be restricted in size if the average soil water content calculated for a layer is to approximate its actual water content from the top of the layer to the bottom of the layer. This should not be a problem if the recommendations given for use of CERES are followed. CERES documentation (Jones, 1985) recommends that the first two layers be less than 15 cm each, preferably 10 cm, and that all the additional layers should be less than 30-40 cm. In the simulation, the layers from top to bottom were defined to be 15, 17, 22, 24, 45, 47, and 22 cm. A better definition would have been to split the top two layers into 3 layers.

The soil at the site was determined to be similar to a Tappan loam with an impermeable layer at a depth varying between 1 and 2 meters. Information from the Nebraska soil survey on the Tappan loam was used to determine the soil water characteristic curve for use in both DRAINMOD and HYDRO. A utility program by Ritchie (Jones, 1985), based on field measurements, was used to determine the soil water limits from the soil texture for use in CERES. The program gave the lower limit (LL), drain upper limit (DUL), and the saturation limit (SAT) as 14%, 23%, and 28% water by volume. The DUL is generally the water content that corresponds to a pressure head between 10 and 33 kPa. The survey sheet, on the other hand, gave 31% water by volume at

33 kPa which exceeds what the program predicted at saturation or 0.0 kPa (28%). Since the soil survey uses laboratory measurements and in lieu of direct field measurements, values closer to the results of the utility program were used in the simulation with LL, DUL, and SAT being 14, 26, and 36% respectively.

The utility program gave soil water limits for each defined layer but because HYDRO and DRAINMOD currently uses only one curve, the curve for the first layer and its corresponding soil water limits calculated were used for the top 4 layers, down to 78 cm. As the soil is quite uniform over this depth, this provided an adequate description for this simulation. Generally, however, a soil water curve and the corresponding limits should be defined for each layer in the profile. HYDRO could be adapted to calculate the soil water contents for layered soils as shown in Figure 12.

The evapotranspiration calculation in CERES requires solar radiation in addition to minimum and maximum temperature to calculate potential ET. As information on solar radiation was not available from the weather stations used, the Thornthwaite method in DRAINMOD was used to calculate the potential ET for the day. This potential ET was transferred to CERES where the actual ET was still calculated using the method in CERES as the sum of soil evaporation, E_s , and plant transpiration, E_p as described before.

The calculation of the soil evaporation, E_s , by CERES was supplemented by a method that included the effect of a water table as described previously. Figure 13 shows the comparison between E_s values calculated by CERES and those calculated by the supplemental method. The peaks show an increase in E_s calculated by CERES due to

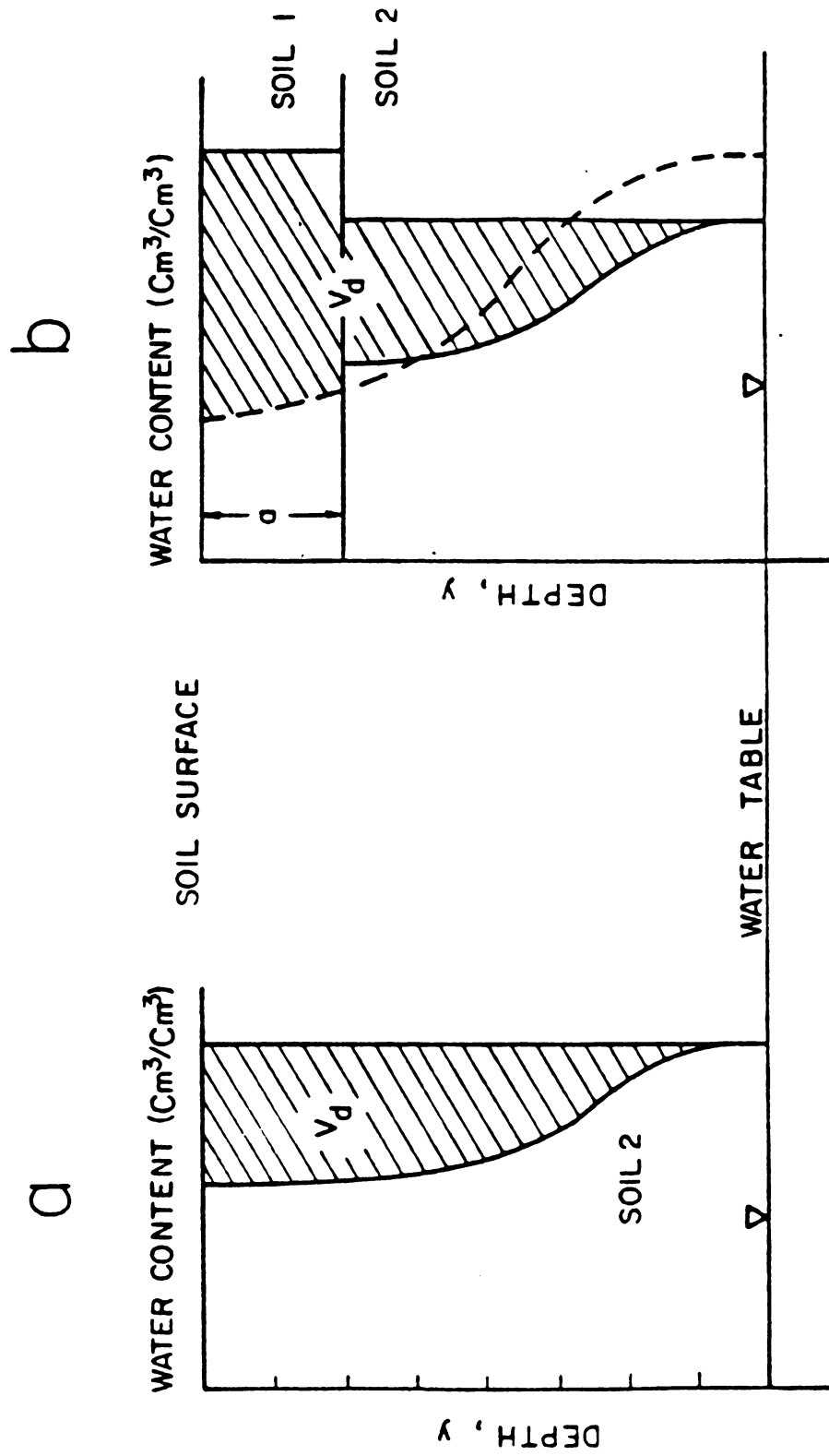


Figure 12. Soil water distribution for a uniform soil (a) and a layered soil (b) drained to equilibrium to a water table. The broken curve in (b) represents the soil water distribution for a uniform soil 1.

Source: Skaggs (1980)

an infiltration event. After an event, CERES's calculation of E_s decreased in value and eventually became less than what the supplemental calculation predicted. In either case, the two values of E_s predicted were compared, and the higher value of E_s was taken to be the soil evaporation for each day.

The results of several simulations showed that a better description of the effective root zone depth was achieved. Root growth is now affected by the soil water conditions. During conventional drainage, when the water table was kept drained to a 1.0 m depth, the roots extended deep into the soil. During subirrigation, when the water table was raised to 0.60 m depth, the roots remained closer to the surface. If the water table was raised up near or into some roots, so that the soil water content of the layer containing those roots was above the root upper limit, RUL, for 2 days, the roots were reduced for every succeeding day that the excess water conditions persisted, eventually killing those roots. The root zone depth fluctuating as a result of the water table movement can be seen in Figure 14.

The results were compared to simulations run with the yield version of DRAINMOD, using the crop response parameters from Ohio. Under conventional drainage, the yield version of DRAINMOD had a yield reduction due to drought conditions, while the synthesized model experienced none. Because the effective rooting depth is a fixed function in DRAINMOD, it does not respond to dry conditions or to a low water table by increasing in depth. In DRAINMOD, the maximum effective depth for the simulation was fixed at 0.30 m. The effective depth in the synthesized model which varies according to soil

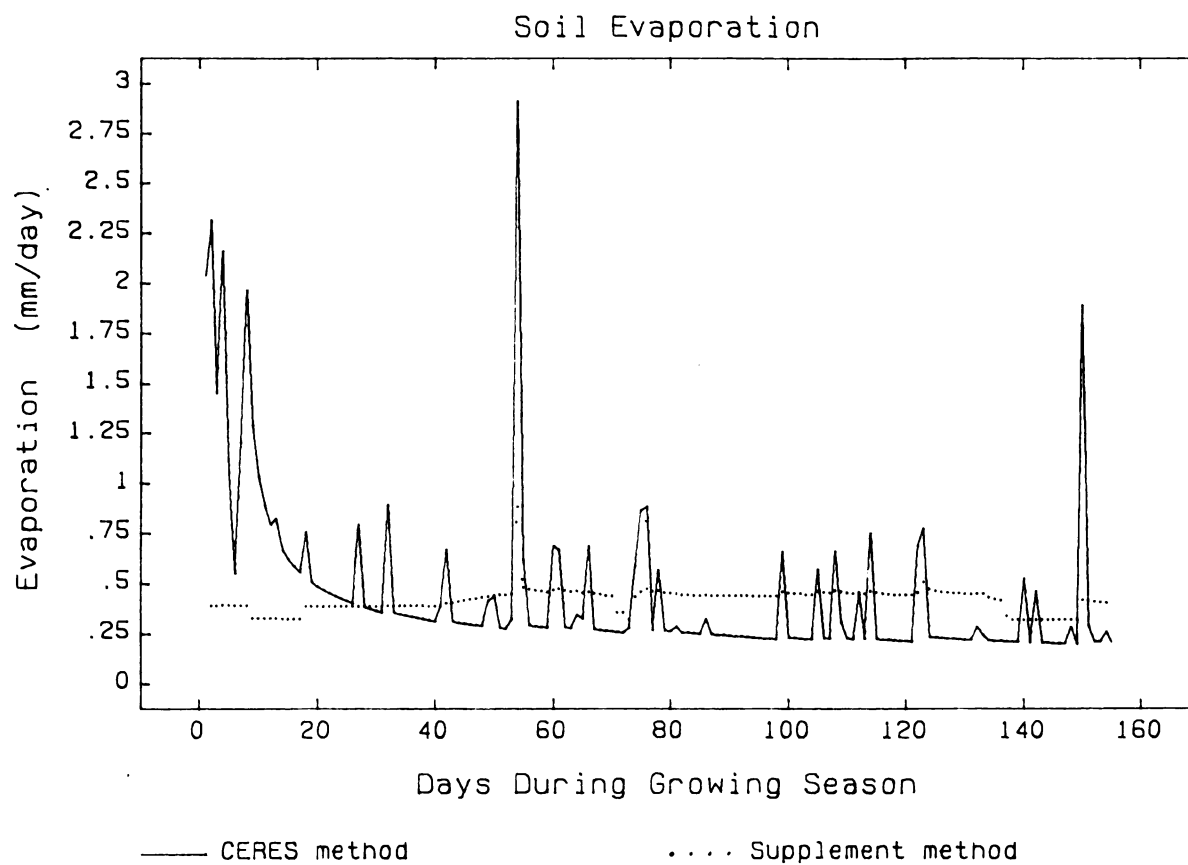


Figure 13. Comparison of the two methods of estimating soil evaporation. CERES accounts for infiltration, which causes the peaks. The other method accounts for surface soil water content as calculated by HYDRO.

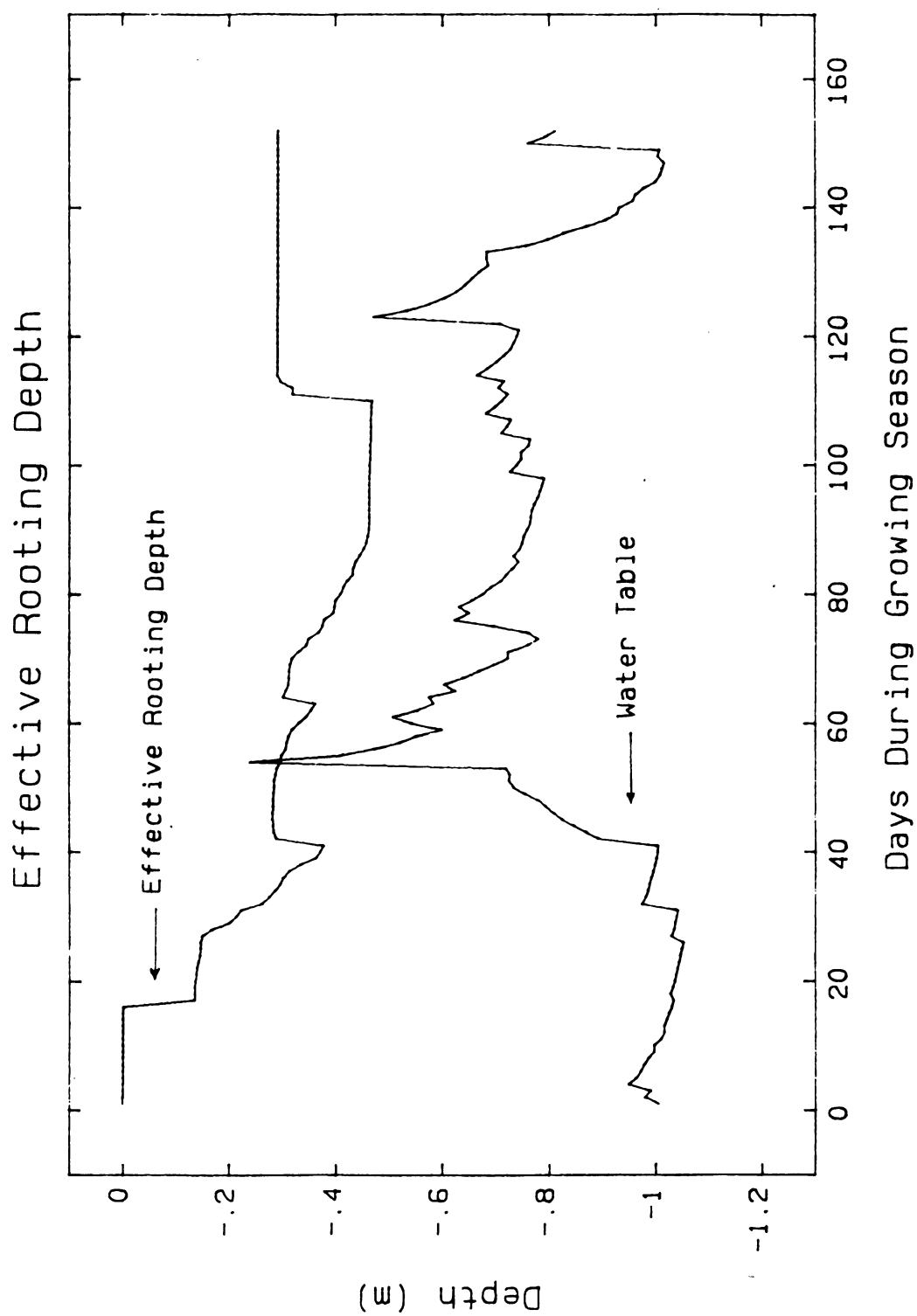


Figure 14. Root zone depth shown to be responsive to soil water conditions.

conditions, on the other hand, extended down to 0.48 m. The plants suffered no stress from lack of water, hence, the yield predicted was maximum at 18621 kg/ha. Though this yield is high, it must be remembered that the soil fertility was considered to be adequate; the yield predicted shows response to water stress conditions only.

The depth and distribution of plant roots are affected especially by soil water conditions, but other varying factors, including physical and chemical barriers, and fertilizer distribution are also important. Factors that might reduce root growth or prevent it can be accounted for in each layer by root preference factors, one of CERES' input. These factors can range from zero for no growth to one for maximum growth.

When the input root preference factors were adjusted so that the roots in the synthesized model were not allowed to exceed 0.32 m, the crop experienced dry stress, resulting in yield reductions comparable to the yield version of DRAINMOD, shown in Figure 15. It must be mentioned that while the yield version of DRAINMOD gives yield as a percent, CERES and hence the synthesized model predicts the actual yield. To compare the results of the two models, the yields predicted by synthesized model were converted to percents by dividing by 18621 kg/ha, which was the maximum yield predicted. While the average yield percent predicted for both was about 80%, a quick look shows that the results are not real consistent with each other. The correlation between the two was quite low, only 0.36, suggesting that the factors responsible for the reduction are not the same for both models.

Operation of the synthesized model indicates that the CERES growth component of the model lacks sensitivity to wet conditions.

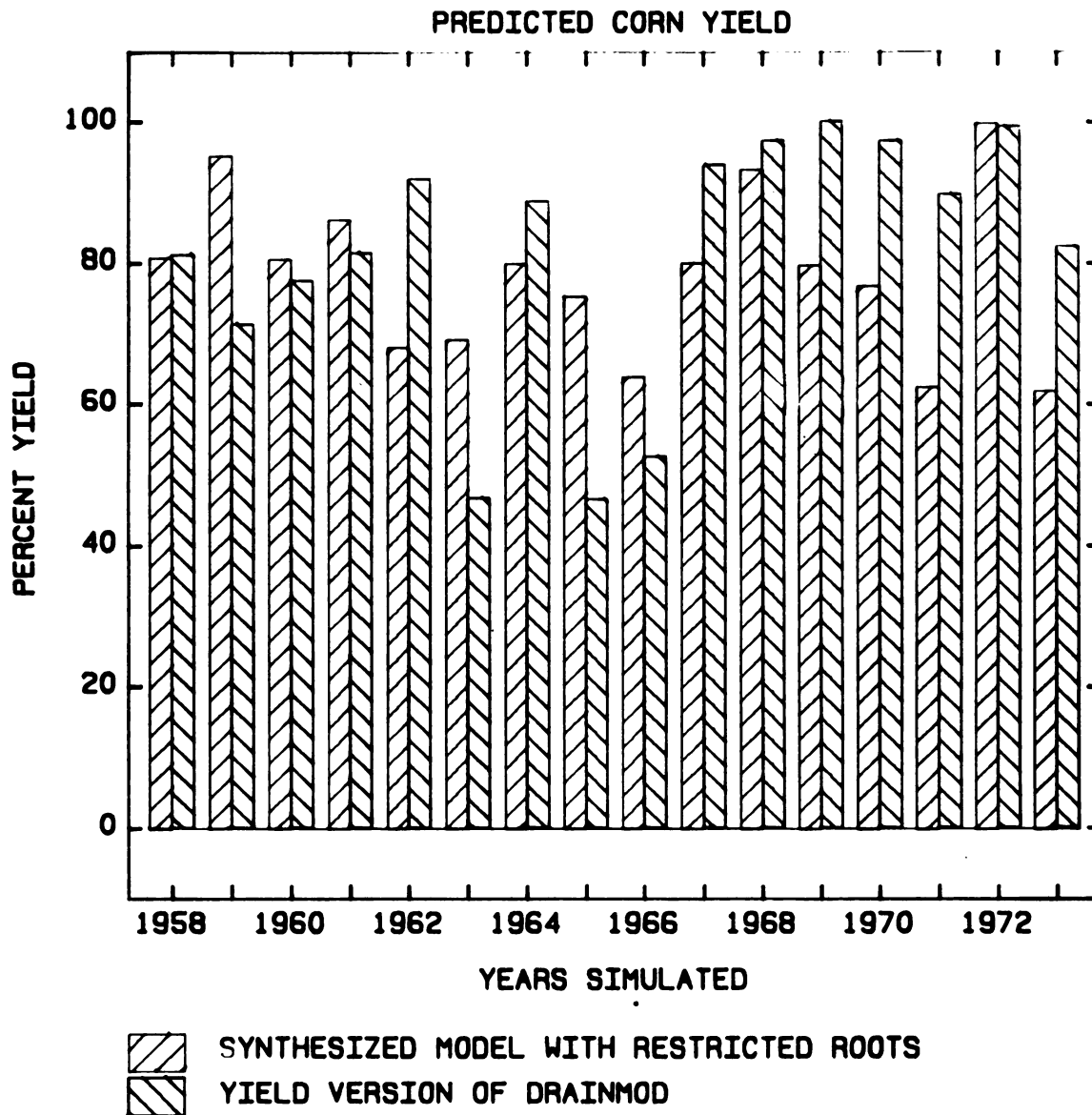


Figure 15. Comparison of yields between the synthesized model and the yield version of DRAINMOD when the roots are restricted to the same depth for both.

Even though the root growth function was modified to be responsive to wet conditions, yield reductions did not occur unless the roots were completely killed. For example, maximum yields were obtained when the crop was subirrigated at 0.40 m; however, when the crop was subirrigated at 0.30 m, the roots were completely killed, resulting in no yield. In comparison, the yield version of DRAINMOD predicted a relative yield due to excess water of 99.0 and 94.9% respectively, showing a better resolution to wet stress conditions.

There appears to be two reasons for this. One is that even though the roots might be reduced appreciably because of a high water table, even a few roots can usually and apparently do supply the needed water as they can increase their intake above the normal range as shown in Figure 2-8. It was thought at first that the reduction in roots would reduce yield, but since the few roots that remained supplied the needed water, the plants still produced maximum yields. Some means of reducing water uptake when the roots are under wet stress needs to be implemented to more correctly handle how the plant behaves in the field.

The second is that photosynthesis and cell expansion in the model are affected by dry stress, but not wet stress, due to the nature of CERES being developed to be responsive to dry, but not wet, conditions. For dry stress, the factors that affect photosynthesis and cell expansion, SWDF1 and SWDF2 respectively, are reduced in some proportion to the amount the root water uptake is less than or equal to the demand. They are then further adjusted with factors determined for different crop growth stages. Field experience indicates that when under wet stress, plants exhibit similar characteristics as when

they experience dry stress, such as wilting. If the root water uptake function was corrected on the wet side so that water uptake was reduced when excessive wet conditions occurred, then a similar scheme for reducing these factors in some proportion to the amount the root water uptake is less than or equal to the demand could be implemented. These factors could then be further adjusted by factors that account for different crop growth stages, same as is done for the dry stress. The proportion between the growth factors and the water uptake and crop growth stage factors will need to be determined. By correcting the root water uptake and the crop growth response to excess water conditions, the synthesized model could be made more sensitive to wet stress conditions.

5. Conclusions

The water management model, DRAINMOD, and the crop growth model, CERES, have been successfully linked to obtain a synthesized model that capitalizes on the strengths of each. The synthesized model conducts the water balance for a water management system and simulates crop growth and yield. A procedure was developed to convert the soil water regime status calculated by DRAINMOD into soil water content by layers required by CERES. Crop growth and water use calculated by CERES was transferred back to DRAINMOD.

Operation and behavior of the synthesized model was investigated by performing a 16 year simulation for a site in Michigan. Results show that important improvements in modeling crop response to a water management system have been made. A better description of the effective root zone depth was achieved as the root zone depth responds realistically to soil water conditions existing in drainage. During subirrigation, the roots remained close to the surface; during conventional drainage, the roots extended deeper into the soil. In addition, an improved evapotranspiration routine was obtained by adding a supplementary method that accounts for the presence of a water table.

Crop growth stress and resulting yield reductions caused by

deficient soil water conditions has been shown to occur when the roots were not allowed to extend below 0.32 m. The root stress factor, one of three crop stress factors CERES calculates, was modified to account for wet stress thereby affecting root growth potential and the amount of roots. This first attempt at defining wet stress seems to be in the right direction as root growth and the amount of roots were reduced. However, root water uptake, photosynthesis, and cell expansion were not modified to be affected by wet stress conditions. Thus, unless the roots were completely killed, excessive water did not reduce yield, showing the synthesized model lacks sensitivity to excessive water conditions. The investigation indicates the need for further modification before the linkage between DRAINMOD and CERES can be used as a working model.

6. Recommendations

1. Growth stress factors and corresponding crop growth stage factors for wet stress need to be determined and implemented for photosynthesis and cell expansion. Some of the research currently being done on wet stress for the yield version of DRAINMOD could be used to establish these stress factors for plant growth to make the model responsive to not only dry conditions, but also to wet conditions.

2. The root water uptake function needs to be defined for excessive water conditions.

3. The root growth potential function needs to be defined more precisely as presently, the roots are reduced somewhat arbitrarily. A better method would be having a variable account for the time and severity of stress for the roots similar to the SEW concept used in DRAINMOD, possibly as

$$REW = \sum (1 - SWDF) \quad (15)$$

A relationship could then be determined between REW and root senescence.

4. The subroutine HYDRO needs to be adapted to calculate the soil water content for layered soils. A soil water curve for each

layer in the profile needs to be defined and entered.

5. Better methods of determining the soil water curve and the corresponding lower limit, drained upper limit, and saturation limit need to be developed.

6. Input data and variables that are duplicated for both models need to be consolidated. The number of layers that DRAINMOD could handle, for example, might be increased to 10 to be consistent with CERES so that the same variables might be used for defining the layers.

7. CERES has a function to calculate delay in germination due to lack of moisture, but it does not account for planting delay due to wet conditions. The routine in the yield version of DRAINMOD could be used to determine planting delay due to excessive wet conditions hindering trafficability.

8. In the synthesized model, though DRAINMOD is technically a subroutine of CERES, the structure of both models is for the most part left intact. It might be feasible to make one more of a subroutine of the other. Presently, setting up CERES to have a drainage option seems to be the more reasonable approach. Either way, however, neither model can be reduced very much without it losing its integrity.

a. Soil Survey Results for Tappan Loam

SAMPLE NOS. 74B453-74B460

DEPTH	(SATURATED PASTE)	NA	NA	SALT	GYP	(- - - - -)	SATURATION EXTRACT	8A1-	- - - - -)	ATTERBERG
	8E1 8C1B 8A	5D2	5E	8D5	6P1A	8A1A 6M1B 6O1B	6P1B 6Q1B	6I1A 6J1A 6K1A	6L1A 6N1A	4F1 4T2
	REST PH H2O ESP	SAR	TOTL	SOLG	RHROS/	CH	CA NG NA K CG3 HC03 CL SO4 NO3	LQID PLST	LBIT INDI	
CH	CH	PCT	PCT	PPH	PCT	CH	(- - - - -)	HQ / LITER	- - - - -)	PCT
0-28										
28-32										
32-37										
37-54										
54-78										22 7
78-123										
123-170	3300	7.9	33.2		.71					20 7
170-192	1400	7.6	32.4		2.44					

Pedon classification: Typic Haplaquoll; fine-loamy, mixed (calcareous), mesic
 Series classification: (Same)
 Soil: Tappan
 Soil Nos.: S74MT-63-1 (BLS Nos. 74B453-74B460)
 Location: Huron County, Michigan; 152 feet south and 2340 feet west of the northeast corner of Sec. 19, T15N, R10E.
 Climate: Average annual precipitation is about 28 inches. Mean annual air temperature is about 47° F., and the mean summer air temperature is about 68° F. Frost-free season is 150-160 days.
 Vegetation and land use: Navy beans. Cropland.
 Parent material: Loam till.
 Physiography: Till plain.
 Topography: Nearly level. Gradient is 1 percent.
 Drainage: Poorly drained.
 Ground water: At 48 inches.
 Erosion: Slight.
 Permeability: Moderate or moderately slow.
 Described by: N. Stroesenreuther, L. Linsemier, S. Cowan, and W. Frederick.

(Colors are for moist soil unless otherwise stated.)

Ap 453 0 to 28 cm (0 to 11 inches). Very dark grayish brown (10YR 3/2) loam, grayish brown (10YR 5/2) dry; weak coarse granular structure; friable; few fine roots; 1 percent by volume of pebbles; slight effervescence; moderately alkaline; abrupt smooth boundary.

A12 454 28 to 32 cm (11 to 13 inches). Very dark grayish brown (10YR 3/2) loam, grayish brown (10YR 5/2) dry; weak medium subangular blocky structure; friable; few fine roots; about 2 percent by volume of pebbles; slight effervescence; moderately alkaline; abrupt wavy boundary.

B11g 455 32 to 37 cm (13 to 15 inches). Light brownish gray (10YR 6/2)(50%) and gray (10YR 5/1)(50%) loam; few fine prominent yellowish brown (10YR 5/6) mottles; weak medium subangular blocky structure; friable; few fine roots; about 5 percent by volume of pebbles and cobbles; slight effervescence; moderately alkaline; clear wavy boundary.

B12g 456 37 to 54 cm (15 to 21 inches). Grayish brown (10YR 5/2)(60%) and dark yellowish brown (10YR 4/4)(40%) loam; few fine distinct yellowish brown (10YR 5/6) mottles; moderate fine angular blocky structure; firm; 6 percent by volume of pebbles and cobbles; strong effervescence; moderately alkaline; clear wavy boundary.

B2g 457 54 to 78 cm (21 to 31 inches). Gray (10YR 5/1) loam; common medium prominent yellowish brown (10YR 5/6) and few fine prominent strong brown (7.5YR 5/6) mottles; moderate coarse platy parting to moderate medium angular blocky structure; firm; 4 percent by volume of pebbles and cobbles; strong effervescence; moderately alkaline; gradual wavy boundary.

C1 458 78 to 123 cm (31 to 48 inches). Yellowish brown (10YR 5/4) loam; common medium prominent gray (10YR 5/1) and common fine distinct yellowish brown (10YR 5/6) mottles; weak coarse angular blocky structure; firm; 4 percent by volume of pebbles and cobbles; strong effervescence; moderately alkaline; gradual smooth boundary.

C2 459 123 to 170 cm (48 to 67 inches). Yellowish brown (10YR 5/4) loam; few fine distinct yellowish brown (10YR 5/6) and few medium prominent light gray (10YR 6/1) mottles; weak coarse platy structure; firm; 4 percent by volume of pebbles and cobbles; strong effervescence; moderately alkaline; gradual smooth boundary.

C3 460 170 to 192 cm (67 to 76 inches). Dark brown to brown (7.5YR 4/4) loam, grayish brown (10YR 5/2) on faces of pedis; strong coarse platy structure; firm; 4 percent by volume of pebbles and cobbles; strong effervescence; moderately alkaline.

1237A



b. Input data for DRAINMOD

*** Job Title ***

Tappan Loam 4 layers (2 in CERES)

For CERES and DRAINMOD simulation

*** Printout Control ***

2

*** Climate ***

b:flint b:lapeer 202846 204655 1958 1 1973 12 4303 40

1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00

*** Drainage System Design ***

01

100.00	52.85	1006.00	2.50	3.50	1.00	11.11	0.00
1.00	0.50						

0100 0100 0100 0100 0100 0100 0100 0100 0100 0100

*** Soils ***

192.00

32. 4.00 54. 3.00 123. 2.00 170. 0.50 192. 0.20

99

1114

0.36000	0.0	
0.30000	-25.0	
0.26000	-50.0	
0.22500	-75.0	
0.20000	-100.0	
0.18500	-150.0	
0.16000	-200.0	
0.14500	-300.0	
0.14100	-400.0	
0.14000	-500.0	
0.13000	-1000.0	
0.0000	0.0000	0.1700
10.0000	0.1200	0.1700
20.0000	0.4800	0.1700
30.0000	1.0700	0.1000
40.0000	1.8300	0.0500
50.0000	2.7500	0.0300
60.0000	3.8200	0.0160
80.0000	6.3800	0.0060
100.0000	9.3800	0.0030
120.0000	12.6400	0.0014
150.0000	17.7500	0.0005
200.0000	27.1300	0.0001
500.0000	50.0000	0.0000
1000.0000	100.0000	0.0000

6

0.00	0.00	2.00
30.00	0.44	2.00
60.00	1.32	1.50
120.00	2.06	1.25
150.00	5.28	1.25
500.00	5.28	1.25

*** Trafficability ***

415	520	820	3.0	1.0	1.0
915	1031	820	3.0	1.0	1.0

*** Crop ***

0.130		
6	1	9
6	1	9

10

1	1	3.0	5	1	3.0	512	4.0	522	8.0	6	1	16.0	615	22.0	7	1	30.0	915	30.0
916	3.0	1232	3.0																
121	130	0.5000	8.0000	1.8000	29.0000														
30	3	11.1600	-1.1700	0.0580	-0.0005	100.0000	1.5000												
100.000	1.220	103.000	0.420	110	130	1													
0	420.51	43	800.33	811	400.02														
0.000	0.000	0.500	0.500	0.501	0.001	0.001	0.001	0.001	0.752	0.002	0.001	0.301	0.301	0.301	0.301	0.301	0.201	0.000	0.50
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00

*** Wastewater Irrigation ***

0	0	0	365	0	0														
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.00000	0.00000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

c. Input data for CERES

i. Soil data

DEPTH (CM)	LL	DUL	SAT	ROOTING PREFERENCE
15.000	.13	.26	.36	1.0
17.000	.13	.26	.36	.9
22.000	.13	.26	.36	.5
24.000	.13	.26	.36	.01
45.000	.14	.23	.33	.00
47.000	.14	.23	.33	.00
22.000	.14	.23	.33	.00
soil	no. of	runoff		
albedo	layers	drainage	coef.	
.11	7.00	.09	78.00	

ii. Corn genetics information

DEKALB 987 - cultivar name

190 - growing degree days with a base temperature of 8°C (GDD₈) from seedling emergence to the end of the juvenile phase.

.500 - photoperiod sensitivity coefficient (1/hr).

685.0 - GDD₈ from silking to physiological maturity.

825.4 - potential kernel number (kernels/plant)

10.15 - potential kernel growth rate (mg/(kernel d))

d. Abbreviated List of Synthesized Model Output

FOR YEAR 1958

VARIETY NUMBER 916 VARIETY NAME DEKALB 987

LAT =42.7 , SOWING DEPTH = 5.0 CM , PLANT POP = 7.0 PLANTS/M**2

GENETIC CONSTANTS P1 =190. P2 =.50 P5=685. G2 =825. G3 =10.

SOIL ALBEDO=0.11 U= 7.0 SWCON=0.09 RUNOFF CURVE NO.=78. SOIL NO.=134

0	DEPTH-CM	LOW LIM	UP LIM	SAT SW	EXT SW	INIT SW	WR
	0.- 15.	0.130	0.260	0.360	0.130	0.260	1.000
	15.- 32.	0.130	0.260	0.360	0.130	0.260	0.900
	32.- 54.	0.130	0.260	0.360	0.130	0.260	0.500
	54.- 78.	0.130	0.260	0.360	0.130	0.260	0.010
	78.- 123.	0.140	0.230	0.330	0.090	0.230	0.000
	123.- 170.	0.140	0.230	0.330	0.090	0.230	0.000
	170.- 192.	0.140	0.230	0.330	0.090	0.230	0.000
	78.0	26.1	46.5	65.7	20.4	46.5	TOTAL PROFILE

DAY	JUL DAY	CUM DTT	PHENOLOGICAL STAGE	CUMULATIVE	WATER BALANCE COMPONENTS AFTER GERMINATION				
5/ 3/84	124	0.	SOWING	BIOMASS	LAI	CSD1	ET	PREC	PESW
5/ 4/84	125	3.	GERMINATION				19.	0.	30.3
5/19/84	140	51.	EMERGENCE				7.	0.	30.5
6/ 8/84	160	202.	END JUVENILE STAGE	15.	0.33	0.00	21.	0.	0.0
6/14/84	166	280.	TASSEL INITIATION	45.	0.81	0.00	35.	0.	0.0
7/21/84	203	766.	SILKING, LNO= 19.0	1050.	4.89	0.00	204.	0.	24.4
8/ 3/84	216	934.	BEGIN GRAIN FILL	1401.	4.54	0.00	259.	0.	0.0
9/10/84	254	1418.	END FILL, GPP=650.	2795.	1.15	0.01	403.	0.	
9/12/84	256	1443.	PHYSIO MATURITY	2795.	1.15				

	PREDICTED VALUES	MEASURED VALUES
SILKING JD	203	0
MATURITY JD	256	0
GRAIN YIELD KG/HA (15)	18621.	0.
KERNEL WEIGHT G (DRY)	0.3460	0.0000
FINAL GPSM	4547.	0.
GRAINS/EAR	650.	0.
MAX. LAI	4.89	0.
BIOMASS G/SM	2795.	0.

Table 1. Relative yield results for years 1958 to 1973*

Year	A	B	C	D	E
1958	100.00	100.00	80.89	94.45	81.08
1959	100.00	100.00	95.32	99.17	71.24
1960	100.00	100.00	80.62	99.75	77.41
1961	100.00	100.00	86.27	99.49	81.39
1962	100.00	100.00	68.19	93.42	91.87
1963	100.00	99.73	69.33	99.99	46.64
1964	100.00	100.00	80.03	98.99	88.7
1965	100.00	100.00	75.45	93.31	46.45
1966	100.00	99.72	63.98	100.	52.47
1967	100.00	100.00	80.14	100.	93.8
1968	100.00	100.00	93.41	98.92	97.27
1969	100.00	100.00	79.93	100.	100.
1970	100.00	100.00	76.96	98.11	97.29
1971	100.00	100.00	62.61	99.07	89.7
1972	100.00	100.00	100.00	99.25	99.25
1973	100.00	100.00	62.04	100.	82.29

- * A. Synthesized model, subirrigation.
 B. Synthesized model, conventional drainage.
 C. Synthesized model, conventional drainage, roots limited to 32 cm.
 D. Yield version of DRAINMOD, subirrigation.
 E. Yield version of DRAINMOD, conventional drainage.

B. Source Code of Synthesized Model

```

C      PROGRAM MAIZE
C      THIS IS THE CERES-MAIZE PROGRAM FOR IBM-PC 5.1
C
C      THIS HAS BEEN REPROGRAMMED FOR THE IBM-PC BY ED MARTIN AND FRIENDS
C      REPROGRAMMED FOR USE WITH DRAINMOD BY PHIL BRINK AND OTHERS
C      WEATHER TAPE IS NOW TAPE 1
C      SOIL TAPE IS NOW TAPE 2
C      IRRIGATION TAPE IS NOW TAPE 3
C
C      THIS PROGRAM HAS AUTOMATIC IRRIGATION AND SOWING.  TO TURN OFF
C      THE AUTOMATIC IRRIGATION, LET IIRR=0
C
C      ALSO, THE OUTPUT SWITCH HAS BEEN TURNED OFF
C
C      CORNMODL-----DS
C
C      MAIN PROGRAM CERES-MAIZE JANUARY 1985 VERSION*
C      DEVELOPED BY RITCHIE,KINIRY,JONES,KNIEVEL,DYKE AND OTHERS
C      REAL LAT,LL,LAI,LFWT,MAXLAI
C      COMMON /PARAM/ ISOW,PLANTS,KOUTGR,KOUTWA,SDEPTH,IIRR,
1     LAT,KVARTY,KSOIL,IQUIT,NEWSOL,NEWWET,MULTYR,ISWSWB,U,
2     SOILN,ISLKJD,MATJD,XYIELD,XGRWT,XGPSM,XGPE,XLAI,XBIOM,
3     IDATE,ICDTT
C      COMMON /GENET/ P1,P2,P3,P5,G2,G3
C      COMMON /SOILI/ SALB,SWCON,CN2,DLAYR(10),DUL(10),LL(10),SW(10),
1     SAT(10),DEPMAX,TDUL,NLAYR,SMX,WF(10),WR(10),RWU(10),SWEF
C      COMMON /IRRIG/ NIRR,JDAY(366),AIRR(366)
C      COMMON /TITL/ TITLE(20)
C      COMMON /CLIMT/ TEMPMN,TEMPMX,RAIN,SOLRAD,TMFAC(8)
C      COMMON /DATEC/ MO,ND,IYR3,JDATE,JDATEX,IDIM(12)
C      COMMON /WATER/ SUMES1,SUMES2,T,TLL,PESW,TSW,CUMDEP,ESW(10),
1     CSD1,CSD2,SI1(5),SI2(5),ICSDUR,ES,EP,ET,EO,CES,CEP,CET,
1     RLV(10),PRECIP,CRAIN,DRAIN,IDRSW,RTDEP,SWDF1,SWDF2,
1     SWDF3,TRWU,RWUMX,SUMIR,SWUT
C      COMMON /WRITS/ AES,AEP,AET,AEO,ASOLR,ATEMX,ATEMN,ARUNOF,
1     ADRAIN,APRECP,ASWDF1,ASWDF2,IOUTGR,IOUTWA,JHEAD,KHEAD,
2     TPRECP,RUNOFF
C      COMMON /PHENL/ CUMDTT,TBASE,SUMDTT,S1,C1,ISTAGE,JJDATE,
1     DTT,IDUR,CUMPH,SSTT,CSTT,SIND,P9,TEMPM
C      COMMON /GROTH/ GPSM,GPP,GRORT,LAI,BIOMAS,PLA,SENLA,PTF,TLNO,
1     LFWT,SEEDRV,REGM,LN,XPLANT,RTWT,STMWT,GRNWT,SWMIN,LWMIN,

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1  EARWT,EMAT,SUMP,IDURP,PLAY,PLAMX,CARBO,XN,XNTI,
1  FLAG,GROSTM,GBLA(35),SLA(35),EARS
COMMON /FILE/SWATER,CIRRIG,WEATHER,CGENET,MISOIL,WATCORN,BIOCORN
COMMON /CDNO/LOPC,MFLAG,LOPE,IQUIT3,JDATE3,JDAY3
COMMON/CDET/CDTWT,CROOT,CFVOL,DWET(10),SURWET,TRD60,IPET,PETD,AETC
COMMON/PERCIP/RVOL,CRO
CHARACTER*12 SWATER
CHARACTER*12 CIRRIG
CHARACTER*12 WEATHER
CHARACTER*12 CGENET
CHARACTER*12 MISOIL
CHARACTER*12 WATCORN
CHARACTER*12 BIOCORN
WRITE(*,*)'ENTER 1 TO USE DRAINMOD PET, 9 TO USE CERES PET '
READ(*,240) IPET
WRITE(*,*) IPET
240 FORMAT( I2)
CALL PARMFLS
OPEN(22,FILE=SWATER, STATUS='OLD')
OPEN(23,FILE='CNDET')
OPEN(5, FILE=CIRRIG,STATUS='OLD')
OPEN(4, FILE=WEATHER,STATUS='OLD')
OPEN(2, FILE=MISOIL, STATUS='OLD')
OPEN(12,FILE=WATCORN,STATUS='OLD')
OPEN(13,FILE=BIOCORN,STATUS='OLD')
OPEN(17,FILE='FLOW', STATUS='OLD')
OPEN(15,FILE=CGENET, STATUS='OLD')
OPEN(16,FILE='COUT', STATUS='OLD')
DO 3 I=1,10
  DWET(I)=0.
3  CONTINUE
MFLAG=0
LOPC=0
IQUIT=0
IQUIT3=0
CRO=0.
RVOL=0.
TRD60=0.
ET=0.
RTDEP=0.
5  CALL PROGRI
IF (ISWSWB.NE.0) CALL SOILRI
REWIND 2
READ (4,30) IYR3,JDATE,SOLRAD,TEMPMX,TEMPMN,RAIN
JDATE3=JDATE
GO TO 15
10 READ (4,30,END=20) IYR3,JDATE,SOLRAD,TEMPMX,TEMPMN,RAIN
15 IF(JDATEX.EQ.367)CALL CALDAT
PRECIP=RVOL
LOPC=LOPC+1
AETC=ET*0.1
CROOT=.60*RTDEP
WRITE(17,*) 'RTDEP,TRD60',RTDEP,TRD60
17 CALL CDMOD

```

```

IF(IQUIT3.LT.-1) GOTO 5
IF (ISWSWB.NE.0) CALL WATBAL
IF(JDATE.EQ.ISOW.OR.ISTAGE.NE.7) CALL PHENOL(*5)
IF (ISTAGE.LT.6) CALL GROSUB
CALL WRYTE
GO TO 10
20 IQUIT=999
   IQUIT3=999
   AETC=0.
   GOTO 17
   STOP

C
C
70 FORMAT(20A4)
30 FORMAT (7X,I2,1X,I3,3X,F4.0,3F6.1)
   END

C
C
***** PROGRAM INITIALIZATION *****

SUBROUTINE PROGRI
REAL LAT,LL,LAI,LFWT,MAXLAI
COMMON /TITL/ TITLE(20)
COMMON /PARAM/ISOW,PLANTS,KOUTGR,KOUTWA,SDEPTH,IIRR,
1 LAT,KVARTY,KSOIL,IQUIT,NEWSOL,NEWWET,MULTYR,ISWSWB,U,
2 SOILN,ISLKJD,MATJD,XYIELD,XGRWT,XGPSM,XGPE,XLAI,XBIOM,
3 IDATE,ICDTT
COMMON /GENET/ P1,P2,P3,P5,G2,G3
COMMON /CLIMT/ TEMPMN,TEMPMX,RAIN,SOLRAD,TMFAC(8)
COMMON /DATEC/ MO,ND,IYR,JDATE,JDATEX,IDIM(12)
COMMON /WATER/ SUMES1,SUMES2,T,TLL,PESW,TSW,CUMDEP,ESW(10),
1 CSD1,CSD2,S11(5),S12(5),ICSDUR,ES,EP,ET,EO,CES,CEP,CET,
1 RLV(10),PRECIP,CRAIN,DRAIN,IDRSW,RTDEP,SWDF1,SWDF2,
1 SWDF3,TRWU,RWUMX,SUMIR,SWUT
COMMON /WRITS/ AES,AEP,AET,AEO,ASOLR,ATEMX,ATEMN,ARUNOF,
1 ADRAIN,APRECP,ASWDF1,ASWDF2,IOUTGR,IOUTWA,JHEAD,KHEAD,
2 TPRECP,RUNOFF
COMMON /PHENL/ CUMDTT,TBASE,SUMDTT,S1,C1,ISTAGE,JDATE,
1 DTT,IDUR,CUMPH,SSTT,CSTT,SIND,P9,TEMPM
COMMON /GROTH/ GPSM,GPP,GRORT,LAI,BIOMAS,PLA,SENLA,PTF,TLNO,
1 LFWT,SEEDRV,REGM,LN,XPLANT,RTWT,STMWT,GRNWT,SWMIN,LWMIN,
1 EARWT,EMAT,SUMP,IDURP,PLAY,PLAMX,CARBO,XN,XNTI,
1 PLAG,GROSTM,GBLA(35),SLA(35),EARS
COMMON /CDNO/LOPC,MFLAG,LOPE,IQUIT3,JDATE3,JDAY3
DIMENSION VARTY(5)
10 NEWSOL=1
   NEWWET=1
   MULTYR=0
   ISWSWB=1
20 IF(IQUIT.EQ.999) GOTO 65
C 39 IF (NEWWET.EQ.0) REWIND 10
   IF (NEWWET.EQ.0) NEWWET=2
   XPLANT=PLANTS
   S1=SIN(LAT*0.01745)
   C1=COS(LAT*0.01745)

```

```

ISTAGE=7
TBASE=10
LAI=0.
SWDF1=1.0
SWDF2=1.0
ICSDUR=0
JHEAD=0
KHEAD=0
IF(ISWSWB.EQ.0) KOUTWA=0
IF (KOUTWA.NE.0) CALL OUTWA
IF (KOUTGR.NE.0) CALL OUTGR
C *****INITIALIZING NEW PARAMETERS*****
SUMIR=0.
IDATE=0
ICDTT=0
C *****
JDATEX=367
CUMDTT=0.
SUMDTT=0.
DTT=0.
CRAIN=0.
PRECIP=0.
REWIND 15
40 READ (15,110,END=50) IVARTY,(VARTY(NN),NN=1,4),P1,P2,P5,G2,G3
IF (IVARTY.NE.KVARTY) GO TO 40
REWIND 15
GO TO 60
50 WRITE (16,120) KVARTY
STOP
60 CONTINUE
WRITE (16,130) IVARTY,(VARTY(NN),NN=1,4)
WRITE (16,90) LAT,SDEPTH,PLANTS
WRITE (16,180) P1,P2,P5,G2,G3
RETURN
65 WRITE(16,140)
C
C IF DRAINMOD GOES ANOTHER YEAR, REINITILIZE PARAMETERS
C
IF(IQUIT3.LT.-1) THEN
REWIND 4
REWIND 2
REWIND 22
REWIND 15
IQUIT=0
IQUIT3=0
GO TO 10
END IF

C
C WE NOW CLOSE THE FILES AND STOP THE PROGRAM
C
CLOSE(1)
CLOSE(2)
CLOSE(3)

```



```

CLOSE(12)
CLOSE(13)
CLOSE(15)
CLOSE(22)
CLOSE(6)
STOP
C
90 FORMAT (/1X,5X,'LAT =' ,F4.1,' , SOWING DEPTH = ',F3.1,
1 ' CM , PLANT POP = ',F4.1,' PLANTS/M**2')
110 FORMAT (1X,I4,1X,4A4,F6.2,F6.4,F6.2,F6.2,F6.3)
120 FORMAT (' CROP VARIETY INFORMATION IS MISSING FOR',I5)
130 FORMAT (6X,'VARIETY NUMBER ',I4,' VARIETY NAME ',4A4)
180 FORMAT (/1X,5X,'GENETIC CONSTANTS' ,2X,'P1 =' ,F4.0,2X,
1 'P2 =' ,F3.2,2X,'P5=' ,F4.0,2X,'G2 =' ,F4.0,2X,'G3 =' ,F3.0)
140 FORMAT(' CROP MATURE FOR SINGLE YEAR RUN')
END
C
C ***** SUBROUTINE TO READ AND INITIALIZE SOIL INFORMATION ***
C
SUBROUTINE SOILRI
REAL LAT,LL,LAI,LFWT,MAXLAI
COMMON /PARAM/ISOW,PLANTS,KOUTGR,KOUTWA,SDEPTH,IIRR,
1 LAT,KVARTY,KSOIL,IQUIT,NEWSOL,NEWWET,MULTYR,ISWSWB,U,
2 SOILN,ISLKJD,MATJD,XYIELD,XGRWT,XGPSM,XGPE,XLAI,XBIOM,
3 IDATE,ICDTT
COMMON /SOILI/ SALB,SWCON,CN2,DLAYR(10),DUL(10),LL(10),SW(10),
1 SAT(10),DEPMAX,TDUL,NLAYR,SMX,WF(10),WR(10),RWU(10),SWEF
COMMON /IRRIG/ NIRR,JDAY(366),AIRR(366)
COMMON /WATER/ SUMES1,SUMES2,T,TLL,PESW,TSW,CUMDEP,ESW(10),
1 CSD1,CSD2,S11(5),S12(5),ICSDUR,ES,EP,ET,EO,CES,CEP,CET,
1 RLV(10),PRECIP,CRAIN,DRAIN,IDRSW,RTDEP,SWDF1,SWDF2,
1 SWDF3,TRWU,RWUMX,SUMIR,SWUT
COMMON /PHENL/ CUMDTT,TBASE,SUMDTT,S1,C1,ISTAGE,JJDATE,
1 DTT,IDUR,CUMPH,SSTT,CSTT,SIND,P9,TEMP
COMMON /GROTH/ GPSM,GPP,GRORT,LAI,BIOMAS,PLA,SENLA,PTF,TLNO,
1 LFWT,SEEDRV,REGM,LN,XPLANT,RTWT,STMWT,GRNWT,SWMIN,LWMIN,
1 EARTW,EMAT,SUMP,IDURP,PLAY,PLAMX,CARBO,XN,XNTI,
1 PLAG,GROSTM,GBLA(35),SLA(35),EARS
IF (NEWSOL.EQ.0) GO TO 60
10 READ (2,210,END=30) NSOIL,SALB,U,SWCON,CN2
IF (NSOIL.NE.KSOIL) GO TO 10
WRITE (16,120) SALB,U,SWCON,CN2,NSOIL
GO TO 30
30 DEPMAX=0.
CUMDEP=0.
DO 40 NLAYR=1,10
READ (2,130) DLAYR(NLAYR),LL(NLAYR),DUL(NLAYR),SAT(NLAYR),
1WR(NLAYR)
130 FORMAT (4F10.3,10X,F10.3)
IF (SOILN.LE.1.)GO TO 37
38 IF (DLAYR(NLAYR).GT.0.) READ(22,135) SW(NLAYR)
135 FORMAT (1X,F5.3)
GO TO 39
37 SW(NLAYR)=LL(NLAYR)+(DUL(NLAYR)-LL(NLAYR))*SOILN

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      CUMDEP=CUMDEP+DLAYR(NLAYR)
      IF(CUMDEP.LE.110.) GO TO 39
      DLL=0.008*(CUMDEP-110.)*(DUL(NLAYR)-LL(NLAYR))+LL(NLAYR)
      IF(SW(NLAYR).LT.DLL) SW(NLAYR)=DLL
39  CONTINUE
      DEPMAX=DEPMAX+DLAYR(NLAYR)
      IF (DLAYR(NLAYR).LE.0.) GO TO 50
40  CONTINUE
      GO TO 60
50  NLAYR=NLAYR-1
60  GOTO 80
C   60 IF (IIRR.EQ.0) GO TO 80
C   WRITE (16,140)
C   J=1
C   NIRR=0
C   70 READ (IIRR,150) JDAY(J),AIRR(J)
C   IF (JDAY(J).EQ.0) GO TO 80
C   WRITE (*,160) JDAY(J),AIRR(J)
C   J=J+1
C   NIRR=NIRR+1
C   GO TO 70
C   80 CONTINUE
      SWR=(SW(1)-LL(1))/(DUL(1)-LL(1))
      IF (SWR.GE..9) GO TO 90
      SUMES2=25.-27.8*SWR
      SUMES1=U
      T=(SUMES2/3.5)**2
      GO TO 100
90  SUMES2=0.
      SUMES1=100.-SWR*100.
      T=0.
100 CONTINUE
      WRITE (16,190)
      XX=0.
      TSW=0.
      TPESW=0.
      TDUL=0.
      TLL=0.
      TSAT=0.
      CUMDEP=0.
      DL1=0.
      IDRSW=0
      DO 110 L=1,NLAYR
        DL2=DL1+DLAYR(L)
        ESW(L)=DUL(L)-LL(L)
        WRITE (16,200) DL1,DL2,LL(L),DUL(L),SAT(L),ESW(L),SW(L),
1       WR(L)
        DL1=DL2
        CUMDEP=CUMDEP+DLAYR(L)
        TSW=TSW+SW(L)*DLAYR(L)
        TPESW=TPESW+ESW(L)*DLAYR(L)
        TLL=TLL+LL(L)*DLAYR(L)
        TDUL=TDUL+DUL(L)*DLAYR(L)
        TSAT=TSAT+SAT(L)*DLAYR(L)

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      WX=1.016*(1.-EXP(-4.16*CUMDEP/DEPMAX))
      WF(L)=WX-XX
      XX=WX
110 CONTINUE
      DEPMAX=0.
      DO 115 L=1,NLAYR
        IF(WR(L).EQ.0) GO TO 116
        DEPMAX=DEPMAX+DLAYR(L)
115 CONTINUE
116 RTDEP=DEPMAX
      WRITE (16,170) RTDEP,TLL,TDUL,TSAT,TPESW,TSW
      CN1=-16.91+1.348*CN2-0.01379*CN2**2+0.0001172*CN2**3
      SMX=254.*(100./CN1-1.)
      SWEF=0.9-0.00038*(DLAYR(1)-30.)**2
      CET=0.
      CES=0.
      CEP=0.
      CRAIN=0.
      RWUMX=0.03
      RETURN
C
120 FORMAT (1X,5X,'SOIL ALBEDO=',F4.2,2X,'U=',F4.1,2X,
1  'SWCON=',F4.2,' RUNOFF CURVE NO.=',F3.0,' SOIL NO.=',I3)
C 130 FORMAT (6F10.3)
140 FORMAT (/6X,'JULIAN DAY      IRRIGATION(MM)')
150 FORMAT (2X,I3,5X,F5.0)
160 FORMAT (8X,I5,7X,F5.0)
170 FORMAT (/1X,8X,6F9.1,' TOTAL PROFILE',/)
190 FORMAT (1H0,6X,'DEPTH-CM',6X,'LOW LIM',3X,' UP LIM',3X,'SAT SW',
1  3X,'EXT SW',3X,'INIT SW',4X,'WR',/)
200 FORMAT (1H ,3X,F6.0,'-',F6.0,2X,6F9.3)
210 FORMAT (I4,34X,2F6.2,6X,2F6.2)
220 FORMAT (' SOIL DATA IS MISSING')
      END
C
C
C
C
C
C ***** OUTPUT SUBROUTINE FOR WATER BALANCE*****
C
      SUBROUTINE OUTWA
      REAL LAT,LL,LAI,LFWT,MAXLAI
      COMMON /TITL/ TITLE(20)
      COMMON /PARAM/ISOW,PLANTS,KOUTGR,KOUTWA,SDEPTH,IIRR,
1  LAT,KVARTY,KSOIL,IQUIT,NEWSOL,NEWWET,MULTYR,ISWSWB,U,
2  SOILN,ISLKJD,MATJD,XYIELD,XGRWT,XGPSM,XGPE,XLAI,XBIOM,
3  IDATE,ICDTT
      COMMON /SOILI/ SALB,SWCON,CN2,DLAYR(10),DUL(10),LL(10),SW(10),
1  SAT(10),DEPMAX,TDUL,NLAYR,SMX,WF(10),WR(10),RWU(10),SWEF
      COMMON /DATEC/ MO,ND,IYR,JDATE,JDATEX,IDIM(12)
      COMMON /WATER/ SUMES1,SUMES2,T,TLL,PESW,TSW,CUMDEP,ESW(10),
1  CSD1,CSD2,SI1(5),SI2(5),ICSDUR,ES,EP,ET,EO,CES,CEP,CET,
1  RLV(10),PRECIP,CRAIN,DRAIN,IDRSW,RTDEP,SWDF1,SWDF2,
1  SWDF3,TRWU,RWUMX,SUMIR,SWUT

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COMMON /WRITS/ AES,AEP,AET,AEO,ASOLR,ATEMX,ATEMN,ARUNOF,
1  ADRAIN,APRECP,ASWDF1,ASWDF2,IOUTGR,IOUTWA,JHEAD,KHEAD,
2  TPRECP,RUNOFF
DIMENSION AVEARG(10)
EQUIVALENCE (AVEARG(1),AES)

C
  IF (JHEAD.EQ.1) GO TO 10
  IF(KOUTWA.NE.0)WRITE(12,45)TITLE
  IF (KOUTWA.NE.0) WRITE (12,50)
  JHEAD=1
  GO TO 30
10 DAWA=FLOAT(IOUTWA)
  DO 20 I=1,7
    AVEARG(I)=AVEARG(I)/DAWA
20 CONTINUE
  CALL CALDAT
  WRITE (12,60) MO,ND,IYR,JDATE,AVEARG,SW,PESW
C   THE FOLLOWING STATEMENT CAN BE USED TO STORE SOIL
C   WATER CONTENTS IN LOGICAL UNIT 9 FOR USE IN PLOTTING
C   RESULTS IF THE COMMENT CODE IS REMOVED.
C   WRITE(9,70)JDATE,(SW(I),I=1,6)
30 DO 40 I=1,10
  AVEARG(I)=0.
40 CONTINUE
  IOUTWA=0
  RETURN
45 FORMAT (1H1,/,20X,20A4/)
50 FORMAT (1H ,9X,'JUL',2X,12('-'),' AVERAGE ',12('-'),2X,
1  '----- PERIOD -----',2X,8('-'),' SOIL WATER CONTENT ',
2  'WITH DEPTH ',9('-'),T123,'TOTAL',/,4X,'DAY',3X,'DAY',3X,'ES',
3  3X,'EP',3X,'ET',3X,'EO',2X,'SR  MAX  MIN RUNOFF',
4  ' DRAIN PREC  SW1  SW2  SW3  SW4  SW5  SW6  SW7  SW8  SW9 SW10
5  PESW')
60 FORMAT (1X,I2, '/',I2, '/',I2,I4,4F5.1,F5.0,2F5.1,F6.2,2F6.2,10(1X,
1  F4.2),3X,F7.1)
C 70 FORMAT(I3,6F6.3)
  END

C
C *****OUTPUT SUBROUTINE FOR GROWTH*****
C
SUBROUTINE OUTGR
COMMON /TITL/ TITLE(20)
REAL LAT,LL,LAI,LFWT,MAXLAI
COMMON /CLIMT/ TEMPMN,TEMPMX,RAIN,SOLRAD,TMFAC(8)
COMMON /PARAM/ISOW,PLANTS,KOUTGR,KOUTWA,SDEPTH,IIRR,
1  LAT,KVARTY,KSOIL,IQUIT,NEWSOL,NEWWET,MULTYR,ISWSWB,U,
2  SOILN,ISLKJD,MATJD,XYIELD,XGRWT,XGPSM,XGPE,XLAI,XBIOM,
3  IDATE,ICDTT
COMMON /WATER/ SUMES1,SUMES2,T,TLL,PESW,TSW,CUMDEP,ESW(10),
1  CSD1,CSD2,SI1(5),SI2(5),ICSDUR,ES,EP,ET,EO,CES,CEP,CET,
1  RLV(10),PRECIP,CRAIN,DRAIN,IDRSW,RTDEP,SWDF1,SWDF2,
1  SWDF3,TRWU,RWUMX,SUMIR,SWUT
COMMON /DATEC/ MO,ND,IYR,JDATE,JDATEX,IDIM(12)
COMMON /WRITS/ AES,AEP,AET,AEO,ASOLR,ATEMX,ATEMN,ARUNOF,

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1  ADRAIN,APRECP,ASWDF1,ASWDF2,IOUTGR,IOUTWA,JHEAD,KHEAD,
2  TPRECP,RUNOFF
COMMON /PHENL/ CUMDTT,TBASE,SUMDTT,S1,C1,ISTAGE,JJDATE,
1  DTT,IDUR,CUMPH,SSTT,CSTT,SIND,P9,TEMPM
COMMON /GROTH/ GPSM,GPP,GRORT,LAI,BIOMAS,PLA,SENLA,PTF,TLNO,
1  LFWT,SEEDRV,REGM,LN,XPLANT,RTWT,STMWT,GRNWT,SWMIN,LWMIN,
1  EARWT,EMAT,SUMP,IDURP,PLAY,PLAMX,CARBO,XN,XNTI,
1  PLAG,GROSTM,GBLA(35),SLA(35),EARS
IF (KHEAD.EQ.1) GO TO 10
IF(KOUTGR.NE.0)WRITE(13,25)TITLE
IF (KOUTGR.NE.0) WRITE (13,30)
KHEAD=1
GO TO 20
10 DAGR=FLOAT(IOUTGR)
ASWDF1=ASWDF1/DAGR
ASWDF2=ASWDF2/DAGR
CALL CALDAT
WRITE (13,40) MO,ND,IYR,JDATE,BIOMAS,LN,LAI,SUMDTT,TRWU,
1  RTWT,STMWT,GRNWT,LFWT,SENLA,ASWDF1,ASWDF2,RTDEP,PTF,
2  RLV(1),RLV(2),RLV(3),RLV(4),RLV(5),RLV(6),RLV(7),RLV(8)
C   THE FOLLOWING STATEMENT CAN BE USED TO STORE SOIL
C   WATER CONTENTS IN LOGICAL UNIT 9 FOR USE IN PLOTTING
C   RESULTS IF THE COMMENT CODE IS REMOVED.
C   WRITE (9,50) JDATE,BIOMAS,LAI,PSW,RTWT,STMWT,GRNWT,LFWT,RTDEP
20 ASWDF1=0.
ASWDF2=0.
IOUTGR=0
RETURN
25 FORMAT (1H1,/,20X,20A4//)
30 FORMAT (1H ,4X,'DATE JUL BIO LEAF LAI SUMDTT TRWU',
1  3X,'ROOT STEM GRAIN LEAF SEN SW SW ROOT ',5X,
2  'ROOT LENGTH VOLUME',/,11X,'DAY MASS NO.',16X,' ',2X,'WT',5X,
3  'WT',5X,'WT',5X,'WT',4X,' LFA DF1 DF2 DPTH PTF L1 L2',
4  2X,'L3 L4 L5 L6 L7 L8',/)
40 FORMAT (1X,I2, '/',I2, '/',I2,I4,1X,F5.0,1X,I3,1X,F5.2,1X,F5.0,
1  F5.2,4(1X,F6.2),1X,F5.0,2(1X,F3.1),1X,F4.0,F5.2,8(1X,F3.1))
C 50 FORMAT (I3,2X,F5.0,2X,F5.2,2X,F6.1,2X,F7.3,2X,3(F6.3,2X),F4.0)
END
C
C ***** SUBROUTINE TO CONVERT JULIAN DAY TO CALENDAR DATE ****
C
SUBROUTINE CALDAT
COMMON /DATEC/ MO,ND,IYR,JDATE,JDATEX,IDIM(12)
C   WRITE(*,*) 'CALDAT'
IF (JDATE.GE.JDATEX) GO TO 20
DO 10 I=1,12
IDIM(I)=31
10 CONTINUE
IDIM(4)=30
IDIM(6)=30
IDIM(9)=30
IDIM(11)=30
IDIM(2)=28
IF (MOD(IYR,4).EQ.0) IDIM(2)=29

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      IF (JDATEX.EQ.367) WRITE (12,50) JDATE
20  MO=1
      ND=31
30  IF (ND.GE.JDATE) GO TO 40
      MO=MO+1
      ND=ND+IDIM(MO)
      GO TO 30
40  ND=JDATE-ND+IDIM(MO)
      JDATEX=JDATE
      RETURN
C
50  FORMAT (/12X,'THE PROGRAM STARTED ON JULIAN DATE',2X,I3,/)
      END
C
C ***** WATER BALANCE SUBROUTINE *****
C
      SUBROUTINE WATBAL
      REAL LAT,LL,LAI,LFWT,MAXLAI
      COMMON /PARAM/ISOW,PLANTS,KOUTGR,KOUTWA,SDEPTH,IIRR,
1  LAT,KVARTY,KSOIL,IQUIT,NEWSOL,NEWWET,MULTYR,ISWSWB,U,
2  SOILN,ISLKJD,MATJD,XYIELD,XGRWT,XGPSM,XGPE,XLAI,XBIOM,
3  IDATE,ICDTT
      COMMON /SOILI/ SALB,SWCON,CN2,DLAYR(10),DUL(10),LL(10),SW(10),
1  SAT(10),DEPMAX,TDUL,NLAYR,SMX,WF(10),WR(10),RWU(10),SWEF
      COMMON /IRRIG/ NIRR,JDAY(366),AIRR(366)
      COMMON /CLIMT/ TEMPMN,TEMPMX,RAIN,SOLRAD,TMFAC(8)
      COMMON /DATEC/ MO,ND,IYR3,JDATE,JDATEX,IDIM(12)
      COMMON /WATER/ SUMES1,SUMES2,T,TLL,PESW,TSW,CUMDEP,ESW(10),
1  CSD1,CSD2,SI1(5),SI2(5),ICSDUR,ES,EP,ET,EO,CES,CEP,CET,
1  RLV(10),PRECIP,CRAIN,DRAIN,IDRSW,RTDEP,SWDF1,SWDF2,
1  SWDF3,TRWU,RWUMX,SUMIR,SWUT
      COMMON /WRITS/ AES,AEP,AET,AEO,ASOLR,ATEMX,ATEMN,ARUNOF,
1  ADRAIN,APRECP,ASWDF1,ASWDF2,IOUTGR,IOUTWA,JHEAD,KHEAD,
2  TPRECP,RUNOFF
      COMMON /PHENL/ CUMDTT,TBASE,SUMDTT,S1,C1,ISTAGE,JJDATE,
1  DTT,IDUR,CUMPH,SSTT,CSTT,SIND,P9,TEMPM
      COMMON /GROTH/ GPSM,GPP,GRORT,LAI,BIOMAS,PLA,SENLA,PTF,TLNO,
1  LFWT,SEEDRV,REGM,LN,XPLANT,RTWT,STMWT,GRNWT,SWMIN,LWMIN,
1  EARWT,EMAT,SUMP,IDURP,PLAY,PLAMX,CARBO,XN,XNTI,
1  PLAG,GROSTM,GBLA(35),SLA(35),EARS
      COMMON/CDET/CDTWT,CROOT,CFVOL,DWET(10),SURWET,TRD60,IPET,PETD,AETC
      DIMENSION RLDF(10)
C/  to account for surface evaporation when D has precipataion
      WINF=CFVOL
C\
      ICSDUR=ICSDUR+1
C *****POTENTIAL EVAPORATION ROUTINE*****
100 TD=0.60*TEMPMX+0.40*TEMPMN
      ALBEDO=SALB
      IF (ISTAGE.LT.5) ALBEDO=0.23-(0.23-SALB)*EXP(-0.75*LAI)
      EEQ=SOLRAD*(2.04E-4-1.83E-4*ALBEDO)*(TD+29.)
      EO=EEQ*1.1
      IF(TEMPMX.GT.35.)EO=EEQ*((TEMPMX-35.)*0.05+1.1)
      IF(TEMPMX.LT.5.0)EO=EEQ*0.01*EXP(0.18*(TEMPMX+20.))

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      PETD=PETD*10.
C      WRITE(17,*)'-PET- EO PETD',EO,PETD
      IF(IPET.LT.2)EO=PETD
      EOS=EO*(1.-0.43*LAI)
      IF (LAI.GT.1.)EOS=EO/1.1*EXP(-0.4*LAI)
C      *****SOIL AND PLANT EVAPORATION ROUTINE*****
      IF (SUMES1.GE.U.AND.WINF.GE.SUMES2) GO TO 110
      IF (SUMES1.GE.U.AND.WINF.LT.SUMES2) GO TO 120
      IF (WINF.GE.SUMES1) GO TO 150
      SUMES1=SUMES1-WINF
      GO TO 160
110 IF (WINF.LT.SUMES2) GO TO 120
      WINF=WINF-SUMES2
      SUMES1=U-WINF
      T=0.
      IF (WINF.GT.U) GO TO 150
      GO TO 160
120 IF(SW(1).LT.LL(1))GO TO 180
      T=T+1.
      ES=3.5*T**0.5-SUMES2
      IF (WINF.GT.0.) GO TO 130
      IF (ES.GT.EOS) ES=EOS
      GO TO 140
130 ESX=0.8*WINF
      IF (ESX.LE.ES) ESX=ES+WINF
      IF (ESX.GT.EOS) ESX=EOS
      ES=ESX
140 CONTINUE
      SUMES2=SUMES2+ES-WINF
      T=(SUMES2/3.5)**2
      GO TO 191
150 SUMES1=0.
160 SUMES1=SUMES1+EOS
      IF (SUMES1.GT.U) GO TO 170
      ES=EOS
      GO TO 191
170 ES=EOS-0.4*(SUMES1-U)
      SUMES2=0.6*(SUMES1-U)
      T=(SUMES2/3.5)**2
      GO TO 191
180 IF(ES.GT.EOS)ES=EOS
      SUMES2=SUMES2+ES-WINF
C/
C---ROUTINE TO CHECK FOR Es BY SOIL WATER CONTENT
C---SURWET IS WATER IN TOP 3 CM OF WATER
C---IF THE ES CALCULATED HERE IS GT ONE ABOVE THEN IT IS USED
191 IF (SURWET.LT. 0.32) THEN
      ESY=0.94*SURWET+.2
      ELSE
      ESY=9.4*SURWET-2.5
      END IF
      WRITE(17,53) ES,ESY,EOS
53  FORMAT(1X,'ES ESY EOS',3F7.3)
      IF (ES.LT.ESY) ES=ESY

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      IF (ES.GT.EOS) ES=EOS
C\
C&      GO TO 200
C      WRITE (17,51) (SW(I),I=1,NLAYR)
      SW(1)=SW(1)-ES*.1/DLAYR(1)
      IF(SW(1).GE.LL(1)*SWEF)GO TO 192
      ES=0.
      SW(1)=LL(1)*SWEF
192 NIND=NLAYR-1
      DO 195 L=1,NIND
      IF(L.GT.5) GOTO 200
      M=L+1
      THET1=SW(L)-LL(L)
      IF(THET1.LE.0.)THET1=0.
      THET2=SW(M)-LL(M)
      IF(THET2.LE.0.)THET2=0.
      DBAR=0.88*EXP(35.4*(THET1+THET2)*0.5)
      IF (DBAR.GT.100.) DBAR=100.
      FLOW=DBAR*(THET2-THET1)/((DLAYR(L)+DLAYR(M))*0.5)
      SW(L)=SW(L)+FLOW/DLAYR(L)
      SW(M)=SW(M)-FLOW/DLAYR(M)
195 CONTINUE
C&
200 CONTINUE
C      WRITE (17,51) (SW(I),I=1,NLAYR)
      51 FORMAT(1X,'SW',10F8.3)
      CES=CES+ES
      EP=0.
      IF (ISTAGE.GE.6) GO TO 210
      IF (LAI.LE.3.0) EP=EO*(1.-EXP(-LAI))
      IF (LAI.GT.3.0) EP=EO
C&
C      WRITE (17,*) 'EP EO ES',EP,EO,ES
      IF (EP+ES.GT.EO) EP=EO-ES
      GO TO 300
210 ET=ES
      CET=CET+ET
      TSW=0.
      DO 220 L=1,NLAYR
      TSW=TSW+SW(L)*DLAYR(L)
220 CONTINUE
      PESW=TSW-TLL
      RETURN
C      *****ROOT GROWTH AND DEPTH ROUTINE*****
300 IF (GRORT.EQ.0.) GO TO 340
      RLNEW=GRORT*0.80*PLANTS
      TRLDF=0.
      CUMDEP=0.
      DO 310 L=1,NLAYR
      L1=L
      CUMDEP=CUMDEP+DLAYR(L)
      SWDF=1.
      IF(SW(L)-LL(L).LT.0.25*ESW(L))SWDF=4.*(SW(L)-LL(L))/ESW(L)
C/

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C---CHECK FOR IF SHOULD REDUCE ROOTS GROWTH POTENTIAL DUE TO EXCESSIVE WATER
C
    RUL=.5*(SAT(L)-DUL(L))+DUL(L)
    IF ((SW(L).GT.RUL).OR.(DWET(L).GE.1.0))THEN
        IF (SW(L).LE.RUL) THEN
            DWET(L)=0.
        ELSE
            DWET(L)=DWET(L)+1.
            IF(DWET(L).GT.2.)SWDF=1+(RUL-SW(L))/(SAT(L)-RUL)
            WRITE(17,56) L,DWET(L),SWDF
56      FORMAT(1X,'DWET SWDF ',I2,2F8.3)
        END IF
    END IF
C\
    IF(SWDF.LT.0.)SWDF=0.
    RLDF(L)=SWDF*WR(L)
    IF (CUMDEP.LT.RTDEP) GO TO 310
    RTDEP=RTDEP+DTT*0.22*AMIN1(SWDF*2.0,SWDF)
    IF (RTDEP.GT.DEPMAX) RTDEP=DEPMAX
    RLDF(L)=RLDF(L)*(1.-(CUMDEP-RTDEP)/DLAYR(L))
    TRLDF=TRLDF+RLDF(L)
    GO TO 320
310  TRLDF=TRLDF+RLDF(L)
320  IF(TRLDF.LT.RLNEW*0.00001)GO TO 340
    RNLF=RLNEW/TRLDF
    TRV=0.
    CUMDEP=0.
    DO 330 L=1,L1
        RLV(L)=RLV(L)+RLDF(L)*RNLF/DLAYR(L)
C/---REDUCE OR KILL ROOTS IF BEEN WET MORE THAN 3 DAYS
    R2R=RLV(L)
    IF(DWET(L).GT.2.)RLV(L)=RLV(L)*SWDF
C      WRITE(17,57) L,R2R,RLV(L)
57    FORMAT(1X,'L RLV(L) ',I2,1X,2F10.4)
C\
    IF(RLV(L).LT.0) RLV(L)=0.
    IF(RLV(L).GT.5.0)RLV(L)=5.0
    TRV=TRV+RLV(L)
    IF(RLV(L).GT.0.000001)CUMDEP=CUMDEP+DLAYR(L)
330  CONTINUE
    IF(RTDEP.GT.CUMDEP+1.)RTDEP=CUMDEP+1.
    TRV=TRV*.9
    TR60=0.
    TRD60=0.
    I=0
335  I=I+1
    XTR60=TR60+RLV(I)
    IF(XTR60.LT.TRV) THEN
        TR60=XTR60
        TRD60=TRD60+DLAYR(I)
        GOTO 335
    ELSE
        TRD60=TRD60+((TRV-TR60)/RLV(I))*DLAYR(I)
    END IF

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```

340  CONTINUE
      IF (TRD60.LT.2.) TRD60=2.
C     ***** CALCULATE WATER UPTAKE AND SOIL DEFICIT FACTORS *****
C     WRITE (17,*) 'EP=',EP
      IF (EP.EQ.0.) GO TO 370
      EP1=EP*0.1
      TRWU=0.
      DO 350 L=1,NLAYR
      IF (RLV(L).EQ.0.0) GO TO 355
      AEEJ=62.*(SW(L)-LL(L))
      RWU(L)=2.67E-3*EXP(62.*(SW(L)-LL(L)))/(6.68-ALOG(RLV(L)))
      IF (RWU(L).GT.RWUMX) RWU(L)=RWUMX
C(sic) IF (SW(L).LT.LL(L)) RWU(L)=RWUMX
      RWU(L)=RWU(L)*DLAYR(L)*RLV(L)
      TRWU=TRWU+RWU(L)
350  CONTINUE
355  WUF=1.
      IF (EP1.LE.TRWU) WUF=EP1/TRWU
      TSW=0.
      DO 360 L=1,NLAYR
      RWU(L)=RWU(L)*WUF
      SW(L)=SW(L)-RWU(L)/DLAYR(L)
      TSW=TSW+SW(L)*DLAYR(L)
360  CONTINUE
      PESW=TSW-TLL
C&    WRITE (17,*) 'PESW IN 2595 = ', PESW
      SWDF2=1.
      IF (TRWU/EP1.LT.1.5) SWDF2=0.67*TRWU/EP1
      IF (ISTAGE.GE.2) GO TO 362
      SWDF3=0.3+35.*(SW(1)-LL(1))
      IF (SWDF3.LT.0.) SWDF3=0.
362  SWDF1=1.
      IF (EP1.LT.TRWU) GO TO 370
      SWDF1=TRWU/EP1
365  EP=TRWU*10.
370  ET=ES+EP
      CEP=CEP+EP
      CET=CET+ET
      CSD1=CSD1+1.0-SWDF1
      CSD2=CSD2+1.0-SWDF2
      RETURN
      END

C
C     ***** SUBROUTINE TO CALCULATE PHENOLOGICAL STAGE *****
C
      SUBROUTINE PHENOL (*)
      REAL LAT,LL,LAI,LFWT,MAXLAI
      COMMON /PARAM/ISOW,PLANTS,KOUTGR,KOUTWA,SDEPTH,IIRR,
1  LAT,KVARTY,KSOIL,IQUIT,NEWSOL,NEWWET,MULTYR,ISWSWB,U,
2  SOILN,ISLKJD,MATJD,XYIELD,XGRWT,XGPSM,XGPE,XLAI,XBIOM,
3  IDATE,ICDTT
      COMMON /GENET/ P1,P2,P3,P5,G2,G3
      COMMON /SOILI/ SALB,SWCON,CN2,DLAYR(10),DUL(10),LL(10),SW(10),
1  SAT(10),DEPMAX,TDUL,NLAYR,SMX,WF(10),WR(10),RWU(10),SWEF

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COMMON /DATEC/ MO,ND,IYR,JDATE,JDATEX,IDIM(12)
COMMON /CLIMT/ TEMPMN,TEMPMX,RAIN,SOLRAD,TMFAC(8)
COMMON /WATER/ SUMES1,SUMES2,T,TLL,PESW,TSW,CUMDEP,ESW(10),
1   CSD1,CSD2,SI1(5),SI2(5),ICSDUR,ES,EP,ET,EO,CES,CEP,CET,
1   RLV(10),PRECIP,CRAIN,DRAIN,IDRSW,RTDEP,SWDF1,SWDF2,
1   SWDF3,TRWU,RWUMX,SUMIR,SWUT
COMMON /WRITS/ AES,AEP,AET,AEO,ASOLR,ATEMX,ATEMN,ARUNOF,
1   ADRAIN,APRECP,ASWDF1,ASWDF2,IOUTGR,IOUTWA,JHEAD,KHEAD,
2   TPRECP,RUNOFF
COMMON /PHENL/ CUMDTT,TBASE,SUMDTT,S1,C1,ISTAGE,JJDATE,
1   DTT,IDUR,CUMPH,SSTT,CSTT,SIND,P9,TEMPM
COMMON /GROTH/ GPSM,GPP,GRORT,LAI,BIOMAS,PLA,SENLA,PTF,TLNO,
1   LFWT,SEEDRV,REGM,LN,XPLANT,RTWT,STMWT,GRNWT,SWMIN,LWMIN,
1   EARWT,EMAT,SUMP,IDURP,PLAY,PLAMX,CARBO,XN,XNTI,
1   PLAG,GROSTM,GBLA(35),SLA(35),EARS
TEMPM=(TEMPMX+TEMPMN)/2.
DTT=TEMPM-TBASE
IF (TEMPMX.GT.TBASE) GO TO 31
DTT=0.
GO TO 20
31 IF (TEMPMN.GE.TBASE) GO TO 15
TCOR=(TEMPMX-TBASE)/(TEMPMX-TEMPMN)
DTT=(TEMPMX-TBASE)/2.*TCOR
15 IF (TEMPMX.LE.34.) GO TO 20
TCOR=(TEMPMX-34.)/(TEMPMX-TEMPMN)
DTT=(26.-1.3*(TEMPMX-34.))*TCOR+(0.5*TEMPMN+17.-TBASE)*(1.-TCOR)
20 SUMDTT=SUMDTT+DTT
CUMDTT=CUMDTT+DTT
GO TO (1,2,3,4,5,6,7,8,9), ISTAGE
*****DETERMINE SOWING DATE*****
C
C
7 CALL CALDAT
WRITE (16,220)
WRITE (16,130) MO,ND,IYR,JDATE,CUMDTT
NDAS=0.
CALL PHASEI
IF (ISWSWB.EQ.0) RETURN
CUMDEP=0.
DO 30 L=1,4
CUMDEP=CUMDEP+DLAYR(L)
IF (SDEPTH.LT.CUMDEP) GO TO 40
30 CONTINUE
40 LO=L
RETURN
C *****DETERMINE GERMINATION DATE*****
8 IF (ISWSWB.EQ.0) GO TO 50
IF (SW(LO).GT.LL(LO)) GO TO 50
SWSD=(SW(LO)-LL(LO))*0.65+(SW(LO+1)-LL(LO+1))*0.35
NDAS=NDAS+1
IF(NDAS.LT.40) GO TO 45
ISTAGE=5
PLANTS=0.01
WRITE (6,100)
100 FORMAT (1X,'CROP FAILURE BECAUSE OF LACK OF GERMINATION',

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1 ' WITHIN 40 DAYS OF SOWING')
  GPP=1.
  GRNWT=0.
  RETURN
45 IF(SWSD.LT.0.02) RETURN
50 CALL CALDAT
  WRITE (16,140) MO,ND,IYR,JDATE,CUMDTT,CET,CRAIN,PESW
  CALL PHASEI
  RETURN
C *****DETERMINE SEEDLING EMERGENCE DATE*****
9 RTDEP=RTDEP+0.15*DTT
  IF (SUMDTT.LT.P9) RETURN
  CALL CALDAT
  WRITE (16,150) MO,ND,IYR,JDATE,CUMDTT,CET,CRAIN,PESW
  CALL PHASEI
  RETURN
C *****DETERMINE END OF JUVENILE STAGE*****
1 IF (SUMDTT.LT.P1) RETURN
  CALL CALDAT
  IF(ISWSWB.NE.0) CSC1=CSD1/ICSDUR
  IF(ISWSWB.NE.0) CSD2=CSD2/ICSDUR
  WRITE(16,160) MO,ND,IYR,JDATE,CUMDTT,BIOMAS,LAI,CSD1,CET,CRAIN,PESW
C IF(ISWSWB.NE.0)WRITE(8,280) IYR,JDATE,BIOMAS,LAI,CSD1,CSD2,
  CALL PHASEI
  RETURN
C *****DETERMINE DATE OF TASSEL INITIATION*****
2 DEC=0.4093*SIN(0.0172*(JDATE-82.2))
  DLV=(-S1*SIN(DEC)-0.1047)/(C1*COS(DEC))
  IF(DLV.LT.-.87) DLV=-.87
  HRLT=7.639*ACOS(DLV)
  IF (HRLT.LT.12.5) HRLT=12.5
  RATEIN=1./(4.+P2*(HRLT-12.5))
  SIND=SIND+RATEIN
  IF (SIND.LT.1.0) RETURN
  CALL CALDAT
  IF (ISWSWB.NE.0) CSD1=CSD1/ICSDUR
  IF (ISWSWB.NE.0) CSD2=CSD2/ICSDUR
  WRITE(16,360) MO,ND,IYR,JDATE,CUMDTT,BIOMAS,LAI,CSD1,CET,CRAIN,PESW
C IF(ISWSWB.NE.0)WRITE(8,280) IYR,JDATE,BIOMAS,LAI,CSD1,CSD2,
  CALL PHASEI
  RETURN
C *****DETERMINE END OF LEAF GROWTH (AND SILKING)*****
3 IF (SUMDTT.LT.P3) RETURN
  CALL CALDAT
  MAXLAI=LAI
  ISDATE=JDATE
  IF (ISWSWB.NE.0) CSD1=CSD1/ICSDUR
  IF (ISWSWB.NE.0) CSD2=CSD2/ICSDUR
  WRITE(16,380) MO,ND,IYR,JDATE,CUMDTT,TLNO,BIOMAS,LAI,CSD1,CET,CRAIN
  +,PESW
C IF(ISWSWB.NE.0)WRITE(8,280) IYR,JDATE,BIOMAS,LAI,CSD1,CSD2,
  CALL PHASEI
  RETURN
C *****DETERMINE BEGINNING OF EFFECTIVE GRAIN FILLING PERIOD*****

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4 IF (SUMDTT.LT.170.) RETURN
  CALL CALDAT
  PSKER=SUMP*1000/IDURP*3.4/5.0
  GPP=G2*(PSKER-195.0)/(1213.2+PSKER-195.0)
  IF (GPP.LT.0.0)GPP=0.0
  EARS=PLANTS
C*****DETERMINE BARRENESS*****
  IF (GPP.LT.G2*0.55)EARS=PLANTS*((GPP-50.)/(G2-50))**0.33
  IF(EARS.LT.0.0)EARS = 0.0
  GPSM=GPP*EARS
  IF (ISWSWB.NE.0) CSD1=CSD1/ICSDUR
  IF (ISWSWB.NE.0) CSD2=CSD2/ICSDUR
  WRITE(16,400) MO,ND,IYR,JDATE,CUMDTT,BIOMAS,LAI,CSD1,CET,CRAIN,PESW
C  IF(ISWSWB.NE.0)WRITE(8,280) IYR,JDATE,BIOMAS,LAI,CSD1,CSD2,
  CALL PHASEI
  RETURN
C *****DETERMINE END OF EFFECTIVE FILLING PERIOD*
5 IF (SUMDTT.LT.0.95*P5) RETURN
  CALL CALDAT
  IF (ISWSWB.NE.0) CSD1=CSD1/ICSDUR
  IF (ISWSWB.NE.0) CSD2=CSD2/ICSDUR
  WRITE(16,440) MO,ND,IYR,JDATE,CUMDTT,GPP,BIOMAS,LAI,CSD1,CET,CRAIN,
+PESW
C  IF(ISWSWB.NE.0)WRITE(8,280) IYR,JDATE,BIOMAS,LAI,CSD1,CSD2,
  CALL PHASEI
  RETURN
C *****DETERMINE PHYSIOLOGICAL MATURITY*****
6 IF (DTT.EQ.0.0)SUMDTT=P5
  IF (SUMDTT.LT.P5)RETURN
  MDATE=JDATE
  CALL CALDAT
  WRITE(16,480) MO,ND,IYR,JDATE,CUMDTT,BIOMAS,LAI
  YIELD=GRNWT*10.*EARS
  YIELD=YIELD/0.845
  SKERWT=GRNWT/GPP
  GPSM=GPP*EARS
  YIELDB=YIELD/62.8
  IF (ISLKJD.EQ.0)PLSEMS=0.0
  IF (ISLKJD.NE.0) PLSEMS=ISLKJD-ISOW
  IF(PLSEMS.LT.0)PLSEMS = 365.-ISOW + ISDATE
  PLSEPR=ISDATE-ISOW
  IF(PLSEPR.LT.0)PLSEPR=365.-ISOW + ISLKJD
  IF (MATJD.EQ.0 .OR. ISLKJD .EQ. 0) SEMTMS=0.0
  IF (MATJD.NE.0.AND.ISLKJD.NE.0)SEMTMS=MATJD-ISLKJD
  IF(SEMTMS.LT.0)SEMTMS=365. - ISDATE + MDATE
  SEMTPR=MDATE-ISDATE
  IF(SEMTPR.LT.0)SEMTPR=365. - ISLKJD + MATJD
C  WRITE(09,311) KVARTY,YIELD,XYIELD,GPP,XGPE,PLSEPR,PLSEMS,
C  2SEMTPR,SEMTMS
C311 FORMAT(I3,2X,2F7.0,2F5.0,4F5.0)
  WRITE(16,305)
306 FORMAT(/1X,' YIELD = ',F6.0,' BUSHEL/ACRE')
  WRITE(16,310) ISDATE,ISLKJD,MDATE,MATJD,YIELD,XYIELD,SKERWT,XGRWT,
1GPSM,XGPSM,GPP,XGPE,MAXLAI,XLAI,BIOMAS,XBIOM

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CALL PHASEI
RETURN

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135 FORMAT(/1X,1X,I2,'/',I2,'/',I2,1X,I3,5X,' SOWING')
130 FORMAT (1H ,1X,I2,'/',I2,'/',I2,1X,I3,1X,F5.0,2X,'SOWING',13X,'BIO
+MASS',3X,'LAI',4X,'CSD1',2X,'ET',2X,'PREC',1X,'PESW')
140 FORMAT (1H ,1X,I2,'/',I2,'/',I2,1X,I3,1X,F5.0,2X,'GERMINATION',30X
+,F4.0,1X,F4.0,1X,F4.1)
150 FORMAT (1H ,1X,I2,'/',I2,'/',I2,1X,I3,1X,F5.0,2X,'EMERGENCE',32X,F
+4.0,1X,F4.0,1X,F4.1)
160 FORMAT (1H ,1X,I2,'/',I2,'/',I2,1X,I3,1X,F5.0,2X,'END JUVENILE STA
+GE',1X,F5.0,3X,F4.2,5X,F4.2,1X,F4.0,1X,F4.0,1X,F5.1)
220 FORMAT(1H ,10X,'JUL',3X,'CUM',34X,'WATER BALANCE COMPONENTS',/,4X,
1'DAY',4X,'DAY',3X,'DTT',3X,'PHENOLOGICAL STAGE',2X,'CUMULATIVE
2 AFTER GERMINATION',/)
280 FORMAT (3X,I2,2X,I3,2X,F5.0,2X,3(F5.2,2X),5(F6.1,2X))
360 FORMAT (1H ,1X,I2,'/',I2,'/',I2,1X,I3,1X,F5.0,2X,'TASSEL INITIATIO
+N',2X,F5.0,3X,F4.2,5X,F4.2,1X,F4.0,1X,F4.0,1X,F5.1)
380 FORMAT (1H ,1X,I2,'/',I2,'/',I2,1X,I3,1X,F5.0,2X,'SILKING, LNO= ',
+F4.1,1X,F5.0,3X,F4.2,5X,F4.2,1X,F4.0,1X,F4.0,1X,F5.1)
400 FORMAT (1H ,1X,I2,'/',I2,'/',I2,1X,I3,1X,F5.0,2X,'BEGIN GRAIN FILL
+',3X,F5.0,3X,F4.2,5X,F4.2,1X,F4.0,1X,F4.0,1X,F5.1)
440 FORMAT (1H ,1X,I2,'/',I2,'/',I2,1X,I3,1X,F5.0,2X,'END FILL, GPP=',
+F4.0,1X,F5.0,3X,F4.2,5X,F4.2,1X,F4.0,1X,F4.0,1X,F5.1)
480 FORMAT(1H ,1X,I2,'/',I2,'/',I2,1X,I3,1X,F5.0,2X,'PHYSIO MATURITY',
+4X,F5.0,3X,F4.2)
305 FORMAT (1X,/,26X,'PREDICTED VALUES',5X,'MEASURED VALUES',/)
310 FORMAT (1X,'SILKING JD',20X,I3,15X,I3,/,1X,'MATURITY JD',21X,I3,
*15X,I3,/,1X,'GRAIN YIELD KG/HA (15)',5X,F7.0,11X,F7.0,/,1X,
*'KERNEL WEIGHT G (DRY)',6X,F7.4,11X,F7.4,/,1X,'FINAL GPSM',
*19X,F7.0,11X,F
*7.0,/,1X,'GRAINS/EAR',20X,F6.0,12X,F6.0,/,1X,'MAX. LAI',21X,F6.2,
*12X,F6.2,/,1X,'BIOMASS G/SM',16X,F7.0,11X,F7.0,/)
END

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***** GROWTH SUBROUTINE *****

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SUBROUTINE GROSUB
REAL LAT,LL,LAI,LFWT,MAXLAI
COMMON /CLIMT/ TEMPMN,TEMPMX,RAIN,SOLRAD,TMFAC(8)
COMMON /DATEC/ MO,ND,IYR,JDATE,JDATEX,IDIM(12)
COMMON /PARAM/ISOW,PLANTS,KOUTGR,KOUTWA,SDEPTH,IIRR,
1 LAT,KVARTY,KSOIL,IQUIT,NEWSOL,NEWWET,MULTYR,ISWSWB,U,
2 SOILN,ISLKJD,MATJD,XYIELD,XGRWT,XGPSM,XGPE,XLAI,XBIOM,
3 IDATE,ICDTT
COMMON /GENET/ P1,P2,P3,P5,G2,G3
COMMON /PHENL/ CUMDTT,TBASE,SUMDTT,S1,C1,ISTAGE,JJDATE,
1 DTT,IDUR,CUMPH,SSTT,CSTT,SIND,P9,TEMPM
COMMON /GROTH/ GPSM,GPP,GRORT,LAI,BIOMAS,PLA,SENLA,PTF,TLNO,
1 LFWT,SEEDRV,REGM,LN,XPLANT,RTWT,STMWT,GRNWT,SWMIN,LWMIN,
1 EARWT,EMAT,SUMP,IDURP,PLAY,PLAMX,CARBO,XN,XNTI,
1 PLAG,GROSTM,GBLA(35),SLA(35),EARS
COMMON /WATER/ SUMES1,SUMES2,T,TLL,PESW,TSW,CUMDEP,ESW(10),

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1    CSD1,CSD2,SI1(5),SI2(5),ICSDUR,ES,EP,ET,EO,CES,CEP,CET,
1    RLV(10),PRECIP,CRAIN,DRAIN,IDRSW,RTDEP,SWDF1,SWDF2,
1    SWDF3,TRWU,RWUMX,SUMIR,SWUT
    CLG=4.5
    PAR=0.02*SOLRAD
    PCARB=5.0*PAR/PLANTS*(1.-EXP(-0.65*LAI))
    PRFT=1.-0.0025*((0.25*TEMPMN+0.75*TEMPMX)-26.)**2
    IF (PRFT.LT.0.) PRFT=0.
    CARBO=PCARB*AMIN1(PRFT,SWDF1)
    IF(ISTAGE.GT.3) GO TO 12
    PC=1.
    IF(CUMPH.LT.5) PC=.66+0.068*CUMPH
    TI=DTT/(38.9 *PC)
    CUMPH=CUMPH + DTT/(38.9*PC)
    XN=CUMPH + 1.
    LN=XN
12  GO TO (1,2,3,4,5,6),ISTAGE
1   PLAG=CLG*XN*XN*TI*SWDF2
    IF(XN.LT.4.) PLAG=3.*XN*TI*SWDF2
    PLA=PLA+PLAG
    XLFWT=(PLA/267.)**1.25
    GROLF=XLFWT-LFWT
    GRORT=CARBO-GROLF
    IF (GRORT.GT.0.25*CARBO) GO TO 20
    GRORT=CARBO*0.25
    SEEDRV=SEEDRV+CARBO-GROLF-GRORT
    IF (SEEDRV.GT.0.) GO TO 20
    SEEDRV=0.
    GROLF=CARBO*0.75
    PLA=(LFWT+GROLF)**0.8*267.
20  LFWT=LFWT+GROLF
    SLAN=SUMDTT*PLA/10000.
    GO TO 40
2   PLAG=CLG*XN*XN*TI*SWDF2
    PLA=PLA+PLAG
    XLFWT=(PLA/267.)**1.25
    GROLF=XLFWT-LFWT
    IF (GROLF.LT.CARBO*0.75) GO TO 25
    GROLF=CARBO*0.75
    PLA=(LFWT+GROLF)**0.8*267.
25  GRORT=CARBO-GROLF
    LFWT=LFWT+GROLF
    SLAN=SUMDTT*PLA/10000.
    GO TO 40
3   IF (XN.GE.12.) GO TO 21
    PLAG = CLG * XN * XN * TI * SWDF2
    GROLF = 0.00116 * PLAG * PLA ** 0.25
    GROSTM = GROLF * 0.0182*(XN-XNTI)**2
    GO TO 24
21  IF (XN.GE.TLNO-3.) GO TO 22
    PLAG = CLG * 170. * TI * SWDF2
    GROLF = 0.00116 * PLAG * PLA ** 0.25
    GROSTM = GROLF*0.0182*(XN-XNTI)**2
    GO TO 24

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22 PLAG = 170. * CLG / ((XN + 5. - TLNO)**0.5)*TI*SWDF2
   GROLF = 0.00116 * PLAG * PLA **0.25
   GROSTM = 3.100 * CLG * TI * SWDF2
24 GRORT = CARBO - GROLF - GROSTM
   IF (GRORT.GT.0.10*CARBO) GO TO 30
   GRF=CARBO*0.90/(GROSTM+GROLF)
   GROLF=GROLF*GRF
   GROSTM=GROSTM*GRF
   GRORT=CARBO*0.10
30 PLA=(LFWT+GROLF)**0.8*267.
   LFWT=LFWT+GROLF
   SLAN=PLA/1000.
   STMWT=STMWT+GROSTM
   GO TO 40
4 GROEAR=0.22*DTT*SWDF2
   GROSTM=GROEAR*0.40
   GRORT=CARBO-GROEAR-GROSTM
   IF (GRORT.GE.0.08*CARBO) GO TO 10
   GRF=CARBO*0.92/(GROEAR+GROSTM)
   GRORT=CARBO*0.08
   GROEAR=GROEAR*GRF
   GROSTM=GROSTM*GRF
10 SLAN=PLA*(0.05+SUMDTT/170.*0.05)
   EARWT=EARWT+GROEAR
   STMWT=STMWT+GROSTM
   SUMP=SUMP+CARBO
   IDURP=IDURP+1
   GO TO 40
5 IF (PLANTS.EQ.0.01) RETURN
   SLAN=PLA*(0.1+0.80*(SUMDTT/P5)**3)
   RGFILL=0.0
   RGFILL=1.0-0.0025*(TEMPM-26)**2
   IF (RGFILL.LT.0.) RGFILL=0.
   GROGRN=RGFILL*GPP*G3*0.001
   IF (RGFILL .GT. 0.1)GO TO 300
   EMAT=EMAT+1.
   IF (EMAT .EQ. 1.) GO TO 301
   SUMDTT = P5
300 EMAT=0.
301 CONTINUE
   GRORT=0.
   GROSTM=CARBO-GROGRN
   IF (GROSTM.LT.0.) GO TO 33
   STMWT=STMWT+GROSTM*0.5
   GRORT=GROSTM*0.5
   IF (SUMDTT/P5.LT.0.08) GPP=GPP*(1.+0.004*GRORT)
   GO TO 35
33 STMWT=STMWT+CARBO-GROGRN
   IF (STMWT.GT.SWMIN*1.07) GO TO 35
   IF (LFWT.LE.LWMIN) GO TO 34
   STMWT=STMWT+LFWT*0.0050
   LFWT=LFWT*0.9950
34 IF (STMWT.GE.SWMIN) GO TO 35
   STMWT=SWMIN

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      GROGRN=CARBO
35  GRNWT=GRNWT+GROGRN
      EARWT=EARWT+GROGRN
40  SLFW=0.95+0.05*SWDF1
      SLFC=1.0
      IF(LAI.GT.4.)SLFC=1.-0.008*(LAI-4.)
      SLFT=1.
      IF(TEMPMN.GT.0.)GO TO 50
      SLFT=1.-0.0015*(TEMPMN+TEMPM+20.)**2
      IF(SLFT.LT.0.)SLFT=0.
50  PLAS=(PLA-SENLA)*(1.0-AMIN1(SLFW,SLFC,SLFT))
      SENLA=SENLA+PLAS
      IF(SENLA.LT.SLAN)SENLA=SLAN
      IF(SENLA.GE.PLA)SENLA=PLA
      LAI=(PLA-SENLA)*PLANTS*0.0001
      RTWT=RTWT+0.5*GRORT-0.005*RTWT
      BIOMAS=(LFWT+STMWT+EARWT)*PLANTS
      PTF=(LFWT+STMWT+EARWT)/(RTWT+LFWT+STMWT+EARWT)
6   RETURN
      END

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C
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***** WRITE SUBROUTINE *****

SUBROUTINE WRYTE

COMMON /PARAM/ISOW,PLANTS,KOUTGR,KOUTWA,SDEPTH,IIRR,

1 LAT,KVARTY,KSOIL,IQUIT,NEWSOL,NEWWET,MULTYR,ISWSWB,U,

2 SOILN,ISLKJD,MATJD,XYIELD,XGRWT,XGPSM,XGPE,XLAI,XBIOM,

3 IDATE,ICDTT

COMMON /CLIMT/ TEMPMN,TEMPMX,RAIN,SOLRAD,TMFAC(8)

COMMON /WRITS/ AES,AEP,AET,AEO,ASOLR,ATEMX,ATEMN,ARUNOF,

1 ADRAIN,APRECP,ASWDF1,ASWDF2,IOUTGR,IOUTWA,JHEAD,KHEAD,

2 TPREC, RUNOFF

COMMON /WATER/ SUMES1,SUMES2,T,TLL,PESW,TSW,CUMDEP,ESW(10),

1 CSD1,CSD2,SI1(5),SI2(5),ICSDUR,ES,EP,ET,EO,CES,CEP,CET,

1 RLV(10),PRECIP,CRAIN,DRAIN,IDRSW,RTDEP,SWDF1,SWDF2,

1 SWDF3,TRWU,RWUMX,SUMIR,SWUT

COMMON /PHENL/ CUMDTT,TBASE,SUMDTT,S1,C1,ISTAGE,JJDATE,

1 DTT,IDUR,CUMPH,SSTT,CSTT,SIND,P9,TEMPM

COMMON /GROTH/ GPSM,GPP,GRORT,LAI,BIOMAS,PLA,SENLA,PTF,TLNO,

1 LFWT,SEEDRV,REGM,LN,XPLANT,RTWT,STMWT,GRNWT,SWMIN,LWMIN,

1 EARWT,EMAT,SUMP,IDURP,PLAY,PLAMX,CARBO,XN,XNTI,

1 PLAG,GROSTM,GBLA(35),SLA(35),EARS

CRAIN=CRAIN+PRECIP

IF (KOUTWA.EQ.0) GO TO 10

IOUTWA=IOUTWA+1

AES=AES+ES

AEP=AEP+EP

AET=AET+ET

AEO=AEO+EO

ASOLR=ASOLR+SOLRAD

ATEMX=ATEMX+TEMPMX

ATEMN=ATEMN+TEMPMN

IF (IOUTWA.EQ.KOUTWA) CALL OUTWA

```

10 IF (KOUTGR.EQ.0) RETURN
   IF (ISTAGE.GT.6) RETURN
   IOUTGR=IOUTGR+1
   ASWDF1=ASWDF1+SWDF1
   ASWDF2=ASWDF2+SWDF2
   IF (IOUTGR.EQ.KOUTGR) CALL OUTGR
   RETURN
   END

```

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***** PHASE INITIALIZATION SUBROUTINE *****

```

SUBROUTINE PHASEI
  REAL LAT,LL,LAI,LFWT,MAXLAI
  COMMON /PARAM/ISOW,PLANTS,KOUTGR,KOUTWA,SDEPTH,IIRR,
1  LAT,KVARTY,KSOIL,IQUIT,NEWSOL,NEWWET,MULTYR,ISWSWB,U,
2  SOILN,ISLKJD,MATJD,XYIELD,XGRWT,XGPSM,XGPE,XLAI,XBIOM,
3  IDATE,ICDTT
  COMMON /SOILI/ SALB,SWCON,CN2,DLAYR(10),DUL(10),LL(10),SW(10),
1  SAT(10),DEPMAX,TDUL,NLAYR,SMX,WF(10),WR(10),RWU(10),SWEF
  COMMON /WATER/ SUMES1,SUMES2,T,TLL,PESW,TSW,CUMDEP,ESW(10),
1  CSD1,CSD2,SI1(5),SI2(5),ICSDUR,ES,EP,ET,EO,CES,CEP,CET,
1  RLV(10),PRECIP,CRAIN,DRAIN,IDRSW,RTDEP,SWDF1,SWDF2,
1  SWDF3,TRWU,RWUMX,SUMIR,SWUT
  COMMON /PHENL/ CUMDTT,TBASE,SUMDTT,S1,C1,ISTAGE,JJDATE,
1  DTT,IDUR,CUMPH,SSTT,CSTT,SIND,P9,TEMPM
  COMMON /GROTH/ GPSM,GPP,GRORT,LAI,BIOMAS,PLA,SENLA,PTF,TLNO,
1  LFWT,SEEDRV,REGM,LN,XPLANT,RTWT,STMWT,GRNWT,SWMIN,LWMIN,
1  EARWT,EMAT,SUMP,IDURP,PLAY,PLAMX,CARBO,XN,XNTI,
1  PLAG,GROSTM,GBLA(35),SLA(35),EARS
  COMMON /GENET/ P1,P2,P3,P5,G2,G3
  IF (ISTAGE.GT.5) GO TO 32
  SI1(ISTAGE)=CSD1
  SI2(ISTAGE)=CSD2
  CSD1=0.
  CSD2=0.
  ICSDUR=0
32 GO TO (1,2,3,4,5,6,7,8,9), ISTAGE
1  ISTAGE=2
  SIND=0.
  RETURN
2  ISTAGE=3
  TLNO=IFIX(CUMDTT/21.+6.0)
  P3=(TLNO - 2.)*38.9+96.-SUMDTT
  XNTI=XN
  SUMDTT=0.
  RETURN
3  ISTAGE=4
  EARWT=0.167*STMWT
  STMWT=STMWT-EARWT
  SWMIN=STMWT*.8
  PTF=1.0
  SUMP=0
  IDURP=0
  SUMDTT=SUMDTT-P3

```

```

    PLAMX=PLA
    RETURN
4  ISTATE=5
    LWMIN=LFWT*0.85
    EMAT=0
    RETURN
5  ISTATE=6
    RETURN
6  ISTATE=7
    CUMDTT=0.
    CRAIN=0.
    CES=0.
    CEP=0.
    CET=0.
    DTT=0.
    RETURN
7  ISTATE=8
    RTDEP=SDEPTH
    SUMDTT=0.
    RETURN
8  ISTATE=9
    CET=0.
    P9=15.+6.*SDEPTH
    CES=0.
    CEP=0.
    CUMDTT=0.
    CRAIN=0.
    SUMDTT=0.
    TBASE=10.
    RETURN
9  ISTATE=1
    P3=400.
    SUMDTT=SUMDTT-P9
    CUMDTT=CUMDTT-P9
    PLA=1.0
    PLAY=1.0
    PLAG=0.0
    LAI=PLANTS*PLA*0.0001
    LFWT=0.20
    SEEDRV=0.20
    DO 90 I =1,35
    SLA(I)=0.0
    GBLA(I)=0.0
90  CONTINUE
    STMWT=0.
    GROSTM=0.
    GRNWT=0.
    EARWT=0.
    SENLA=0.
    GRORT=0.
    RTWT=LFWT
    BIOMAS=0.
    REGM=1.
    IDUR=0

```

```

CUMPH=.514
TLNO=30.
CSD1=0.0
CSD2=0.0
TBASE=8.0
CUMDEP=0.
LN=1
IF (ISWSWB.EQ.0) RETURN
DO 100 L=1,NLAYR
    CUMDEP=CUMDEP+DLAYR(L)
    RLV(L)=0.20*PLANTS/DLAYR(L)
    IF (CUMDEP.GT.RTDEP) GO TO 110
100 CONTINUE
110 RLV(L)=RLV(L)*(1.-(CUMDEP-RTDEP)/DLAYR(L))
    L1=L+1
    IF (L1.GE.NLAYR) GO TO 121
    DO 120 L=L1,NLAYR
        RLV(L)=0.
120 CONTINUE
121 DO 130 L=1,NLAYR
130 RWU(L)=0.
    RETURN
    END

```

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*****NEW SUBROUTINE FOR SEMINAR*****

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SUBROUTINE PARMFLS
REAL LAI
COMMON /PARAM/ISOW,PLANTS,KOUTGR,KOUTWA,SDEPTH,IIRR,
1 LAT,KVARTY,KSOIL,IQUIT,NEWSOL,NEWWET,MULTYR,ISWSWB,U,
2 SOILN,ISLKJD,MATJD,XYIELD,XGRWT,XGPSM,XGPE,XLAI,XBIOM,
3 IDATE,ICDTT
COMMON /FILE/SWATER,CIRRIG,WEATHER,CGENET,MISOIL,WATCORN,BIOCORN
CHARACTER ASW
CHARACTER*12 BIOCORN
CHARACTER*12 CIRRIG
CHARACTER*12 SWATER
CHARACTER*12 CGENET
CHARACTER*12 WATCORN
CHARACTER*12 MISOIL
CHARACTER*12 WEATHER
REAL LAT
OPEN(100,FILE='PARM',ACCESS='SEQUENTIAL',STATUS='OLD')
READ(100,510) WEATHER,CGENET,MISOIL,ASW,CIRRIG,SWATER,KVARTY,
1 KSOIL,ISOW,SDEPTH,LAT,PLANTS,KOUT,ISLKJD,MATJD,XYIELD,XGRWT
READ(100,520) XGPSM,XGPE,XLAI,XBIOM,SOILN,BIOCORN,WATCORN
90 CONTINUE
WRITE(*,100)
100 FORMAT(1H1,' PLEASE CHOSE THE PARAMETER YOU WISH TO CHANGE.')
WRITE(*,110)
110 FORMAT(1X,' ENTER ZERO (0) IF NONE.')
WRITE(*,120) WEATHER,KOUT

```

```

120 FORMAT(//1X,' 1. WEATHER FILE = ',A12,7X,' 13. FREQUENCY OF OUTPU
    1T = ',I2)
    WRITE(*,130) CGENET,ISLKJD
130 FORMAT(1X,' 2. GENETICS FILE = ',A12,6X,' 14. DATE OF SILKING =
    1',I3)
    WRITE(*,140) MISOIL,MATJD
140 FORMAT(1X,' 3. SOILS FILE = ',A12,9X,' 15. DATE OF MATURITY = ',
    1I3)
    WRITE(*,150) ASW,XYIELD
150 FORMAT(1X,' 4. IRRIGATION DATA (Y/N) = ',A1,9X,' 16. GRAIN YIELD
    1 (KG/HA) = ',F6.0)
    WRITE(*,160) CIRRIIG,XGPSM
160 FORMAT(1X,' 5. IRRIGATION FILE = ',A12,4X,' 17. NUMBER OF GRAINS/
    1M**2 = ',F6.0)
    WRITE(*,170) SWATER,XGPE
170 FORMAT(1X,' 6. INITIAL SW FILE = ',A12,4X,' 18. NUMBER OF GRAINS/
    1EAR = ',F4.0)
    WRITE(*,180) KVARTY,XLAI
180 FORMAT(1X,' 7. THE CROP VARIETY NUMBER = ',I3,5X,' 19. MAXIMUM LA
    1I = ',F4.1)
    WRITE(*,190) KSOIL,XBIOM
190 FORMAT(1X,' 8. THE SOIL NUMBER = ',I3,13X,' 20. BIOMASS (GRAMS/M*
    1*2) = ',F5.0)
    WRITE(*,200) ISOW,SOILN
200 FORMAT(1X,' 9. THE SOWING DATE = ',I3,13X,' 21. SOILN = ',F3.1)
    WRITE(*,210) SDEPTH,BIOCORN
210 FORMAT(1X,' 10. THE SOWING DEPTH = ',F3.1,11X,' 22. BIOMASS OUTPU
    1T FILE = ',A12)
    WRITE(*,220) LAT,WATCORN
220 FORMAT(1X,' 11. THE LATITUDE = ',F4.1,14X,' 23. WATER OUPUT FILE
    1= ',A12)
    WRITE(*,230) PLANTS,XGRWT
230 FORMAT(1X,' 12. PLANTS/M**2 = ',F4.1,15X,' 24. GRAIN WEIGHT (DRY)
    1 = ',F4.2)
    WRITE(*,232)
232 FORMAT(1X,' ')
    WRITE(*,233)
233 FORMAT(1X,' ')
    WRITE(*,234)
234 FORMAT(///1X,' ')
    READ(*,240) ICHOSE
240 FORMAT( I2)
    IF(ICHOSE.LT.0.OR.ICHOSE.GT.24) GOTO 490
    IF(ICHOSE.LT.1) GOTO 500
    IF(ICHOSE.LT.2) GOTO 250
    IF(ICHOSE.LT.3) GOTO 260
    IF(ICHOSE.LT.4) GOTO 270
    IF(ICHOSE.LT.5) GOTO 280
    IF(ICHOSE.LT.6) GOTO 290
    IF(ICHOSE.LT.7) GOTO 300
    IF(ICHOSE.LT.8) GOTO 310
    IF(ICHOSE.LT.9) GOTO 320
    IF(ICHOSE.LT.10) GOTO 330
    IF(ICHOSE.LT.11) GOTO 340

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```

IF(ICHOSE.LT.12) GOTO 350
IF(ICHOSE.LT.13) GOTO 360
IF(ICHOSE.LT.14) GOTO 370
IF(ICHOSE.LT.15) GOTO 380
IF(ICHOSE.LT.16) GOTO 390
IF(ICHOSE.LT.17) GOTO 400
IF(ICHOSE.LT.18) GOTO 410
IF(ICHOSE.LT.19) GOTO 420
IF(ICHOSE.LT.20) GOTO 430
IF(ICHOSE.LT.21) GOTO 440
IF(ICHOSE.LT.22) GOTO 450
IF(ICHOSE.LT.23) GOTO 460
IF(ICHOSE.LT.24) GOTO 470
IF(ICHOSE.LT.25) GOTO 480
250 WRITE(*,251)
251 FORMAT(/IX,' PLEASE ENTER CORRECT WEATHER FILE NAME.')
    READ(*,'(A)') WEATHER
    GOTO 90
260 WRITE(*,261)
261 FORMAT(/IX,' PLEASE ENTER CORRECT GENETICS FILE NAME.')
    READ(*,'(A)') CGENET
    GOTO 90
270 WRITE(*,271)
271 FORMAT(/IX,' PLEASE ENTER CORRECT SOIL FILE NAME.')
    READ(*,'(A)') MISOIL
    GOTO 90
280 IF(ASW.EQ.'N') GOTO 281
    ASW='N'
    GOTO 90
281 ASW='Y'
    GOTO 90
290 WRITE(*,291)
291 FORMAT(/IX,' PLEASE ENTER CORRECT IRRIGATION FILE NAME.')
    READ(*,'(A)') CIRRIIG
    GOTO 90
300 WRITE(*,301)
301 FORMAT(/IX,' PLEASE ENTER CORRECT INITIAL SOIL WATER FILE NAME.')
    READ(*,'(A)') SWATER
    GOTO 90
310 WRITE(*,311)
311 FORMAT(/IX,' PLEASE ENTER CORRECT CROP VARIETY NUMBER (000).')
    READ(*,312) KVARTY
312 FORMAT( I3)
    GOTO 90
320 WRITE(*,321)
321 FORMAT(/IX,' PLEASE ENTER CORRECT SOIL NUMBER (000).')
    READ(*,322) KSOIL
322 FORMAT( I3)
    GOTO 90
330 WRITE(*,331)
331 FORMAT(/IX,' PLEASE ENTER CORRECT SOWING DATE (000).')
    READ(*,332) ISOW
332 FORMAT( I3)
    GOTO 90

```



```

340 WRITE(*,341)
341 FORMAT(/1X,' PLEASE ENTER CORRECT SOWING DEPTH (0.0) CM.')
```

 READ(*,342) SDEPTH

```

342 FORMAT( F3.1)
GOTO 90
```

```

350 WRITE(*,351)
351 FORMAT(/1X,' PLEASE ENTER CORRECT LATITUDE (00.0).')
```

 READ(*,352) LAT

```

352 FORMAT( F4.1)
GOTO 90
```

```

360 WRITE(*,361)
361 FORMAT(/1X,' PLEASE ENTER THE CORRECT NUMBER OF PLANTS/M**2 (00.0
1).')
```

 READ(*,362) PLANTS

```

362 FORMAT( F4.1)
GOTO 90
```

```

370 WRITE(*,371)
371 FORMAT(/1X,' PLEASE ENTER THE CORRECT FREQUENCY OF DAYS FOR OUTPUT
1 (00).')
```

 READ(*,372) KOUT

```

372 FORMAT( I2)
GOTO 90
```

```

380 WRITE(*,381)
381 FORMAT(/1X,' PLEASE ENTER THE CORRECT DATE OF SILKING (000).')
```

 READ(*,382) ISLKJD

```

382 FORMAT( I3)
GOTO 90
```

```

390 WRITE(*,391)
391 FORMAT(/1X,' PLEASE ENTER THE CORRECT DATE OF MATURITY (000).')
```

 READ(*,392) MATJD

```

392 FORMAT( I3)
GOTO 90
```

```

400 WRITE(*,401)
401 FORMAT(/1X,' PLEASE ENTER THE CORRECT YIELD (00000.).')
```

 READ(*,402) XYIELD

```

402 FORMAT( F6.0)
GOTO 90
```

```

410 WRITE(*,411)
411 FORMAT(/1X,' PLEASE ENTER THE CORRECT GRAINS/M**2 (00000.).')
```

 READ(*,412) XGPSM

```

412 FORMAT( F6.0)
GOTO 90
```

```

420 WRITE(*,421)
421 FORMAT(/1X,' PLEASE ENTER THE CORRECT GRAINS/EAR (000.).')
```

 READ(*,422) XGPE

```

422 FORMAT( F4.0)
GOTO 90
```

```

430 WRITE(*,431)
431 FORMAT(/1X,' PLEASE ENTER THE CORRECT MAXIMUM LAI (00.0).')
```

 READ(*,432) XLAI

```

432 FORMAT( F4.1)
GOTO 90
```

```

440 WRITE(*,441)
441 FORMAT(/1X,' PLEASE ENTER THE CORRECT BIOMASS (GRAMS/M**2 - 0000.)
```

```

1.')
  READ(*,442) XBIOM
442 FORMAT( F5.0)
  GOTO 90
450 WRITE(*,451)
451 FORMAT(/1X,' PLEASE ENTER THE CORRECT VALUE FOR SOILN (0.0).')
  READ(*,452) SOILN
452 FORMAT( F3.1)
  GOTO 90
460 WRITE(*,461)
461 FORMAT(/1X,' PLEASE ENTER THE CORRECT BIOMASS OUTPUT FILE NAME.')
  READ(*,'(A)') BIOCORN
  GOTO 90
470 WRITE(*,471)
471 FORMAT(/1X,' PLEASE ENTER THE CORRECT WATER BALANCE OUTPUT FILE NA
1ME.')
  READ(*,'(A)') WATCORN
  GOTO 90
480 WRITE(*,481)
481 FORMAT(/1X,' PLEASE ENTER THE CORRECT GRAIN WEIGHT (GRAMS - 0.00).
1')
  READ(*,482) XGRWT
482 FORMAT( F4.2)
  GOTO 90
490 WRITE(*,495)
495 FORMAT(1X,' PLEASE CHOOSE A NUMBER BETWEEN 0 AND 23. ')
  GOTO 90
500 CLOSE(100)
  OPEN(100,FILE='PARM',ACCESS='SEQUENTIAL',STATUS='OLD')
  WRITE(100,510) WEATHER,CGENET,MISOIL,ASW,CIRRIG,SWATER,KVARTY,
1 KSOIL,ISOW,SDEPTH,LAT,PLANTS,KOUT,ISLKJD,MATJD,XYIELD,XGRWT
  WRITE(100,520) XGPSM,XGPE,XLAI,XBIOM,SOILN,BIOCORN,WATCORN
510 FORMAT(A12,A12,A12,A1,A12,A12,3I3,F3.1,2F4.1,I2,2I3,F6.0,F4.2)
520 FORMAT(F6.0,F4.0,F4.1,F5.0,F3.1,A12,A12)
  CLOSE(100)
  KOUTWA=KOUT
  KOUTGR=KOUT
  IF(ASW.EQ.'Y') IIRR=5
  IF(ASW.EQ.'N') IIRR=0
  RETURN
END

C
C
C
C
C SUBROUTINE CDMOD
C
C SUBROUTINE TO CONTROL SWITCHING BETWEEN DRAINMOD AND CERES
C
COMMON/CDNO/LOPC,MFLAG,LOPE,IQUIT3,JDATE3,JDAY3
COMMON/DATEC/MO,ND,IYR3,JDATE,JDATEX,IDIM(12)
DIMENSION HOURLY(744),ET(31),FACTOR(12)
10 IF (MFLAG .NE. 0) GO TO 20
CALL DRAINOD(IYR3,MO3,ET,HOURLY,LOOP,IYED,FACTOR,NOPORT)
C

```

```

20  CALL FORSUB(IYR3,MO3,ET,HOURLY,LOOP,IYED,FACTOR,NOPORT)
    LOPC=LOPC+1
    IF (JDAY3.LT.JDATE3) GOTO 10
    IF((IQUIT3.GT.1).AND.(LOPE.LT.1)) GO TO 10
    IF((LOPE.GT.1).AND.(MFLAG .NE. 0))GO TO 20
    IF(IQUIT3.GT.1) CALL PROGRI
    IF(IQUIT3.LT.-1) RETURN
    CALL WET
    RETURN
    END
    SUBROUTINE WET

C
C  SUBROUTINE TO INTEGRATE BETWEEN DRAINMOD'S WATER TABLE AND CERES
C  SOIL WATER CONTENT BY LAYERS
C
    COMMON/WHX/WATER(1000),W(101),H(101),X(101),NN,UPVOL,WETZ,WP
    COMMON/SOILI/ SALB,SWCON,CN2,DLAYR(10),DUL(10),LL(10),SW(10),
1  SAT(10),DEPMAX,TDUL,NLAYR,SMX,WF(10),WR(10),RWU(10),SWEF
    COMMON/CDT/CDTWT,CROOT,CFVOL,DWET(10),SURWET,TRD60,IPET,PETD,AETC
    COMMON/DATEC/MO,ND,IYR3,JDATE,JDATEX,IDIM(12)
    COMMON/EVAPO/PET,DDZ,ROOTD
    DIMENSION LK(10)
    WRITE(17,131) UPVOL,WETZ,DDZ,CDTWT
131  FORMAT(1X, 'UPVOL WETZ DDZ CDTWT',4F10.3)
    IF(NN.GT.10) THEN
        NN=1
        FIND DEPTH TO BOTTOM OF EACH LAYER DEFINED BY CERES
        LK(1)=DLAYR(1)+1
        DO 7 I=2,NLAYR
            LK(I)=LK(I-1)+DLAYR(I)
        7  CONTINUE
        IDEEP=LK(NLAYR)
        END IF

C
C  FIND WATER CONTENT IN SOIL PROFILE FOR EACH LAYER DEFINED BY CERES
C
        IDZ=DDZ+1
        CAN MAKE UP =UPVOL/DDZ
        UP=UPVOL/DDZ
        SURWET=0.
        IWETZ=WETZ+1
        IWT=CDTWT+1
        J=1
        SMSW=0.
        IF(IDZ.LT.3) GO TO 12

C
C  DRY ZONE
C
        DO 11 I=2,IDZ
            IF(I.LE.LK(J)) THEN
                SMSW=SMSW+WP+UP
                IF(I.LT.5)SURWET=SURWET+WP
            ELSE

```

```

        SW(J)=SMSW/DLAYR(J)
        SMSW=WP+UP
        J=J+1
        IF(J.GT.NLAYR) GO TO 17
    END IF
11 CONTINUE
12 CONTINUE
C
C   WET ZONE
C
    DO 13 I=IDDZ+1,IWT
        K=IWT-I+1
        IF(I.LE.LK(J)) THEN
            SMSW=SMSW+(WATER(K)+WATER(K+1))/2.
            IF(I.LT.5)SURWET=SURWET+(WATER(K)+WATER(K+1))/2.
        ELSE
            SW(J)=SMSW/DLAYR(J)
            SMSW=WATER(K)
            J=J+1
            IF(J.GT.NLAYR) GO TO 17
        END IF
13 CONTINUE
C
C   SAT ZONE
C
    DO 15 I=IWT+1,IDEEP
        IF(I.LE.LK(J)) THEN
            SMSW=SMSW+WATER(1)
            IF(I.LT.5)SURWET=SURWET+WATER(1)
        ELSE
            SW(J)=SMSW/DLAYR(J)
            SMSW=WATER(1)
            J=J+1
            IF(J.GT.NLAYR) GO TO 17
        END IF
15 CONTINUE
17 SW(J)=SMSW/DLAYR(J)
C
C   DO 19 I=1,NLAYR
C   IF(SW(I).GT.SAT(I)) SW(I)=SAT(I)
19 CONTINUE
C
C   SURWET IS FOR CALCULATING ES BY SOIL WATER CONTENT IN TOP 3 CM
C
        SURWET=SURWET/3.0
C
C   FOLLOWING FOR GRAPHING
C
        WRITE(11,70)JDATE,CDTWT,(SW(I),I=1,NLAYR)
70  FORMAT(I3,1X,10F7.3)
        RETURN
    END
C
C

```

```

SUBROUTINE DRAINOD(KYR,KMO,ET,HOURLY,LOOP,IIYED,FACTOR,NOPORT)
CC
CC VERSION: NORTH CAROLINA 2A
C   MODIFIED FOR PC FORTRAN AND MODIFIED WEATHER DATA FILES
C   BY PHIL BRINK AND OTHERS
CC LANGUAGE: FORTRAN (COMPILERS -66,-G,-H, OR -77)
CC
CC THIS MODEL REQUIRES FIVE READ/WRITE FILES:
CC
CC          LUN    R/W    DESCRIPTION
CC          1      R      FIELD DATA (DESCRIBED IN USER'S MANUAL)
CC          9      R      HOURLY RAINFALL (IN.)
CC          7      R      DAILY MIN/MAX TEMPERATURES (FAHREN.)
CC          3      W      DAILY/MONTHLY/YEARLY OUTPUTS
CC          10     W      A PRINTOUT OF FIELD DATA FILE #1
C *****
C   THIS MAIN PROGRAM READS HOURLY PRECIP AND DAILY MAX AND MIN
C   TEMPERATURES FROM EITHER CARDS OR DISK (I/O UNIT 9), DETERMINES PET
C   USING THORNTWHAITE METHOD, AND TRANSFERS HOURLY PRECIP AND DAILY
C   PET VALUES BY MONTH TO THE SUBROUTINE FORSUB.
C
COMMON/NAMES/ TITLE1(20),TITLE2(20)
COMMON/CDNO/LOPC,MFLAG,LOPE,IQUIT3,JDATE3,JDAY3
DIMENSION E(241),TMAX(31),TMIN(31)
DIMENSION FACTOR(12)
DIMENSION HOURLY(744),ET(31),SET(12),IDAYBG(12),REL(366)
INTEGER TMAX,TMIN,TITLE1,TITLE2
DIMENSION IDAAY(10),IHOUR(10),AMT(10)
DATA SET/.03,.05,.08,.11,.14,.17,.16,.14,.11,.08,.04,.02/
DATA IDAYBG/0,31,60,91,121,152,182,213,244,274,305,335/

C
C   IIYED=0
C   WRITE (*,*) 'DRAINMOD'
C   IF(LOPC.GT.1) GO TO 5
C   LOOP=0
C   LOPE=0

C
C   WRITE (*,*) 'ENTER NAME OF RUN FILE? '
C   READ (*,100) FDN
C   WRITE (*,*) 'FDN=' ,FDN
C   OPEN (1,FILE='TST4',ACCESS='SEQUENTIAL',STATUS='OLD')
C   READ (1,100) FIELD,RAIN,TEMP,OUTDAT,ECHODAT
C   CLOSE (1)
C   OPEN (1,FILE='FDNDAT',STATUS='OLD')
C   OPEN (9,FILE='RAIN',STATUS='OLD')
C   OPEN (7,FILE='TEMP',STATUS='OLD')
C   OPEN (3,FILE='OUTDAT',STATUS='OLD')
C   OPEN (10,FILE='ECHODAT',STATUS='OLD')
C   OPEN (11,FILE='DAILYW',STATUS='OLD')
C 100 FORMAT(A)
C
C   REWIND 1
C   REWIND 9

```

```

REWIND 7
READ(1,610) TITLE1,TITLE2
WRITE(10,610) TITLE1,TITLE2
WRITE(3,619)
WRITE(3,620) TITLE1,TITLE2
READ(1,611) NOPORT
WRITE(10,611) NOPORT
IF((NOPORT.LT.1).OR.(NOPORT.GT.3)) NOPORT=3
READ(1,600) IRID,ITID,IYST,IMST,IIYED,IMED,LAT,HIDX
WRITE(10,600) IRID,ITID,IYST,IMST,IIYED,IMED,LAT,HIDX
READ(1,630) (FACTOR(K),K=1,12)
WRITE(10,630) (FACTOR(K),K=1,12)
I = LAT/100
J = LAT-I*100
WRITE(3,640) IRID,ITID,IYST,IMST,IIYED,IMED,I,J,HIDX
WRITE(3,645) (FACTOR(K),K=1,12)
XLAT1 = FLOAT(I)
XLAT2 = FLOAT(J)
C-----
C  START OF THORNTHWAITE INITIALCALCULATION
C  REL(1-366) ACCOUNTS FOR EVERYDAY IN A YEAR
C
  RLAT=0.0174533*XLAT1+0.0002909*XLAT2
  SINLAT=SIN(RLAT)
  COSLAT=COS(RLAT)
  DO 50 ND=1,366
    XND=ND
    XM=0.0172264*(-6.E-1+XND)
    XLAM=4.874239+XM+0.0334762*SIN(XM)+0.0003502*SIN(XM+XM)
    YD=0.397900*SIN(XLAM)
    XD=SQRT(1.-YD*YD)
    D=ATAN2(YD,XD)
    XD=(-0.014544-(SINLAT*SIN(D)))/(COSLAT*COS(D))
    YD=SQRT(1.-XD*XD)
    REL(ND)= 0.0111111*ATAN2(YD,XD)*57.29578
50  CONTINUE
C
C  E(1-241) ACCOUNTS FOR DAILY TEMPERATURE VARIATION
C
  Y = ALOG(HIDX)
  F = 49239.E-5 + HIDX*(1792.E-5 + HIDX*(-771.E-7 + HIDX *
1    675.E-9))
  DO 60 NT =1,124
    XNT = NT
    X = -3863357.E-6 + F * (1021651.E-6 + ALOG(XNT) - Y)
    ETEMP = EXP(X)
    E(NT+65) = 24.E-2
    IF (ETEMP.LT.24.E-2) E(NT+65) = ETEMP
60  CONTINUE
  DO 70 I = 1,65
    E(I)=0.0
70  CONTINUE
  DO 80 I = 190,241
    E(I)=24.E-2

```

```

      80 CONTINUE
C
C      END OF THORNTWHAITE INITIAL CALCULATION
C-----
C      POSITION WEATHER FILES
C
C----RAIN FILE
C
C      3 READ (9,*,END=300) IYEAR,MONTH1
C&
C      WRITE(*,*) 'RAIN',IYEAR,MONTH1
C      IF (IYEAR .GT. IYST) IYST=IYEAR
C      IF (IYEAR .EQ. IYST) GO TO 4
C      GOTO 3
C
C----TEMP FILE
C
C      4 READ (7,*,END=310) IYEAR,MONTH2
C&
C      WRITE(*,*) 'TEMP', IYEAR,MONTH2
C      IF (IYEAR .GT. IYST) THEN
C      IYST=IYEAR
C      REWIND 7
C      GOTO 3
C      END IF
C      IF (IYEAR .LT. IYST) GO TO 4
C      IF (MONTH2 .NE. MONTH1) GO TO 4
C
C      KYR=IYEAR
C      IYRST=IYEAR
C      KMO=MONTH1
C      GO TO 10
C
C
C+++++
C LOOP BEGINS HERE, READ IN WEATHER DATA ONE MONTH AT A TIME
C
C      5 READ( 9, *, END= 20 ) KYR, KMO
C      10 CONTINUE
C      DO 11 I = 1, 744
C      HOURLY(I) = 0.0
C      11 CONTINUE
C      12 READ( 9, 520 ) (IDAAAY(I),IHOUR(I),AMT(I), I=1, 7 )
C&
C      WRITE(*,520) (IDAAAY(I),IHOUR(I),AMT(I),I=1,7)
C      DO 13 IK = 1, 7
C      IF( IDAAAY( IK ) .EQ. 0 ) GO TO 20
C      IM = ( IDAAAY( IK ) - 1 ) * 24 + IHOUR( IK )
C      HOURLY( IM ) = AMT( IK )
C      13 CONTINUE
C      GO TO 12
C
C----TEMP DATA
C

```

```

C      SET DAYS OF THE MONTH, MDN
C
20  IF (KMO.EQ.12) THEN
      MDN=31
    ELSE
      MDN=IDAYBG(KMO+1)-IDAYBG(KMO)
    END IF
    IF (KMO .EQ. 2) THEN
      MDN=28
      LPYR1=KYR/4
      LPYR2=LPYR1*4
      IF (LPYR2.EQ.KYR) MDN=29
    END IF
    IF (LOOP.EQ.0) GOTO 25
    READ (7,*,END=410) IYEAR,MONTH
C&
C      WRITE(*,*)'TEMP DATE',IYEAR,MONTH
    IF ((IYEAR.NE.KYR).OR.(MONTH.NE.KMO)) GOTO 400
25  CONTINUE
      READ (7,*,END=410) (TMAX(I),TMIN(I), I=1,MDN)
C&
C      WRITE (*,*)(TMAX(I),TMIN(I),I=1,MDN)
C
C      EVAPOTRANSPIRATION
C
      DO 35 K=1,MDN
        NT=TMAX(K) +TMIN(K) +1
        ET(K)=SET(KMO)
        IF(NT.GT.1) ET(K)=E(NT)*REL(IDAYBG(KMO)+K)
35  CONTINUE
C
      WRITE(*,*) 'KYR,KMO',KYR,KMO
      LOOP = LOOP + 1

      IF((KYR.EQ.IIYED).AND.(KMO.EQ.IMED))LOPE=999
      IF((KYR.NE.IYRST).AND.(LOPE.LT.1)) THEN
        IQUIT3=-9
        IYRST=KYR
      ENDIF
      RETURN
C      CALL FORSUB(KYR,KMO,ET,HOURLY,LOOP,IIYED,FACTOR,NOPORT)
C
C
C      IF (KYR.GT.IIYED) GO TO 800
C      IF ((KYR.EQ.IIYED).AND.(KMO.GT.IMED)) GO TO 800
C
C      GOTO 5
C
300  WRITE(3,*) 'YEAR TO START IN RAIN FILE NOT FOUND',IYST,IYEAR
      GO TO 999
310  WRITE(3,*) 'YEAR TO START IN TEMP FILE NOT FOUND',IYST,IYEAR
      GO TO 999
400  WRITE(3,*) 'WEATHER DATA MISALIGNED'

```



```

      GO TO 999
410  WRITE(3,*) 'END OF TEMP DATA'
      GO TO 999
800  WRITE(3,830) ITDA,KYR,KMO
      GO TO 999
C
C
999  STOP
C
C
520  FORMAT(8 (I2,1X,I2,1X,F3.2,1X) )
530  FORMAT(12F5.2 )

600  FORMAT(2(I6,1X),2(I4,1X,I2,1X),I4,1X,F3.0)
630  FORMAT(12F5.2)
610  FORMAT(/20A4,/,20A4)
619  FORMAT(/47X,19('*')/47X,'* D R A I N M O D */47X,19('*')
1/51X,'TITLE OF RUN'/51X,12('*'))
611  FORMAT(/I2/)
645  FORMAT(' ET MULTIPLICATION FACTOR FOR EACH MONTH',/
*2X,12F6.2/)
620  FORMAT(/,27X,20A4/27X,20A4///50X,'CLIMATE INPUTS'/50X,
* '*****' //
*      6X,'DESCRIPTION',84X,'(VARIABLE)      VALUE  UNIT'/
*      1X,132(1H-))
640  FORMAT(' RAINFALL STATION NUMBER',78(1H.),'(RAINID)',5X,I6/
* ' TEMPERATURE STATION NUMBER',75(1H.),'(TEMPID)',5X,I6/
* ' STARTING YEAR OF SIMULATION',70(1H.),'(START YEAR)',7X,I4,
* 3X,'YEAR'/
* ' STARTING MONTH OF SIMULATION',68(1H.),'(START MONTH)',9X,I2,
* 3X,'MONTH'/
* ' ENDING YEAR OF SIMULATION',74(1H.),'(END YEAR)',7X,I4,
* 3X,'YEAR'/
* ' ENDING MONTH OF SIMULATION',72(1H.),'(END MONTH)',9X,I2,
* 3X,'MONTH'/
* ' TEMPERATURE STATION LATITUDE',71(1H.),'(TEMP LAT)',6X,I2,
* '. ',I2,3X,'DEG.MIN'/
* ' HEAT INDEX',94(1H.),'(HID)',5X,F6.2//)
C
830  FORMAT(/1X,'SIMULATION TERMINATED NORMALLY. ',I6,1X,I4,1X,I2)
840  FORMAT(/1X,'SIMULATION TERMINATED NORMALLY. ',I6,1X,I4,1X,I2)
C
C
      END
C
C
      SUBROUTINE FORSUB(IR,MO,ET,HOURLY,LOOP,IEDYR,FACTOR,NOPORT)
C
C
C * THIS SUBROUTINE IS THE MAIN BODY OF THE MODEL., DRAINMOD.
C * IT CONDUCTS THE BASIC WATER BALANCE CALCULATIONS ON INTERVALS OF 1
C * HR., 2HR., OR 1DAY.
C * INFILTRATION, SURFACE STORAGE, AND WATER MANAGEMENT PARAMETERS SUCH
C * AS SEW-30 ARE CALCULATED WITHIN THIS SUBROUTINE.

```

C * OTHER COMPONENTS SUCH AS DRAINAGE FLUX AND ET ARE CALLED FROM ADD-
C * ITIONAL SUBROUTINES.

C *
C * SECTION 1
C * THIS SECTION RECEIVES DAILY PET AND HOURLY RAINFALL VALUES FOR ONE
C * MONTH FROM THE MAIN PROGRAM AND CHANGES THE VALUE FROM INCHES TO CM
C

COMMON /IWK/SWKHR1,EWKHR1,SWKHR2,EWKHR2
COMMON /WRK/AMIN1,ROUTA1,ROUTT1,AMIN2,ROUTA2,ROUTT2
COMMON/ICNT/ISICNT,ISKIP,IPOST,IK,IPCNT
COMMON/JCNT/JSICNM,JSKIPM,JPOSTM
COMMON/IDAY/FDAYSI,NDAYSI,INTDAY,NOIRR1,NOIRR2,NOIRR3,NOIRR4
COMMON/IHR/IHRSTA,IHREND,INSIRR
COMMON/PAR/TAV,REQDAR,AMTRN,AMTSI,DAMTSI
COMMON/WHX/WATER(1000),W(101),H(101),X(101),NN,UPVOL,WETZ,WP
COMMON/ABDT/EDTWT,AA(1000),BB(1000),A,B
COMMON/EVAPO/PET,DDZ,ROOTD
COMMON/DRABLK/HDRAIN,DEPTH,CONK(5),DZ(5)
COMMON/DLK/SDRAIN,DDRAIN,DC,ADEPTH
COMMON/POND/STOR,GEE,STORRO
COMMON/DBLK/DRNSTO
COMMON/PLT/YODTWT(31),YCDTWT(31),XDATE(31)
COMMON/RAIN/R(24)
COMMON/ORDR/TOSIRR(50),TOTDD(50),TOTWD(50),SEW(50),IRY(50)
COMMON/NAMES/ TITLE1(20),TITLE2(20)

C/
COMMON/CDNO/LOPC,MFLAG,LOPE,IQUIT3,JDATE3,JDAY3
COMMON/CDT/CDTWT,CROOT,CFVOL,DWET(10),SURWET,TRD60,IPET,PETD,AETC
COMMON/SOILI/ SALB,SWCON,CN2,DLAYR(10),DUL(10),LL(10),SW(10),
1 SAT(10),DEPMAX,TDUL,NLAYR,SMX,WF(10),WR(10),RWU(10),SWEF
COMMON/PERCIP/RVOL,CRO

C\
DIMENSION ET(31),HOURLY(744),DAYM(12),FACTOR(12)
DIMENSION DROOT(370)
DIMENSION RVOLM(12),FVOLM(12),ROM(12),DVOLM(12),PUMPVM(12)
DIMENSION DWIER(12),DACHNG(12),TWLOSS(12)
DIMENSION DRYDAY(12),WETDAY(12),WRKDAY(12),WATDAY(12)
DIMENSION ISICNM(12),ISKIPM(12),IPOSTM(12),SIRMMO(12)
DIMENSION F(24),FRATE(24),HET(24),ACCR(24)
DIMENSION WTD(1000),VOL(1001)
DIMENSION SWIER(12)
DIMENSION SEWM(12)
DIMENSION UPFLUX(1000),HPET1(24)
DIMENSION SUMAET(12)
DIMENSION AMTSIM(12)
DIMENSION KALDAY(12)
DIMENSION MOIN(50),IDAYIN(50)
DIMENSION RAIN(366),DEPTHW(366),WLL(366)
INTEGER DAYM,DAY
INTEGER BWKDY1,BWKDY2,SWKHR1,SWKHR2,EWKHR1,EWKHR2,EWKDY1,EWKDY2
INTEGER FDAYSI, HOUR, TITLE1, TITLE2
DATA DAYM/31,28,31,30,31,30,31,31,30,31,30,31/

```

DATA KALDAY/0,31,59,90,120,151,181,212,243,273,304,334/
C
  IF(MFLAG.EQ.1) GO TO 30
  IF(MO.NE.2) GO TO 5
  IR1=IR/4
  IR2=IR1*4
  DAYM(2)=28
  IF(IR .EQ. IR2) DAYM(2)=29
  5 DO 10 I=1,744
    HOURLY(I)=HOURLY(I)*2.54
  10 CONTINUE
    DO 15 I=1,31
      ET(I)=ET(I)*2.54*FACTOR(MO)
  15 CONTINUE
    DAY=0
    IF(LOOP.GT.1) GO TO 30

C
C !-----
C !               END OF SECTION 1
C ! IF LOOP=0, I.E. FIRST TIME THROUGH THIS SECTION, GO TO SECTION 2 TO
C ! READ INITIAL DATA; OTHERWISE GO TO SECTION 4.
C !-----
C
C *****
C *               SECTION 2
C * ALL INPUT DATA FROM FILE #1 IS READ IN THIS SECTION. THE INPUT DATA
C * IS REWRITTEN INTO FILE #10 FOR QUICK CHECKING OF ERRORS AND IS
C * ALSO REFORMATTED AND PRINTED INTO THE OUTPUT FILE #3.
C *
C * STORAGE BLOCKS ARE ALLOCATED AND ARRAYS ARE DIMENSIONED. SOILS,
C * SYSTEM PARAMETER AND PLANT ROOT DATA ARE READ IN AND LISTED ON THE
C * OUTPUT IN THIS SECTION.
C *****
C
C
C
C
  IRFST=IR
  CRITD=500.
  AMINC=100.
  READ(1,720) INWIER
  WRITE(10,720) INWIER
  IF(INWIER.LT.1) INWIER=1
  READ(1,620) DDRAIN,HDRAIN,SDRAIN,STMAX,DC,STORRO,GEE,DTWT
  WRITE(10,620) DDRAIN,HDRAIN,SDRAIN,STMAX,DC,STORRO,GEE,DTWT
  DEPTH=DDRAIN+HDRAIN
  READ(1,650) DITCHB,DITCHS
  WRITE(10,650) DITCHB,DITCHS
  READ(1,705) ADEPTH
  WRITE(10,705) ADEPTH
  READ(1,625)(DZ(I),CONK(I),I=1,5)
  WRITE(10,625)(DZ(I),CONK(I),I=1,5)

C
C
C
C
  PRINT OUT FIGURE

```

```

ICOD=INWIER
IF(ICOD.EQ.1) WRITE(3,756) TITLE1,TITLE2
IF(ICOD.EQ.2) WRITE(3,757) TITLE1,TITLE2
IF(ICOD.EQ.3) WRITE(3,758) TITLE1,TITLE2
WRITE(3,759)STMAX
759  FORMAT(5(/),1X,25X,10X,'STMAX =',F5.2,' CM',19X,'SOIL ',
1'SURFACE'/'+' ,25X,'_/' ,60(' _ '),'/')
WRITE(3,412) ADEPTH,DDRAIN
WRITE(3,413) SDRAIN
WRITE(3,414) HDRAIN
WRITE(3,822)
CST1=0.0
DO 824 I=1,5
CST2=DZ(I)
IF(CONK(I).GT..1E-5) WRITE(3,828)CST1,CST2,CONK(I)
824  CST1=CST2
WRITE(3,800) DDRAIN,HDRAIN,SDRAIN,STMAX,DEPTH
WRITE(3,801) DC,ADEPTH
WRITE(3,802) STORRO,GEE
WRITE(3,820) DITCHB,DITCHS
WRITE(3,794) DTWT
READ(1,675)INDET,XCRITD
WRITE(10,675)INDET,XCRITD
IF(XCRITD.GT.0) WRITE(3,764) XCRITD
675  FORMAT(12,8X,F10.2)
764  FORMAT(/1X,'INDET=0 AND CRITD= ',F6.2,' CM')
IF(XCRITD.GT.0) CRITD=XCRITD
CALL PROP(WTD,VOL,WATER,AA,BB,UPFLUX)
READ(1,709)
WRITE(10,709)
READ(1,710) MOBW1,IDABW1,MOEW1,IDAEW1,SWKHR1,EWKHR1,
1 AMIN1,ROUTA1,ROUTT1
WRITE(10,710) MOBW1,IDABW1,MOEW1,IDAEW1,SWKHR1,EWKHR1,
1 AMIN1,ROUTA1,ROUTT1
READ(1,710) MOBW2,IDABW2,MOEW2,IDAEW2,SWKHR2,EWKHR2,
1 AMIN2,ROUTA2,ROUTT2
WRITE(10,710) MOBW2,IDABW2,MOEW2,IDAEW2,SWKHR2,EWKHR2,
1 AMIN2,ROUTA2,ROUTT2
BWKDY1=KALDAY(MOBW1)+IDABW1
EWKDY1=KALDAY(MOEW1)+IDAEW1
BWKDY2=KALDAY(MOBW2)+IDABW2
EWKDY2=KALDAY(MOEW2)+IDAEW2
READ(1,715) WP
WRITE(10,610) WP
READ(1,670)ISEWMS,ISEWDS,ISEWME,ISEWDE,SEWX
WRITE(10,670)ISEWMS,ISEWDS,ISEWME,ISEWDE,SEWX
READ(1,670>IDRYMS>IDRYDS>IDRYME>IDRYDE
WRITE(10,670>IDRYMS>IDRYDS>IDRYME>IDRYDE
CALL ROOT(DROOT,MOIN,IDAYIN,NNOO)
READ(1,640)(DACHNG(I),DWIER(I),I=1,12)
WRITE(10,640)(DACHNG(I),DWIER(I),I=1,12)
READ(1,600)INSIRR,MOFDA,IDAFDA,INTDAY,IHRSTA,IHREND
WRITE(10,600)INSIRR,MOFDA,IDAFDA,INTDAY,IHRSTA,IHREND
READ(1,725) MONO1, IDANO1, MONO2, IDANO2, MONO3, IDANO3,

```

```

1 MONO4, IDANO4
  WRITE(10,725) MONO1, IDANO1, MONO2, IDANO2, MONO3, IDANO3,
1 MONO4, IDANO4
  FDAYS1=KALDAY(MOFDA)+IDAFDA
  NOIRR1=KALDAY(MONO1)+IDANO1
  NOIRR2=KALDAY(MONO2)+IDANO2
  NOIRR3=KALDAY(MONO3)+IDANO3
  NOIRR4=KALDAY(MONO4)+IDANO4
  READ(1,610)REQDAR, AMTRN, (AMTSIM(I), I=1, 12)
  WRITE(10,610)REQDAR, AMTRN, (AMTSIM(I), I=1, 12)
C
C
  WRITE(3,747)
  WRITE(3,810)AMIN1, AMIN2, ROUTA1, ROUTA2, ROUTT1, ROUTT2
  WRITE(3,815)MOBW1, IDABW1, MOBW2, IDABW2, MOEW1, IDAEW1, MOEW2,
1 IDAEW2, SWKHR1, SWKHR2, EWKHR1, EWKHR2
  WRITE(3,748)
  WRITE(3,761) WP
  WRITE(3,762) ISEWMS, ISEWDS, ISEWME, ISEWDE, SEWX
  WRITE(3,763) IDRYMS, IDRYDS, IDRYME, IDRYDE
  WRITE(3,755)
  DO 76 I=1, NNOO
    JJJ=KALDAY(MOIN(I))+IDAYIN(I)
76   WRITE(3,786) MOIN(I), IDAYIN(I), DROOT(JJJ)
    WRITE(3,749)
    WRITE(3,830) (DACHNG(I), I=1, 12)
    WRITE(3,840) (DWIER(I), I=1, 12)
    IF(INSIRR.EQ.0) WRITE(3,787)
    IF(INSIRR.EQ.0) GO TO 2
    WRITE(3,788)
    WRITE(3,850) FDAYS1, INTDAY, IHRSTA, IHREND, NOIRR1, NOIRR2,
1 NOIRR3, NOIRR4
    WRITE(3,860) REQDAR, AMTRN, (AMTSIM(I), I=1, 12)
C
C
C
2   JDAY=0
C
C !-----
C !                               END OF SECTION 2
C !-----
C
C *****
C *                               SECTION 3
C * INITIALIZATION OF VARIABLES PRIOR TO BEGINNING OF SIMULATION
C *****
C
  DC=DC/24.
  TOFSIR=IHREND-IHRSTA
  IPCNT=0
  EDTWT=DTWT
  LRAIN = 0
  DDAY=0.
  ISKIP=0

```

```

IPOST=0
CRO=0.
IK=0
ISICNT=0
IRRDAY=0
DEBT=0.0
DDZ=0.0
DRNSTO=0.0
STOR=0.0
TOTR=0.
TOTF=0.
TOTD=0.
TOTRO=0.
TOTNT=0.
TOTFD=0.
TOTWF=0.
TPUMPV=0.0
YTAV=0.0
YSUMET=0.0
WETZ=DTWT
ID=DTWT+1.0
YDEBT=0.0
CRITD1=CRITD+1.
ICRIT=CRITD1
CRITAV=VOL(ICRIT)
AVOL=VOL(ID)
TAV=AVOL
UPQ=UPFLUX(ID)
UPVOL=UPQ*24.
UPVOL2=UPQ
XNI=100.

```

C&

```

DELX=DEPMAX/XNI
NI=XNI
NN=NI+1
NR1=NOIRR1
NR2=NOIRR2
NDAYSI=FDAYSI
DO 20 I=1,12
  ISICNM(I)=0
  ISKIPM(I)=0
  IPOSTM(I)=0
  SIRRMO(I)=0.
  TWLOSS(I)=0.0
  SUMAET(I)=0.0
  RVOLM(I)=0.0
  ROM(I)=0.0
  FVOLM(I)=0.0
  DVOLM(I)=0.0
  PUMPVM(I)=0.0
  WRKDAY(I)=0.0
  WETDAY(I)=0.0
  WATDAY(I)=0.0
  DRYDAY(I)=0.

```

```

      SWIER(I)=DWIER(I)
      SEWM(I)=0.0
20  CONTINUE
      DO 23 I=1,50
      IRY(I)=0
      SEW(I)=0.0
      TOTDD(I)=0.0
      TOTWD(I)=0.0
23  TOSIRR(I)=0.0
C
      X(1)=0.0
      DO 25 I=2,NN
      X(I)=X(I-1)+DELX
25  CONTINUE
C
C !-----
C !               END OF SECTION 3
C !-----
C
C *****
C *               SECTION 4
C * INCREMENT DAY, DETERMINE HOURLY RAINFALL, WIER DEPTH, AND ROOT DEPTH
C * FOR NEW DAY.  INITIALIZE VARIABLES FOR A NEW DAY.
C *****
C
30  DAY=DAY+1
      IRRDAY=IRRDAY+1
      JDAY=JDAY+1
      IF (TRD60.GT.1) THEN
      ROOTD=TRD60
      ELSE
      ROOTD=DROOT(JDAY)
      ENDIF
      AMTSI=AMTSIM(MO)
      IF(AMTSI .LT. 0.0)AMTSI=(TAV+AMTSI)/TOFSIR
      IF(AMTSI .LT. 0.0) AMTSI=0.0
C
      DWIER(MO)=SWIER(MO)
      PDEBT=ROOTD*(WATER(1)-WP)
      IF(DAY.LT.DACHNG(MO).AND.MO.EQ.1)GO TO 31
      IF (DAY.LT.DACHNG(MO))DWIER(MO)=DWIER(MO-1)
      GO TO 32
31  DWIER(MO)=DWIER(12)
C
32  DAMTSI=0.0
      DEEPET=DEPTH-DDZ
      JPOSTM=0
      JSKIPM=0
      JSICNM=0
      WLOSS=0.0
      RO=0.0
      RVOL=0.0
      DVOL=0.0
      PUMPV=0.0

```

```

DELTWK=0.0
AMRAIN=0.0
STOR1=STOR
STOR2=STOR
AVOL1=AVOL
HSEW=0.0

C
C FIND HOURLY RAINFALL VALUES FOR NEW DAY
C
    L=(DAY-1)*24
    DO 35 I=1,24
    K=L+I
    R(I)=HOURLY(K)
    AMRAIN=AMRAIN+R(I)
    ACCR(I)=AMRAIN
35 CONTINUE

C
C CHECK IF SURFACE IRRIGATION IS PREPLANNED ON THAT DAY
    IF(IRRDAY.EQ.FDAYSI.OR.IRRDAY.EQ.NDAYSI)CALL SURIRR

C
C FIND WATER CONTENT AND HEAD DISTRIBUTION
C&    CALL WET(WETZ)
C
C/

    PET=ET(DAY)
    PETD=PET
    WRITE(17,*) 'PET, AETC',MO,DAY,PET,AETC
C  USE AET OF CERES
    IF(AETC.GT.0.) PET=AETC
    WRITE(17,*) 'PET,AETC',PET,AETC
C\
C  GET POTENTIAL DAILY EVAPOTRANSPIRATION FOR NEW DAY - DISTRIBUTES PET
C  HOURLY VALUES
C
    CALL EVAP(AET,HET,HPET1,TPET)

C
    DO 40 I=1,24
    IF(R(I).GT.0.0)GO TO 45
40 CONTINUE
    IRAIN=24
    IF(STOR.GT.0.001)GO TO 50
    GO TO 130

C
C IF IT RAINS OR IF PREVIOUS SURFACE STORAGE, FIND HOURLY INFILTRATION
C BY USING THREE MINUTE TIME INCREMENT
C
C !-----
C !                      END OF SECTION 4
C !-----
C
C *****
C *                      SECTION 5
C * DETERMINES INFILTRATION AND CONDUCTS WATER BALANCE CALCULATIONS ON A
C * HOURLY BASIS. ACCUMULATE TOTALS SO AT END OF SECTION 5 HAVE ESTIMAT

```



```

C * ALL PARAMETERS FOR THE DAY.
C *****
C *          SECTION 5A - INFILTRATION CALCULATION
C *****
C
  45 IRAIN=I
  50 DT=1.0
    DDT=0.05
    DTMDT=DT-0.01*DDT
C
  RDT=23-LRAIN+IRAIN
  F(1)=0.001
  IF(RDT.LT.2.5)F(1)=F(LRAIN)
  IF(STOR.GT.0.01)F(1)=F(24)
  IF(DTWT.LT.0.001) F(1)=0.0
  IF(F(1).LT.0.001)F(1)=0.001
  YESF=F(1)
  LRAIN=1
C
  DO 55 I=1,24
    RVOL=RVOL+R(I)
    IF(R(I).GT.0.0001)LRAIN=I
  55 CONTINUE
C
  J=1
  IF(F(J).LT.0.01)CALL SOAK
C DETERMINES INFILTRATION CONSTANTS FOR SMALL INITIAL INFILTRATION
C
  60 CALL DRAINS(DTWT,DFLUX)
    IF(AVOL1.LE.0.01)A=0.0
    IF((A.LT.0.00001).AND.(DTWT.GT.0.10)) CALL SOAK
    IF(A.EQ.0.0)B=HET(J)+DFLUX
    IF((A.LE.0.000001).AND.(B.LT.0.0))B=0.0
    FRATE(J)=A/F(J)+B
    IF(STOR.GT.0.0)GO TO 65
    IF(FRATE(J).GT.R(J))GO TO 90
C
  65 RAT1=FRATE(J)
  70 SUM=0.0
    F1=F(J)
C
  75 DF=RAT1*DDT
    F2=F1+DF
    RAT2=A/F2+B
    IF(STOR.GT.0.0)GO TO 80
    IF(RAT2.GT.R(J))RAT2=R(J)
  80 DF=0.5*(RAT1+RAT2)*DDT
    SPR=STOR+R(J)*DDT
    IF(DF.GT.SPR)DF=SPR
    F1=F1+DF
    SUM=SUM+DDT
    RAT1=A/F1+B
    IF(STOR.GT.0.0)GO TO 85
    IF(RAT1.GT.R(J))RAT1=R(J)

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```

85 STOR=STOR+R(J)*DDT-DF
   IF(STOR.GT.STMAX)STOR=STMAX
   IF(SUM.GE.DTMDT)GO TO 100
   GO TO 75
C
90 F1=F(J)+R(J)*DT
   RAT1=A/F1+B
   IF(RAT1.GT.R(J))GO TO 95
   RAT1=R(J)
   GO TO 70
C
95 RAT1=R(J)
100 F(J)=F1
   DVOL1=DFLUX*DT
   DVOL=DVOL+DVOL1
   IF(DVOL1.LT.0.0)PUMPV=PUMPV+DVOL1
   IF(J.EQ.1)GO TO 105
   FVOL=F(J)-F(J-1)
   GO TO 110
C
C *****
C * SECTION 5B - WATER BALANCE CALCULATION FOR ONE HOUR INTERVAL
C *****
C
C REEVALUATION OF WETZ,DDZ ETC
105 FVOL=F(1)-YESF
110 WETZ=DTWT-DDZ
   IF(INDET.GT.0) GO TO 117
   IF(WETZ.GT.CRITD)GO TO 115
   IF(DEBT.GT.0.01)GO TO 115
   TVOL=FBVOL-HET(J)-DVOL1
   AVOL1=AVOL1-TVOL
   GO TO 120
115 AVOL1=AVOL1+DVOL1
   DEBT=DEBT+HET(J)-FVOL
   IF(DEBT.GT.0.0)GO TO 120
   AVOL1=AVOL1+DEBT
   DEBT=0.0
   GO TO 120
117 CONTINUE
   CALL ETFLUX(AVOL1,DEBT,FVOL,DVOL1,UPVOL2,HPET1(J),HET(J),PDEBT)
120 DDZ=DEBT/(WATER(1)-WP)
   IF(AVOL1.GT.0.001)GO TO 125
   STOR=STOR-AVOL1
   IF(STOR.GT.STMAX)STOR=STMAX
   F(J)=F(J)+AVOL1
   FVOL=FBVOL+AVOL1
   AVOL1=0.0
125 IAVOL=10.*AVOL1+1.0
   AV=10.*AVOL1+1.0
   XV=IAVOL
   WETZ=WTD(IAVOL)+(AV-XV)*(WTD(IAVOL+1)-WTD(IAVOL))
   IWET=WETZ+1.
   UPQ=UPFLUX(IWET)

```

```

IF(WETZ.GT.DEEPET)UPQ=0.0
UPVOL2=UPQ*DT
DTWT=WETZ+DDZ
TAV1=AVOL1+DEBT
DSTOR=STOR-STOR2
STOR2=STOR
RO=R(J)-FVOL-DSTOR
CALL YDITCH(DWIER(MO),DVOL1,YD,RO,WLO,DITCHB,DITCHS)
IF(INWIER.GT. 2)YD=DDRAIN-DWIER(MO)
HDRAIN=DEPTH-DDRAIN+YD
WLOSS=WLOSS+WLO
IF(DTWT.LT.SEWX)HSEW=HSEW+SEWX-DTWT
C   THE FOLLOWING STATEMENTS DETERMINE IF THIS HOUR IS COUNTED
C   AS AN HOUR IN WHICH FIELD WORK CAN BE DONE
DWRKDY=0.0
IF((JDAY .GE. BWKDY1) .AND. (JDAY .LE. EWKDY1))
* CALL WORK(1,J,TAV1,DWRKDY,ACCR(J),DDAY,YTAV)
IF((JDAY .GE. BWKDY2) .AND. (JDAY .LE. EWKDY2))
* CALL WORK(7,J,TAV1,DWRKDY,ACCR(J),DDAY,YTAV)
IF(R(J) .LT. 0.01) DDAY=DDAY+1./24.
DELTWK=DELTWK+DWRKDY
J=J+1
IF(J.GT.24)GO TO 155
F(J)=F(J-1)
IF(F(J).LT.0.001)F(J)=0.001
GO TO 60

C
C   WHEN CALCULATIONS HAVE BEEN MADE FOR HOUR, J=24, GO TO SECTION 7
C   !-----
C   !                     END OF SECTION 5
C   !-----
C
C *****
C *                               SECTION 6
C * WATER BALANCE CALCULATION WHEN HAVE NO RAIN OR SURFACE IRRIGATION
C * DURING THE DAY OR SURFACE STORAGE AT THE BEGINING OF THE DAY.
C * THE WATER BALANCE CALCULATION IS BASED ON A 1 DAY TIME INTERVAL IF
C * DRAINAGE FLUX AT BEGINING OF DAY IS LESS THAN .02 CM./DAY AND ON A
C * 2 HR. INTERVAL IF DFLUX IS GREATER THAN THAT VALUE.
C *****
130 HOUR=0
YESF=0.0
FVOL=0.0
DO 135 I=1,24
F(I)=0.0
FRATE(I)=0.0
135 CONTINUE
C
CALL DRAINS(DTWT,DFLUX)
DVOL1=24.*DFLUX
C   IFINDET>0 USE SUBROUTINE ETFLUX TO ESTIMATE AET
C   THEN CAN GET GOOD ESTIMATE OF DVOL
UPVOL=UPQ*24.0
IF(INDET.LE.0) GO TO 137

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CALL ETFLUX (AVOL1,DEBT,FVOL,DVOL1,UPVOL,TPET,AET,PDEBT)
AVOL1=AVOL
DDZ=DEBT*ROOTD/PDEBT
137 CONTINUE
C CHECK FOR DRAINAGE VOLUME. FOR SMALL VOLUME, TAKE 24 HOUR INCREMENT
C AND FOR LARGE VOLUME TAKE 2 HOURLY INCREMENT
  IF(ABS(DVOL1).LE.0.02)GO TO 145
  AVOL1=AVOL
  DEBT=YDEBT
  AET=AET/12.
  H2PET=TPET/12.
C
140 HOUR=HOUR+2
  UPVOL1=UPQ*2.0
  DVOL1=2.0*DFLUX
145 CONTINUE
  IF(INDET.LE.0) GO TO 147
  IF(HOUR.EQ.0) GO TO 147
  CALL ETFLUX(AVOL1,DEBT,FVOL,DVOL1,UPVOL1,H2PET,AET,PDEBT)
  IF(AVOL1.LT.0.0) AVOL1=0.0
  GO TO 148
147 TVOL=FVOL-AET-DVOL1
  AVOL1=AVOL1-TVOL
  IF(AVOL1.LT.0.0)AVOL1=0.0
  IF(WETZ.GT.CRITD)AVOL1=AVOL1+DVOL1
148 IAVOL=10.*AVOL1+1.0
  AV=10.*AVOL1+1.0
  XV=IAVOL
  WETZ=WTD(IAVOL)+(AV-XV)*(WTD(IAVOL+1)-WTD(IAVOL))
  IWET=WETZ+1.
  UPQ=UPFLUX(IWET)
  DDZ=DEBT*ROOTD/PDEBT
  DTWT=WETZ+DDZ
  IF(WETZ.GT.DEEPET)UPQ=0.0
  CALL YDITCH(DWIER(MO),DVOL1,YD,RO,WLO,DITCHB,DITCHS)
  IF(INWIER.GT.2 )YD=DDRAIN-DWIER(MO)
  HDRAIN=DEPTH-DDRAIN+YD
  WLOSS=WLOSS+WLO
  IF(DVOL1.LT.0.0) PUMPV=PUMPV+DVOL1
  DVOL=DVOL+DVOL1
  CALL DRAINS(DTWT,DFLUX)
  IF(DTWT.LT.SEWX)HSEW=HSEW+2.0*(SEWX-DTWT)
  IF(HOUR.GE.24)AET=AET*12.0
  IF(HOUR.GE.24)GO TO 155
  IF(HOUR.EQ.0)GO TO 150
  GO TO 140
C
150 DVOL2=24.*DFLUX
  HSEW=12.0*HSEW
  DVOL=0.5*(DVOL1+DVOL2)
  IF(DVOL.LT.0.0) PUMPV=DVOL
  CALL YDITCH(DWIER(MO),DVOL,YD,RO,WLO,DITCHB,DITCHS)
  IF(INWIER.GT.2 )YD=DDRAIN-DWIER(MO)
  HDRAIN=DEPTH-DDRAIN+YD

```

```

C
C !-----
C !                      END OF SECTION 6
C !-----
C
C *****
C *                      SECTION 7
C * REEVALUATION OF WATER TABLE DEPTH, DRY ZONE DEPTH, WET ZONE DEPTH, A
C * VOLUMES, AND RUNOFF AT END OF DAY.  ALSO UPDATE SOME VARIABLES TO BE
C * USED DURING NEXT DAY SUCH AS UPQ.
C *****
155 FVOL=F(24)-YESF
    DEBT=YDEBT
    UPVOL=0.5*(24.0*UPQ+UPVOL)
    IF(INDET.LE.0)GO TO 157
    CALL ETFLUX(AVOL,DEBT,FVOL,DVOL,UPVOL,TPET ,AET,PDEBT)
    GO TO 165
C
C *****
C * THE FOLLOWING SECTION (TO STATEMENT NO.165) USES THE CRITICAL DEPTH
C * (CRITD) CONCEPT TO ESTIMATE WHEN UPWARD MOVEMENT OF WATER FROM WATER
C * TABLE IS LIMITED.
C *****
157 CONTINUE
    WETZ=DTWT-DDZ
    IF(WETZ.GE.CRITD)GO TO 160
    IF(DEBT.GT.0.01)GO TO 160
    TVOL=FBOL-AET-DVOL
    AVOL=AVOL-TVOL
    GO TO 165
C
160 AVOL=AVOL+DVOL
    DEBT=DEBT+AET-FVOL
    IF(DEBT.GT.0.0)GO TO 161
    AVOL=AVOL+DEBT
    DEBT=0.0
    GO TO 165
161 TAV=AVOL+DEBT
    IF(WETZ.GT.CRITD1)GO TO 165
    AVOL=CRITAV
    DEBT=TAV-AVOL
C THE THREE ARE NEEDED WHEN HOURLY WETZ<CRITD BUT DEBT>0
    IF(DEBT.GE.0.0)GO TO 165
    AVOL=AVOL+DEBT
    DEBT=0.
C
165 DDZ=DEBT/(WATER(1)-WP)
166 DSTOR=STOR-STOR1
    RO=RVOL-DSTOR-FVOL
    IF(AVOL.LT.0.0)AVOL=0.0
    AV=10.*AVOL+1
    IAVOL=AV
    XV=IAVOL
    WETZ=WTD(IAVOL)+((AV-XV)*(WTD(IAVOL+1)-WTD(IAVOL)))

```

```

IWET=WETZ+1.
UPQ=UPFLUX(IWET)
DTWT=WETZ+DDZ
IF(WETZ.GT.DEEPET)UPQ=0.0
TAV=AVOL+DEBT
TAV1=TAV
TV=10*TAV+1
ITAV=TV
XV=ITAV
EDTWT=WTD(ITAV)+(TV-XV)*(WTD(ITAV+1)-WTD(ITAV))
YDEBT=DEBT
SEWD=0.0

C
C !-----
C !                      END OF SECTION 7
C !-----
C
C *****
C *                      SECTION 8
C * DETERMINATION OF PLANT GROWTH AND TRAFFICABILITY PARAMETERS, OUTPUT
C * OF DAILY SUMMARIES IF DESIRED, AND MONTHLY SUMMARY CALCULATIONS.
C *****
      IF((MO.LT.ISEWMS).OR.(MO.GT.ISEWME))GO TO 169
      IF((MO.EQ.ISEWMS).AND.(DAY.LT.ISEWDS))GO TO 169
      IF((MO.EQ.ISEWME).AND.(DAY.GT.ISEWDE))GO TO 169
      IF(DTWT.GT.SEWX)GO TO 168
      SEWD=SEWX-DTWT
168 CONTINUE
      IF(HSEW.GT.0.01)SEWD=HSEW/24.0
169 CONTINUE

C
C
C
C
      IF(NOPORT.GT.1)GO TO 175
      IF(DAY.NE.1)GO TO 170
C
C DAILY SUMMERIES
      WRITE(3,900)
      WRITE(3,910)IR,MO
      WRITE(3,920)
170 WRITE(3,930)DAY,RVOL,FVOL,AET,DVOL,AVOL,TAV,DDZ,WETZ,DTWT,
      $STOR,RO,WLOSS,YD,DRNSTO,SEWD,DAMTSI
C
C MONTHLY CALCULATIONS
175 RVOLM(MO)=RVOLM(MO)+RVOL
      RAIN(JDAY)=RVOL
      DEPTHW(JDAY)=DTWT
      WLL(JDAY)=WLOSS
C/
C      WRITE(17,*) 'PET,AET',PET,AET
C\
      FVOLM(MO)=FVOLM(MO)+FVOL

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ROM(MO)=ROM(MO)+RO
DVOLM(MO)=DVOLM(MO)+DVOL
PUMPVM(MO)=PUMPVM(MO)+PUMPV
TWLOSS(MO)=TWLOSS(MO)+WLOSS
SUMAET(MO)=SUMAET(MO)+AET
SIRRM(MO)=SIRRM(MO)+DAMTSI
ISICNM(MO)=ISICNM(MO)+JSICNM
ISKIPM(MO)=ISKIPM(MO)+JSKIPM
IPOSTM(MO)=IPOSTM(MO)+JPOSTM
SEWM(MO)=SEWM(MO)+SEWD
JDAY3=JDAY

C& UP
  IF(DDZ.GE.(ROOTD-1.0)) GO TO 172
  IF(RVOL .GT. 0.005) GO TO 176
  GO TO 173
172 IF((MO.LT.IDRYMS).OR.(MO.GT.IDRYME)) GO TO 173
  IF((MO.EQ.IDRYMS).AND.(DAY.LT.IDRYDS)) GO TO 173
  IF((MO.EQ.IDRYME).AND.(DAY.GT.IDRYDE)) GO TO 173
  DRYDAY(MO)=DRYDAY(MO)+1.0
173 CONTINUE
  DELTWK=0.0
  IF(JDAY .GE. BWKDY1) .AND. (JDAY .LE. EWKDY1))
    * CALL WORK(1,-1,TAV,DELTWK,0.0,DDAY,YTAV)
  IF(JDAY .GE. BWKDY2) .AND. (JDAY .LE. EWKDY2))
    * CALL WORK(7,-1,TAV,DELTWK,0.0,DDAY,YTAV)
  DDAY=DDAY+1
176 WRKDAY(MO)=WRKDAY(MO)+DELTWK
  AMINC=0.0
  IF(TAV.LT.AMINC)WATDAY(MO)=WATDAY(MO)+1.
  CFVOL= FVOL

C
  IF(DAY.GE.DAYM(MO))GO TO 180
  YTAV=TAV
  CDTWT=DTWT
  MFLAG=1
  RETURN

C
C IF PREVIOUS DAY WAS LAST DAY OF MONTH GO TO SECTION 9; OTHERWISE
C RETURN TO CERES FOR NEXT DAY
C !-----
C !                      END OF SECTION 8
C !-----
C
C *****
C *                      SECTION 9
C * IF MONTH JUST COMPLETED WAS LESS THAN 12, RETURNS TO MAIN PROGRAM FO
C * NEW SET OF RAINFALL AND ET DATA. IF MONTH=12, THIS SECTION PRINTS 0
C * MONTHLY SUMMARIES, COMPUTES YEARLY SUMMARIES, PRINTS, AND DETERMINES
C * AVERAGES OVER PREVIOUS YEARS OF SIMULATION.
C *****
180 MFLAG=0
  DAYMT=DAYM(MO)
  WETDAY(MO)=DAYMT-WRKDAY(MO)
  IF(MO.LT.12)RETURN

```



```

      IF(NOPORT.GT.2) GO TO 181
C
C MONTHLY SUMMARIES
      WRITE(3,940)IR
      WRITE(3,950)
      WRITE(3,960)(II,RVOLM(II),FVOLM(II),ROM(II),DVOLM(II),SUMAET(II),
2DRYDAY(II),WRKDAY(II),      TWLOSS(II),SEWM(II),SIRRM(II),
      $ISICNM(II),PUMPVM(II),IPOSTM(II),II=1,12)
C
181 CONTINUE
      YEARS=IR-IRFST+1
      IYEAR=YEARS
      IRY(IYEAR)=IR
      WRITE(11,1132) IR
1132 FORMAT(1X,I4)
      WRITE(11,1133)(RAIN(I),DEPTHW(I),WLL(I),I=1,JDAY)
1133 FORMAT(1X,3F10.3)
187 FORMAT(I4,2X,F4.0,2X,F10.3)
C
      DO 185 I=1,12
      TOTR=TOTR+RVOLM(I)
      YSUMET=YSUMET+SUMAET(I)
      TOTF=TOTF+FVOLM(I)
      TOTRO=TOTRO+ROM(I)
      TOTD=TOTD+DVOLM(I)
      TPUMPV=TPUMPV+PUMPVM(I)
      TOTDD(IYEAR)=TOTDD(IYEAR)+DRYDAY(I)
      TOSIRR(IYEAR)=TOSIRR(IYEAR)+SIRRM(I)
      TOTNT=TOTNT+WETDAY(I)
      TOTWD(IYEAR)=TOTWD(IYEAR)+WRKDAY(I)
      TOTFD=TOTFD+WATDAY(I)
      TOTWF=TOTWF+TWLOSS(I)
      SEW(IYEAR)=SEW(IYEAR)+SEWM(I)
      WETDAY(I)=0.0
      WRKDAY(I)=0.0
      DRYDAY(I)=0.0
      PUMPVM(I)=0.0
      RVOLM(I)=0.0
      FVOLM(I)=0.0
      ROM(I)=0.0
      WATDAY(I)=0.0
      TWLOSS(I)=0.0
      DVOLM(I)=0.0
      SIRRM(I)=0.0
      SUMAET(I)=0.0
      ISICNM(I)=0
      ISKIPM(I)=0
      SEWM(I)=0.0
      IPOSTM(I)=0
185 CONTINUE
C
      WRITE(11,1134) SEW(IYEAR),ISEWMS,ISEWDS,ISEWME,ISEWDE,SEWX,TOTR,TOTWF
1134 FORMAT(1X,F7.0,1X,I4,I6,3F10.1)
C YEARLY SUMMARIES

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```

IF(NOPORT.EQ.3) GO TO 191
WRITE(3,990)TOTR,TOTF,TOTRO,TOTD,YSUMET,TOTDD(IYEAR),TOTWD(IYEAR),
$      TOTWF,SEW(IYEAR),TOSIRR(IYEAR),TPUMPV
GO TO 194
191 IF(ICOUNT.EQ.0) WRITE(3,790) TITLE1,TITLE2
   ICOUNT=ICOUNT+1
   IF(ICOUNT.EQ.30) ICOUNT=0
   WRITE(3,791)IRY(IYEAR),TOTR,TOTF,TOTRO,TOTD,YSUMET,
1   TOTDD(IYEAR),TOTWD(IYEAR),TOTWF,SEW(IYEAR),TOSIRR(IYEAR),
2   TPUMPV

C
C REINITIALIZATION
194  TOTR=0.
    TOTF=0.
    TOTRO=0.
    YSUMET=0.0
    TOTD=0.
    TPUMPV=0.0
    TOTNT=0.
    TOTFD=0.
    TOTWF=0.
    ISKIP=0
    IPOST=0
    JDAY=0
    IK=0
    ISICNT=0
    IRRDAY=0
    NDAYS1=FDAYS1
    NOIRR1=NR1
    NOIRR2=NR2

C
IF(IR.EQ.IEDYR) CALL ORDER(IYEAR)

C
412  FORMAT(1X,25X,6X,':',51X,':/
    11X,25X,6X,':',51X,':/
    21X,25X,6X,':',5X,19X,' ',2X,2X,' ',21X,':/
    31X,25X,6X,':',5X,13X,' ',8X,8X,' ',15X,':/
    41X,25X,6X,':',5X,8X,' ',13X,13X,' ',10X,':/
    51X,25X,1X,'ADEPTH =',F4.0,' CM',35X,'DDRAIN =',F4.0,' CM'/
    61X,25X,6X,':',5X,3X,' ',18X,18X,' ',5X,':/
    71X,25X,6X,':',51X,':')
413  FORMAT(1X,25X,6X,':',5X,'O-----SDRAIN =',F6.0,' CM ',
    1'-----0 -')
414  FORMAT(1X,25X,6X,':',51X,':/
    11X,25X,6X,':',51X,':/
    21X,25X,6X,':',44X,'HDRAIN =',F4.0,' CM'/
    31X,25X,6X,':',51X,':/
    41X,25X,6X,':',51X,':/
    51X,25X,34(' - ')/
    61X,25X,6X,':/
    71X,25X,6X,':/
    81X,25X,6X,':/
    91X,25X,6X,':',36X,'IMPERMEABLE LAYER'/'+' ,25X,67(' - ')/
    71X,25X,67(' /'))

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```

600 FORMAT(I2,3X,2I2,1X,2I2,1X,I2,1X,I2)
610 FORMAT(2F10.5,12F5.2)
620 FORMAT(8E10.2)
625 FORMAT(5(F5.0,F5.2))
630 FORMAT(F10.2,2I5)
640 FORMAT(/12(F2.0,F3.0))
645 FORMAT(2I3,2I2,3F10.2)
650 FORMAT(6E10.2)
660 FORMAT(20F4.1)
670 FORMAT(4I2,2X,F10.2)
705 FORMAT(/,F10.0)
709 FORMAT(1X)
710 FORMAT(6I2,8X,3E10.1)
715 FORMAT(/F10.0)
720 FORMAT(/I2)
725 FORMAT(4(I2,I2,6X))
747 FORMAT(1H1,52X,'TRAFFICABILITY'/53X,14('*'))//
748 FORMAT(///56X,'CROP'/56X,'****'//)
749 FORMAT(///,34X,'WIER CONDITIONS AND WASTEWATER IRRIGATION'/34X,
1 41('*'))//
755 FORMAT(//30X,'MO DAY ROOTING DEPTHW(CM)')
756 FORMAT(1H1,2(/),49X,'DRAINAGE SYSTEM DESIGN'/49X,22('*'))//,
1 1X,25X,21X,'*** ',
2'CONVENTIONAL DRAINAGE',' ***'//,1X,25X,'JOB TITLE:',//,
3/35X,20A4/35X,20A4)
757 FORMAT(1H1,2(/),49X,'DRAINAGE SYSTEM DESIGN'/49X,22('*'))//,
1 1X,25X,21X,'*** ',
2'CONTROLLED DRAINAGE ',' ***'//,1X,25X,'JOB TITLE:',//,
3/35X,20A4/35X,20A4)
758 FORMAT(1H1,2(/),49X,'DRAINAGE SYSTEM DESIGN'/49X,22('*'))//,
1 1X,25X,21X,'*** ',
2'SUBIRRIGATION-DRAINAGE SYSTEM',' ***'//,1X,25X,'JOB TITLE:',//,
3/35X,20A4/35X,20A4)
761 FORMAT(1X,'SOIL MOISTURE AT CROP WILTING POINT=',5X,F5.2)
762 FORMAT(
$/1X,'HIGH WATER STRESS: ','BEGIN STRESS PERIOD ON',2X,I2,'/',
$/I2/21X,'END STRESS PERIOD ON',4X,I2,'/',I2/21X,'CROP IS IN ',
$/STRESS WHEN WATERTABLE IS ABOVE ',F5.1,' CM.')
763 FORMAT(/1X,
$/DROUGHT STRESS: ','BEGIN STRESS PERIOD ON',2X,I2,'/',I2/
$/21X,'END STRESS PERIOD ON',4X,I2,'/',I2)
786 FORMAT(30X,I2,3X,I2,7X,F5.1)
787 FORMAT(/5X,'NO WASTEWATER IRRIGATION SCHEDULED:')
788 FORMAT(/5X,'WASTEWATER IRRIGATION IS SCHEDULED:')
789 FORMAT(12(I2,F3.0))
790 FORMAT(1H1,' JOB TITLE: ',20A4/15X,20A4//
$/ 2X,'YEAR ',1X,'RAINFALL',1X,'INFILTRATION',1X,'RUNOFF',1X,
$/DRAINAGE',1X,' ET ', ' DRY DAYS ', ' WRK DAYS ',
$/ 1X,'WATER LOSS',4X,'SEW',3X,'IRRIG VOL PUMPED VOL')
791 FORMAT(1X,I4,2X,7F9.2,4X,4F9.2)
794 FORMAT(/1X,'INITIAL WATERTABLE DEPTH= ',F5.1,' CM')
C
800 FORMAT(/1X,'DEPTH TO DRAIN=',F5.1,'CM'/1X,'EFFECTIVE DEPTH FROM ',
$/DRAIN TO IMPERMEABLE LAYER =',F5.1,'CM'/1X,'DISTANCE BETWEEN ',

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$'DRAINS =' ,F7.1, 'CM',
$/1X, 'MAXIMUM DEPTH OF SURFACE PONDING =' ,F5.2, 'CM'/1X, 'EFFECTIVE ' ,
$'DEPTH TO IMPERMEABLE LAYER=' ,F6.1, 'CM')
801 FORMAT(1X, 'DRAINAGE COEFFICIENT (AS LIMITED BY SUBSURFACE OUTLET ' ,
$')=' ,F5.2, 'CM/DAY'/1X, 'ACTUAL DEPTH FROM SURFACE TO IMPERMEABLE ' ,
$'LAYER=' ,F5.1, 'CM')
802 FORMAT(1X, 'SURFACE STORAGE THAT MUST BE FILLED BEFORE WATER CAN ' ,
$'MOVE TO DRAIN (FIG.2-12) =' ,F5.2, 'CM'/1X, 'FACTOR -G- IN KIRKHAM ' ,
$'EQ. 2-17 =' ,F10.2)
810 FORMAT(86X, 'FIRST PERIOD  SECOND PERIOD'/
$1X, 10X, 'REQUIREMENTS ' , '-MINIMUM AIR VOLUME IN SOIL(CM): ' ,
$23X, 5X, F5.2, 10X, F5.2/25X, '-MAXIMUM ALLOWABLE DAILY RAINFALL(CM): ' ,
$18X, 5X, F5.2, 10X, F5.2/25X, '-MINIMUM TIME AFTER RAIN BEFORE ' ,
$' TILLING CAN CONTINUE: ' , 3X, 5X, F5.2, 10X, F5.2)
815 FORMAT(/1X, 10X, 'WORKING TIMES ' , '-DATE TO BEGIN COUNTING WORK ' ,
$' DAYS: ' , 21X, 5X, I2, '/' , I2, 10X, I2, '/' , I2/25X,
$'-DATE TO STOP COUNTING WORK DAYS: ' , 23X, 5X, I2, '/' , I2, 10X, I2, '/' ,
$I2/25X, '-FIRST WORK HOUR OF THE DAY: ' , 30X, 6X, I2, 13X, I2/25X,
$'-LAST WORK HOUR OF THE DAY: ' , 31X, 6X, I2, 13X, I2)
820 FORMAT(/, 1X, 'WIDTH OF DITCH BOTTOM= ' , F5.1, ' CM'/1X,
1'SIDE SLOPE OF DITCH (HORIZ:VERT)= ' , F5.2, ' : 1.00')
822 FORMAT(///38X, 'DEPTH', 7X, 'SATURATED HYDRAULIC CONDUCTIVITY'/
1 39X, '(CM)', 20X, '(CM/HR)'/)
828 FORMAT(33X, F7.1, ' - ' , F7.1, 7X, F11.3)
830 FORMAT(1X/5X, 'DEPTH OF WIER FROM THE SURFACE'//1X, 'DATE', 9X, '1/'
$, F3.0, 3X, '2/' , F3.0, 3X, '3/' , F3.0, 3X, '4/' , F3.0, 3X, '5/' , F3.0, 3X, '6/'
$, F3.0, 3X, '7/' , F3.0, 3X, '8/' , F3.0, 3X, '9/' , F3.0, 3X, '10/' , F3.0, 2X, '11/'
$, F3.0, 2X, '12/' , F3.0)
840 FORMAT(1X, 'WIER DEPTH', 12F8.1)
850 FORMAT(1X, 'FIRST DAY OF SURFACE IRRIGATION=' , I3/1X,
$'INTERVAL BETWEEN SURFACE IRRIGATION DAYS=' , I3/1X,
$'STARTING HOUR OF SURFACE IRRIGATION=' , I3/1X,
$'ENDING HOUR OF SURFACE IRRIGATION=' , I3/1X,
$'NO SURFACE IRRIGATION INTERVAL 1=' , I4, 2X, I4/1X,
$'NO SURFACE IRRIGATION INTERVAL 2=' , I4, 2X, I4)
860 FORMAT(1X, 'MINIMUM AIR REQUIRED TO HAVE SURFACE IRRIGATION=' ,
$F6.2, 'CM'/1X, 'AMOUNT OF RAIN TO POSTPONE SURFACE IRRIGATION=' ,
$F6.2, 'CM'/1X, 'SURFACE IRRIGATION FOR ONE HOUR=' , 12F6.2, 'CM')
870 FORMAT(1X, 'INDET=' , I2, 'WHEN INDET.GT. 0 USE READ IN VALUES TO DETE
2RMINE ET WHEN LIMITED BY SOIL CONDITIONS')
900 FORMAT(1H1)
910 FORMAT(2I10)
920 FORMAT(//2X, 'DAY', 3X, 'RAIN', 3X, 'INFIL', 6X, 'ET', 4X, 'DRAIN', 2X,
$'AIR VOL', 3X, 'TVOL', 4X, 'DDZ', 4X, 'WETZ', 3X, 'DTWT', 4X, 'STOR',
$1X, 'RUNOFF', 2X, 'WLOSS', 3X, 'YD', 3X, 'DRNSTO', 2X, 'SEW', 2X, 'DMTSI')
930 FORMAT(2X, I3, 8F8.2 , 8F7.2)
940 FORMAT(1H0, 15X, 'MONTHLY VOLUMES IN CENTIMETERS FOR YEAR', I6)
950 FORMAT( 2X, 'MONTH', 1X, 'RAINFALL', 1X, 'INFILTRATION', 1X, 'RUNOFF', 1X,
$'DRAINAGE', 1X, ' ET ' , ' DRY DAYS ' , ' WRK DAYS ' ,
$ 1X , 'WATER LOSS', 4X, 'SEW', 3X, 'MIR', 4X, 'MCN', 1X, 'PUMP', 2X, 'MPT
3')
960 FORMAT(1X, I3, F10.2, F11.2, F10.2, F8.2, F10.2, 2F8.2, F11.2, F10.2,
23X, F5.2, I4, F7.3, I4)
990 FORMAT(1H0/1X, 'TOTALS', 7F9.2, 4X, 4F9.2)

```

```

C
C
C ! -----
C !                      END OF SECTION 9
C !                      END OF FORSUB
C ! RETURN TO MAIN FOR NEW SET OF DATA TO START SIMULATION FOR FIRST MON
C ! OF THE NEXT YEAR.
C ! -----
C
      RETURN
      END

C
C
      SUBROUTINE DRAINS(DTWT,DFLUX)

C
C * THIS SUBROUTINE FINDS THE EFFECTIVE LATERAL HYDRAULIC CONDUCTIVITY A*
C * COMPUTES DRAINAGE OR SUBIRRIGATION FLUX. *
C
      COMMON/DRABLK/HDRAIN,DEPTH,CONK(5),DZ(5)
      COMMON/DLK/SDRAIN,DDRAIN,DC,ADEPTH
      COMMON/POND/STOR,GEE,STORRO
      DIMENSION W(20)
      Y=DTWT
      IF(Y .GT. ADEPTH) Y=ADEPTH
      ABOVE=0.0
      DO 10 I=1,5
        N=I
        L=DZ(I)
        IF(L.EQ.0) GO TO 15
        IF(Y.GT.DZ(I))GO TO 5
        W(I)=DZ(I)-Y
        X=DZ(I)-ABOVE
        IF(W(I).GT.X)W(I)=X
        GO TO 10
      5 W(I)=0.0
      10 ABOVE=DZ(I)
        N=6
      15 N=N-1
        SUM=0.0
        DEEP=0.0
        DO 25 I=1,N
          SUM=SUM+W(I)*CONK(I)
      25 DEEP=DEEP+W(I)
        IF((DEEP.LE. .0001).OR.(SUM.LE. .0001)) GO TO 35
        CONE=SUM/DEEP
        GO TO 45
      35 CONTINUE
        SUM=CONK(1)*DZ(1)
        DEEP=DZ(1)
        DO 40 I=2,5
          SUM=SUM+CONK(I)*DZ(I)
      40 DEEP=DEEP+DZ(I)
        CONE=SUM/DEEP
      45 CONTINUE

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```

HDMIN=DEPTH-DDRAIN
IF(HDRAIN.LT.HDMIN) HDRAIN=HDMIN
IF((STOR.GT. STORRO).AND.(DTWT .LT. 0.5)) GO TO 50

C
EM=DEPTH-Y-HDRAIN
IF(EM .LT. -.0.1) GO TO 42
DFLUX=4.0*CONE*EM*(2.0*HDRAIN+EM) /SDRAIN**2
IF(DFLUX .GT. DC) DFLUX=DC
IF(DFLUX .LT. .0)DFLUX=0.0
IF(EM.LT.0) DFLUX=0.0
RETURN
42 DDRAINP=DDRAIN-0.10
DOT=HDRAIN+ADEPTH-DEPTH
DFLUX=4.0*CONE*EM*HDRAIN*(2.0+EM/DOT)/SDRAIN**2
IF((DEPTH-HDRAIN).GE.DDRAINP)DFLUX=0.
RETURN
50 DFLUX=12.5663*CONE*(DEPTH-HDRAIN+STOR)/(GEE*SDRAIN)
IF(DFLUX.GT.DC) DFLUX=DC

C
RETURN
END
SUBROUTINE ETFLUX (AVOL,DEBT,FVOL,DVOL,UPVOL,POTET,ACTET,PDEBT)

C
C * THIS SUBROUTINE DETERMINES ACTUAL HOURLY OR DAILY ET BASED ON PET AN*
C * UPWARD FLUX FROM THE WATER TABLE. *
C * IF UPWARD FLUX IS INSUFFICIENT TO SUPPLY ET DEMAND, WATER IS REMOVED*
C * FROM ROOT ZONE TO MAKE UP THE DIFFERENCE. *
C * IF ROOT ZONE WATER IS NOT AVAILABLE, ET IS LIMITED. *
C
IF(DEBT.GT.0.0) GO TO 50
IF(UPVOL.LT.POTET) GO TO 25
ACTET=POTET
DEBT=0.0
AVOL=AVOL+DVOL+ACTET-FVOL
RETURN
25 DEBT=DEBT-FVOL
XXD=DEBT+POTET-UPVOL
IF(DEBT.GE.0.0)GO TO 28
ACTET=POTET
AVOL=AVOL+DVOL+DEBT+ACTET
DEBT=0.0
RETURN
28 IF(XXD.GT.PDEBT)GO TO 30
ACTET=POTET
DEBT=DEBT+POTET-UPVOL
AVOL=AVOL+DVOL+UPVOL
RETURN
30 ACTET=PDEBT-DEBT+UPVOL
IF(ACTET.GE.0.0) GO TO 31
ACTET=0.0
DEBT=DEBT-UPVOL
AVOL=AVOL+DVOL+UPVOL
RETURN
31 CONTINUE

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```

DEBT=PDEBT
AVOL=AVOL+DVOL+UPVOL
RETURN
50 IF(POTET.GT.UPVOL) GO TO 25
EXCESS=UPVOL -POTET
ACTET=POTET
DEBT=DEBT-FVOL
YDEB=DEBT
DEBT=DEBT-EXCESS
IF(DEBT.LT.0.0)GO TO 60
AVOL=AVOL+DVOL+UPVOL
GO TO 70
60 AVOL=AVOL+DVOL+ACTET+YDEB
70 IF(DEBT.LT.0.0)DEBT=0.0
C
C
RETURN
END
SUBROUTINE EVAP(ET,HET,HPET1,TPET)
C
C * THIS SUBROUTINE DISTRIBUTES DAILY PET OVER 12 HRS. FROM 0600 TO 1800*
C * WHEN RAINFALL .GT. 0 PET FOR THAT HOUR IS SET=0. *
C * THEN HOURLY PET SUMMED TO GET DAILY PET. *
C
C FIND DAILY EVAPOTRANSPIRATION
C
COMMON/EVAPO/PET,DDZ,ROOTD
COMMON/RAIN/R(24)
DIMENSION HET(24),HPET1(24)
C
C FIGURE ET BASED ON 12 HRS
TPET=0.0
HPET=PET/12.0
DO 5 I=1,6
HET(I)=0.0
HPET1(I)=0.0
5 CONTINUE
DO 10 I=7,18
HET(I)=HPET
HPET1(I)=HPET
C As using aet of ceres for pet of drainmod, need make drainmod use
C all of pet which is what plants actually used in ceres.
C IF(DDZ.GT.ROOTD)HET(I)=0.0
C IF(R(I).GT.0.0)HET(I)=0.0
C IF(R(I).GT.0.0)HPET1(I)=0.0
10 CONTINUE
DO 15 I=19,24
HET(I)=0.0
HPET1(I)=0.0
15 CONTINUE
ET=0.0
DO 20 I=1,24
ET=ET+HET(I)
TPET=TPET+HPET1(I)

```

```

20 CONTINUE
C
  RETURN
  END
  SUBROUTINE ORDER(IYEAR)
C
C * THIS SUBROUTINE DETERMINES THE RANK OF TOTDD, TOTWD, SEW, AND TOSIRR*
C * AND THEIR AVERAGES DURING THE SIMULATED YEARS. *
C
  COMMON/ORDR/TOSIRR(50),TOTDD(50),TOTWD(50),SEW(50),IRY(50)
  DIMENSION NRANK1(50),NRANK2(50),NRANK3(50),NRANK4(50)
  DATA SUMWKY,SUMSEW,SUMDDY,SUMIRR/4*0.0/
  CALL RANK(TOTWD,NRANK1,IYEAR,IRY)
  CALL RANK(SEW,NRANK2,IYEAR,IRY)
  CALL RANK(TOTDD,NRANK3,IYEAR,IRY)
  CALL RANK(TOSIRR,NRANK4,IYEAR,IRY)
  WRITE(3,10)
  DO 20 I=1,IYEAR
    WRITE(3,30)I,TOTWD(I),NRANK1(I),SEW(I),NRANK2(I),TOTDD(I),
  1 NRANK3(I),TOSIRR(I),NRANK4(I)
    SUMWKY=SUMWKY+TOTWD(I)
    SUMSEW=SUMSEW+SEW(I)
    SUMDDY=SUMDDY+TOTDD(I)
  20 SUMIRR=SUMIRR+TOSIRR(I)
C CALCULATE AVERAGES
  AVGWKY=SUMWKY/IYEAR
  AVGSEW=SUMSEW/IYEAR
  AVGDDY=SUMDDY/IYEAR
  AVGIRR=SUMIRR/IYEAR
  WRITE(3,40) AVGWKY,AVGSEW,AVGDDY,AVGIRR
  10 FORMAT('1',14X,'RANK',3X,'WORK DAYS',2X,'YEAR',10X,'SEW',6X,'YEAR'
  1,8X,'DRY DAYS',3X,'YEAR',7X,'IRRIGATION',2X,'YEAR'/)
  30 FORMAT(15X,I4,4(F11.2,I7,5X))
  40 FORMAT('0',10X,'AVERAGE',4(F12.2,11X))
C
C
  RETURN
  END
  SUBROUTINE PROP(WTD,VOL,WATER,AA,BB,UPFLUX)
C
C * THIS SUBROUTINE READS IN SOIL WATER CHARACTERISTIC, INTERPOLATES *
C * VALUES, AND CALCULATES RELATIONSHIP BETWEEN WATER TABLE DEPTH AND *
C * DRAINAGE VOLUME. *
C * AS AN ALTERNATIVE CAN READ IN DRAINED VOLUME - WATER TABLE DEPTH *
C * RELATIONSHIP WHICH MAY ALSO INCLUDE UPWARD FLUX VALUES. *
C * A TABLE OF CONSTANTS FOR THE GREEN - AMPT INFILTRATION EQUATION FOR *
C * VARIOUS WATER TABLE DEPTHS IS READ IN AND INTERPOLATED. *
C * ALL SOIL PROPERTIES ARE STORED IN ARRAYS SO THAT THEY CAN BE EASILY *
C * RECALLED KNOWING THE WATER TABLE DEPTH. *
C
C READ SOIL PROPERTIES AND STORE THE INFORMATION INTO
C PROPER ARRAYS BY INTERPOLATION
  DIMENSION THETA(50),HEAD(50),WATER(1000),VOL(1000),WTD(1000)
  DIMENSION D(10),E(10),F(10),AA(1000),BB(1000)

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      DIMENSION AIA(1000),BIB(1000)
      DIMENSION XVOL(100),X(100)
      DIMENSION UPFLUX(1000),FLUX(100)

C
C ! -----
C ! THE FOLLOWING SECTION READS IN SOIL WATER CHARACTERISTIC, AND CAL-
C ! CULATES RELATIONSHIP BETWEEN DRAINED VOLUME AND WATER TABLE DEPTH.
C ! -----
C
      READ(1,900) NUM,IVREAD
      WRITE(10,900) NUM,IVREAD
      READ(1,905)(THETA(I),HEAD(I),I=1,NUM)
      WRITE(10,905)(THETA(I),HEAD(I),I=1,NUM)
C
      DATA READ IN ORDER OF DECREASING WATER CONTENT
      DO 5 I = 1,NUM
5 HEAD(I) = -HEAD(I)+1.0
      I=1
      WATER(1)=THETA(1)
      P=WATER(1)
      VOL(1)=0
      DO 10 J = 2,1000
      AJ = J
      IF(AJ.GT.HEAD(I+1))I=I+1
      AI = I
      AIM=I-1
      WATER(J) = THETA(I)+(AJ-HEAD(I))/(HEAD(I+1)-HEAD(I))*
C(THETA(I+1)-THETA(I))
      AVG = (WATER(J)+WATER(J-1))/2
      VOL(J) = VOL(J-1) + P-AVG
      10 CONTINUE

C
C ! -----
C ! THE FOLLOWING READS TABULAR VALUES FOR W.T. DEPTH VS. DRAINAGE VOLUM
C ! AND UPWARD FLUX.
C ! THE NUMBER OF VALUES READ IS IVREAD.
C ! IF IVREAD .LE. 0, USE ABOVE W.T.D.-VOL. RELATIONSHIP AND CRITICAL
C ! DEPTH CONCEPT FOR UPWARD FLUX.
C ! -----
C
      IF(IVREAD.LE.0) GO TO 14
C      IF WATER VOL VS. WATER TAB DEPTH IS READ IN GO TO NEXT STEPS
C      IF WATER VOL VS. WATER TAB DEPTH IS READ IN GO TO NEXT STEPS
      READ(1,930)(X(I),XVOL(I),FLUX(I),I=1,IVREAD)
      WRITE(10,930)(X(I),XVOL(I),FLUX(I),I=1,IVREAD)
      IF(X(IVREAD).GE.1000.) GO TO 150
      IVREAD=IVREAD+1
      WRITE(3,701) X(IVREAD)
701  FORMAT(///1X,'PROGRAM TERMINATING... THE LAST ENTERED DEPTH ',
$'VALUE WAS ',F12.2,' CM. THIS WILL CAUSE A RUN-TIME ERROR.')
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      WRITE(3,702)
702  FORMAT(//1X,'TO CORRECT THE INPUT, ADD A FINAL LINE TO THE SOIL',
$' PROPERTIES...//,11X,'X(IVREAD)  XVOL(IVREAD)  FLUX(IVREAD)',
$      /11X,' 1000.      100.      0.0',//
$ 1X,'BE SURE THAT THE SECOND TO THE LAST ENTRY EXTENDS DOWN TO ',
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$ 'A DEPTH THAT IS '/1X,'AT LEAST EQUAL TO THE DEPTH TO THE ',
$ 'IMPERMEABLE LAYER PLUS THE MAXIMUM ROOTING DEPTH')
STOP
150 DO 12 I=1,IVREAD
12 X(I)=X(I)+1.0
UPFLUX(1)=FLUX(1)
VOL(1)=XVOL(1)
I=1
DO 11 L=2,1000
XL=L
IF(XL.GT.X(I+1))I=I+1
XI=I
XIM=XI-1.
UPFLUX(L)=FLUX(I)+((XL-X(I))/(X(I+1)-X(I)))*(FLUX(I+1)-FLUX(I))
11 VOL(L)=XVOL(I)+((XL-X(I))/(X(I+1)-X(I)))*(XVOL(I+1)-XVOL(I))
C
C !-----
C ! CONVERT TO ARRAY SO CAN DIRECTLY DETERMINE WATER TABLE DEPTH (OR WET
C ! ZONE DEPTH) IF KNOW AIR VOLUME.
C !-----
C
14 CONTINUE
DO 15 K = 1,1000
15 VOL(K) = VOL(K)*10.0+1.0
I = 2
AI = I
WTD(1) = 0
DO 25 L = 2,1000
AL = L
ALM = AL-1.0
IF(VOL(L).LT.AI) GO TO 25
20 WTD(I) = ALM + (AI-VOL(L-1))/(VOL(L)-VOL(L-1))-1.0
I = I + 1
AI = I
IF(VOL(L).GT.AI) GO TO 20
25 CONTINUE
WRITE(3,915)
DO 30 I=1,1000
VOL(I) = 0.1*(VOL(I)-1.0)
XI = I
AI = 0.1*(XI-1.0)
BI = I-1
AIA(I)=AI
BIB(I)=BI
30 CONTINUE
DO 50 I=1,301,10
50 WRITE(3,910)AIA(I),WTD(I),BIB(I),WATER(I),VOL(I),UPFLUX(I)
DO 51 I=351,501,50
51 WRITE(3,910)AIA(I),WTD(I),BIB(I),WATER(I),VOL(I),UPFLUX(I)
DO 52 I=601,1000,100
52 WRITE(3,910)AIA(I),WTD(I),BIB(I),WATER(I),VOL(I),UPFLUX(I)
C !-----
C ! READ IN INFILTRATION CONSTANTS FOR GREEN-AMPT EQUATION AND INTERPOLA
C !-----

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      READ(1,900)NUMA
      WRITE(10,900)NUMA
      READ(1,920)(D(I),E(I),F(I),I=1,NUMA)
      WRITE(10,920)(D(I),E(I),F(I),I=1,NUMA)
      IF(D(NUMA).GE.1000.) GO TO 160
      NUMA=NUMA+1
      D(NUMA)=1000.
      E(NUMA)=E(NUMA-1)
      F(NUMA)=F(NUMA-1)
160  WRITE(3,940)
      WRITE(3,945) (D(I),E(I),F(I),I=1,NUMA)
      AA(1)=0.
      BB(1)=0.
      I=1
      J=2
      XJ=J-1
35  IP=I+1
      RATIO=(XJ -D(I))/(D(IP)-D(I))
      AA(J)=E(I)+RATIO*(E(IP)-E(I))
      BB(J)=F(I)+RATIO*(F(IP)-F(I))
      J=J+1
      XJ=J-1
      IF (XJ.GT.D(IP))I=I+1
      IF(I.GE.NUMA)GO TO 45
      GO TO 35
45  CONTINUE
900  FORMAT(2I2)
905  FORMAT(F10.7,F10.1)
910  FORMAT(18X,F6.1,10X,F7.1,10X,':',11X,F7.1,9X,F6.4,9X,F6.2,8X,F7.4)
915  FORMAT(1H1,54X,'SOIL INPUTS'/55X,'*****'//26X,'TABLE 1',
      118X,':',33X,'TABLE 2'/51X,':'/22X,'DRAINAGE TABLE',15X,':',10X,
      2'SOIL WATER CHARACTERISTIC VS VOID VOLUME VS UPFLUX'/51X,':'/
      316X,'VOID VOLUME',3X,'WATER TABLE DEPTH',4X,':',14X,'HEAD',6X,
      4'WATER CONTENT',3X,'VOID VOLUME',5X,'UPFLUX'/20X,'(CM)',13X,
      5'(CM)',10X,':',14X,'(CM)',8X,'(CM/CM)',11X,'(CM)',8X,'(CM/HR)')
920  FORMAT(3E10.2)
940  FORMAT(///10X,'GREEN AMPT INFILTRATION PARAMETERS'/12X,'W.T.D.',
      $ 9X,'A',9X,'B'/13X,'(CM)',7X,'(CM)',7X,'(CM)')
945  FORMAT(6X,3F11.3)
930  FORMAT(3F10.4)
C
      RETURN
      END
      SUBROUTINE RANK(BAF,NK,IYEAR,IR)
C
C *****
C * THIS SUBROUTINE DETERMINES THE RANK FOR AN ARRAY. *
C *****
      DIMENSION NK(50),BAF(50),IR(50)
      DO 10 I=1,IYEAR
      NK(I)=IR(I)
      IF(I.EQ.1) GO TO 10
      K=I-1
C REARRANGE ARRAY BAF FROM MAX TO MIN

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```

DO 20 J=1,K
M=K-J+1
IF(BAF(M+1).LE.BAF(M)) GO TO 10
NN=NK(M+1)
NK(M+1)=NK(M)
NK(M)=NN
AF=BAF(M+1)
BAF(M+1)=BAF(M)
BAF(M)=AF
20 CONTINUE
10 CONTINUE
C
RETURN
END
C
C
SUBROUTINE ROOT(DROOT,MOIN,IDAYIN,NNOO)
C
C * SUBROUTINE TO READ IN TABULAR VALUES OF EFFECTIVE ROOT DEPTH VERSUS *
C * TIME AND INTERPOLATE BETWEEN VALUES SO THAT ROOT DEPTH FOR ANY DAY C*
C * BE CALLED DIRECTLY AS A FUNCTION OF THE DAY. *
C
DIMENSION DROOT(370), INDAY(50),ROOTIN(50)
DIMENSION MOIN(50),IDAYIN(50)
DIMENSION KALDAY(12)
DATA KALDAY/0,31,59,90,120,151,181,212,243,273,304,334/
READ(1,600) NO
WRITE(10,600) NO
NNOO=NO
READ(1,610)(MOIN(I),IDAYIN(I),ROOTIN(I),I=1,NO)
WRITE(10,610)(MOIN(I),IDAYIN(I),ROOTIN(I),I=1,NO)
DO 5 I=1,NO
JJ=MOIN(I)
5 INDAY(I)=KALDAY(JJ)+IDAYIN(I)
J=2
DROOT(1)=ROOTIN(1)
DO 10 I=2,366
AI=I
IF(I.GT.INDAY(J))J=J+1
DROOT(I)=ROOTIN(J-1)+((AI-INDAY(J-1))/(INDAY(J)-INDAY(J-1)))*
2(ROOTIN(J)-ROOTIN(J-1))
10 CONTINUE
610 FORMAT(8(2I2,F6.2))
600 FORMAT(I2)
C
RETURN
END
SUBROUTINE SOAK
C
C * SUBROUTINE TO FIND PARAMETERS IN GREEN-AMPT INFILTRATION EQUATION *
C * BASED ON EFFECTIVE WATER TABLE DEPTH AT BEGINNING OF RAINFALL EVENT.*
C
COMMON/ABDT/EDTWT,AA(1000),BB(1000),A,B
C

```

```

      I=EDTWT+1
      A=AA(I)
      B=BB(I)

C
      RETURN
      END
      SUBROUTINE SURIRR

C
C * THIS SUBROUTINE DETERMINES IF CONDITIONS ARE SUITABLE FOR SURFACE *
C * IRRIGATION FOR WASTE WATER DISPOSAL. *
C * IT ALSO COUNTS THE NUMBER OF IRRIGATION DAYS, SKIPS, AND *
C * POSTPONEMENTS. *
C
      COMMON/ICNT/ISICNT,ISKIP,IPOST,IK,IPCNT
      COMMON/JCNT/JSICNM,JSKIPM,JPOSTM
      COMMON/IDAY/FDAYSI,NDAYSI,INTDAY,NOIRR1,NOIRR2,NOIRR3,NOIRR4
      COMMON/IHR/IHRSTA,IHREND,INSIRR
      COMMON/PAR/TAV,REQDAR,AMTRN,AMTSI,DAMTSI
      COMMON/RAIN/R(24)
      INTEGER FDAYSI

C
      IF(NDAYSI.GE.NOIRR1.AND.NDAYSI.LE.NOIRR2)GO TO 30
      IF(TAV .LT. REQDAR .AND. INSIRR .GT.0) GO TO 20
      IF(TAV .LT. REQDAR) GO TO 10
      IF(R(IHRSTA).GT.AMTRN) GO TO 20
      IHRP1=IHRSTA+1
      DO 5 I=IHRP1,IHREND
      R(I)=R(I)+AMTSI
5 CONTINUE
      DAMTSI=AMTSI*(IHREND-IHRSTA)
      JSICNM=JSICNM+1
      ISICNT=ISICNT+1
      GO TO 15

C
10 ISKIP=ISKIP+1
   JSKIPM=JSKIPM+1
15 NDAYSI=FDAYSI+INTDAY*(ISICNT+ISKIP+IK)
   IPCNT=0
   GO TO 25

C
20 NDAYSI=NDAYSI+1
   IPOST=IPOST+1
   JPOSTM=JPOSTM+1
   IPCNT=IPCNT+1
   IF(IPCNT .GE. 2) GO TO 10
25 IF(NDAYSI.GE.NOIRR1.AND.NDAYSI.LE.NOIRR2) GO TO 30

C
      RETURN
30 MDAYSI=NDAYSI
   DO 35 I=MDAYSI,NOIRR2,INTDAY
      IK=IK+1
      NDAYSI=I+INTDAY
35 CONTINUE
      NOIRR1=NOIRR3

```

```

NOIRR2=NOIRR4

C
RETURN
END
SUBROUTINE WORK(IND,J,TAV,DWRK,ACC,DDAY,YTAV)

C
C * THIS SUBROUTINE DETERMINES IF ALL OR ANY PART OF THIS DAY MAY BE *
C * CONSIDERED A WORK DAY. *
C
COMMON /RAIN/ R(24)
COMMON /IWK/ SWKHR1,EWKHR1,SWKHR2,EWKHR2
COMMON /WRK/ AMIN1,ROUTA1,ROUTT1,AMIN2,ROUTA2,ROUTT2
INTEGER SWKHR1,SWKHR2,EWKHR1,EWKHR2
IF(J.LT.0) GO TO 50
IF(IND.GT. 1) GO TO 25
IF((ACC.GT.ROUTA1).AND. (R(J) .GT. 0.005)) DDAY=0.0
IF((J .LE. SWKHR1) .OR. (J .GT. EWKHR1)) GO TO 60
IF(TAV.LT. AMIN1) GO TO 60
IF(DDAY .LT. ROUTT1) GO TO 60
DWRK=1.0/(EWKHR1-SWKHR1)
RETURN
25 IF((ACC .GT. ROUTA2) .AND. (R(J) .GT. 0.005)) DDAY=0.0
IF((J .LE. SWKHR2) .OR. (J .GT. EWKHR2)) GO TO 60
IF(TAV .LT. AMIN2) GO TO 60
IF(DDAY .LT. ROUTT2) GO TO 60
DWRK=1.0/(EWKHR2-SWKHR2)
RETURN
60 DWRK=0.0
RETURN
50 IF(IND .GT. 1) GO TO 55
IF(TAV.LT. AMIN1) GO TO 60
IF(DDAY .LT. ROUTT1) GO TO 60
DWRK=1.0
IF(YTAV .LT. AMIN1) DWRK=(TAV-AMIN1)/(TAV-YTAV)
RETURN
55 IF(TAV .LT. AMIN2) GO TO 60
IF(DDAY .LT. ROUTT2) GO TO 60
DWRK=1.0
IF(YTAV .LT. AMIN2) DWRK=(TAV-AMIN2)/(TAV-YTAV)

C
RETURN
END
SUBROUTINE YDITCH(DWIEP,DVOL,YD,RO,WLOSS,B,S)

C
C * SUBROUTINE TO DETERMINE WATER LEVEL IN OUTLET DITCH BASED ON WIER SE*
C * ING, DRAINAGE OR SUBIRRIGATION, AND RUNOFF. *
C * THE AMOUNT OF WATER LOST FROM THE SYSTEM AND THAT REMAINING IN THE *
C * DITCH IS CALCULATED. *
C
C FIND WATER LOSS AND WATER DEPTH IN DRAIN
C
COMMON/DLK/SDRAIN,DDRAIN,DC,ADEPTH
COMMON/DBLK/DRNSTO

```

```

V=DRNSTO+RO+DVOL
IF(V.LT.O.)V=0.
CV=V*SDRAIN
YD=((B/S)**2+4.*CV/S)**0.5/2.-0.5*B/S
IF(YD.GT.(DDRAIN-DWIEP))GO TO 10
DDSTO=V-DRNSTO
DRNSTO=V
WLOSS=0.
RETURN

```

```

C
10 YD=DDRAIN-DWIEP
CV=YD*(B+ S*YD)
V=CV/SDRAIN
DDSTO=V-DRNSTO
DRNSTO=V
WLOSS=RO + DVOL-DDSTO
C END OF DRAINMOD SOURCE CODE LISTING
RETURN
END

```

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