DEVELOPMENT OF A DRIP IRRIGATION SCHEDULING MODEL

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TECHNICAL COMPLETION REPORT
Project No. 1-4-23651

August 1987

New Mexico Water Resources Research Institute
in cooperation with
Department of Agronomy and Horticulture
New Mexico State University

The research on which this report is based was financed in part by the New Mexico Interstate Stream Commission and the U.S. Department of the Interior, Geological Survey, through the New Mexico Water Resources Research Institute.

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ABSTRACT

This irrigation scheduling model uses a water balance approach to determine when to irrigate using a trickle irrigation system to apply the water. The model describes the flow of water entering a cube from the left side, filling ellipsoides until water reaches the center of the cube where water from the next emitter combines with the modeled emitter to cause downward flow of water to deep drainage.

The irrigation model applies water to maintain a predetermined soil moisture range within the crop root zone. Rainfall enters the cube as one dimensional flow. Transpiration is calculated using Penman's equation and a crop curve based on growing-degree-days. Evaporation is calculated based on potential evaporation and a leaf area index function for stage-one evaporation and a time base function for stage-two evaporation. The model has not been tested against field data. Testing of the model should be completed before this model is used to schedule trickle irrigations on a production field.

Keywords: computer model, irrigation program, scheduling water

PREFACE

The following report is a description of an irrigation scheduling model that runs on an IBM PC.

The disk containing all the programs associated with the irrigation scheduling model can be obtained by writing to the Water Resources Research Institute, Box 30001, New Mexico State University, Las Cruces, New Mexico 88003. The cost of copying and mailing the program disk is $20.

The computer program upon which this report is based has not been tested under all circumstances and, therefore, cannot be guaranteed to run. The author would, however, appreciate being notified of any problems that might be encountered.

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INTRODUCTION

Trickle irrigation is the relatively precise and uniform application of irrigation water using devices such as trickle emitters, micro-jets, micro-sprays, or spitters. Trickle irrigation can provide substantial benefits to growers in terms of water and energy conservation, increased crop yield, crop quality and management flexibilities. As water becomes limiting, more acreage is being converted from traditional sprinkler or flood irrigation to trickle irrigation especially where the soils are coarse and have high infiltration rates. California has at least 300,000 acres under trickle irrigation. Hawaii has large acreages of sugar cane under trickle irrigation and it is being used in growing vegetables, such as tomatoes, cabbage and lettuce. High cash value crops such as chiles, pecans and grapes are trickle irrigated in New Mexico. Trickle irrigation can provide the plant's water requirements without considerable surface and deep drainage losses often associated with conventional surface and sprinkler irrigation. However, proper management of a trickle irrigation system requires some form of irrigation scheduling especially at locations where part of the water requirement of the crops can be supplied by rainfall.

The yield response from an irrigation application will depend not only upon the timing and amount of irrigation applied but also upon the uniformity under which the water is applied. As water application uniformity decreases, the mean application in the field has to increase to compensate for those areas of the field which are under-irrigated. Soil water movement under a trickle irrigation system is unique compared to other irrigation systems in that the water normally moves in two or three dimensions rather than the simple one-dimensional flow that can be approximated for sprinkler or surface irrigation. Also, unlike surface or sprinkler irrigation, trickle irrigation only wets part of the soil surface; consequently, the evaporation losses under trickle irrigation are different than under surface or sprinkler irrigation.

Irrigation scheduling has been defined by Jensen (1981) as planning and decision-making activities that the water manager or operator of an irrigated farm is involved in before and during most of the growing season for any crop that is grown. Irrigation scheduling involves two decisions; when to irrigate and how much to irrigate. These two decisions are interdependent and require extensive experience on the part of the scheduler in order to identify the optimal choice (English et al. 1980). Irrigation quantities are normally based upon irrigation capacity of the irrigation system and the soil water-holding capacity. However, when using irrigation scheduling for a trickle irrigation system, water is applied at frequent intervals, normally every one or two days, and the amount of water applied is sufficient to satisfy the evapotranspiration of the crops since the previous irrigation date. At the farm-irrigation level the most promising form of irrigation scheduling is a computer-based irrigation scheduling model using micro-meterological data and the soil water budget accounting procedure that is implemented by the farmer on his micro-computer. Irrigation scheduling on a commercial basis has been demonstrated to be economically feasible (English et al. 1980) due to the derived water conservation, energy conservation, crop production improvement, and environmental benefits. When an irrigation procedure is based on the water balance technique in a computerized irrigation scheduling model, the records of irrigation timing and amounts become part of the farmers' total management record of the crop production.

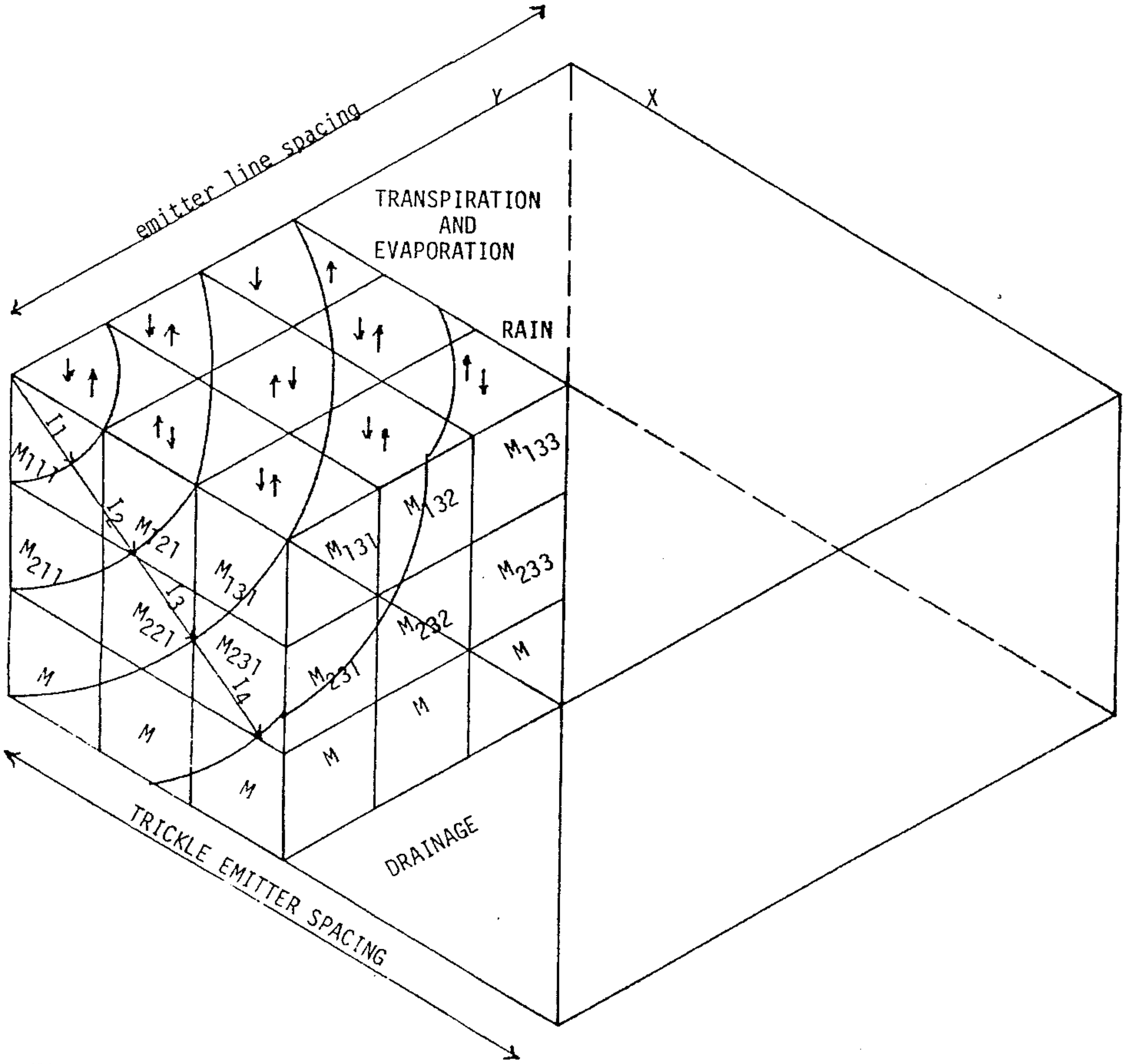
The first irrigation scheduling model proposed by Jensen et al. (1970) had been widely used in the United States for scheduling center pivot and surface irrigation systems. Heermann et al. (1976) showed that computer scheduling procedures can be used to schedule field crop irrigations for an entire season without adjustment to the computer estimated soil moisture depletion; however, field verification of computer estimates are a necessary check on the computer schedules. Field verification can be accomplished through use of tensiometers to measure soil moisture tension, neutron probes to measure soil moisture content, plant-water status by use of a pressure bomb, or measurement of leaf-minus-air-temperature differences using infrared thermometry. Computer models developed by the U. S. Bureau of Reclamation have been operated on large size computers. A very limited number of irrigation scheduling models have been developed for micro-computers (Stegman et al. 1984; Hulsman et al. 1984; Hulsman 1985).

The objective of the research was to develop a trickle irrigation scheduling model that would simulate water use by a crop under trickle irrigation. The model also would schedule irrigations for a climate condition such as New Mexico's where rainfall does not supply a significant portion of the water requirement of the crop and for a climate condition such as Hawaii's where rainfall can supply most of the water requirement of the crop.

Description of Model

All of the water balance irrigation scheduling models including the trickle irrigation scheduling model consist of a climate estimated reference evapotranspiration (ET), an index for relating expected crop water use to reference ET, an index for estimating additional soil water evaporation from a wet soil surface, an index for estimating the effect of soil water depletion on actual ET, an estimate of extractable-soil water by specified crops from specified soil and, with yield as a component, the relationship between expected crop yield and water use. Most crop curves relating reference ET to expected ET have been developed under conditions of surface or sprinkler irrigation and have not been developed or tested under conditions of trickle irrigation. Also, crop response to moisture stress has been documented with a limited sprinkler or furrow irrigation data base. The crop curves and water production functions reported in the literature include the effect of evaporation and they need to be adjusted for trickle irrigation conditions where the evaporation component is significantly different then under flood irrigation. The flood irrigated, crop water production functions and crop curves adjusted back to transpiration are used as a first approximation in the model. The transferability of crop curves and crop water production functions from areas of dry desert climatic conditions to areas of humid conditions have not been investigated or verified. Consequently, the irrigation scheduling model described will work satisfactory in the climatic conditions existing in New Mexico, but may not work in Hawaii or other rainfall areas without adjustments to the crop curves and water production functions.

The irrigation scheduling model is similar to that described by Sammis et al. (1986) for a one dimensional soil-water-flow problem described in appendix A, but modifications in the basic structure of the model have been made to make it appropriate for the trickle irrigation system. Figure 1 gives a schematic diagram of the current structure of the model that is appropriate for three-dimensional water-flow representing a trickle irrigation system. The model computes a reference-crop-potential transpiration based on Penman's Equation (Cuenca et al. 1982), which is adjusted to actual non-stress transpiration based upon a crop curve using accumulated growing-degree-days (Sammis et al. 1985). Crop curves in the literature are based upon experiments that were surface irrigated (Doorenbos and Pruitt 1977). Soil evaporation in the model is based upon a stage-one evaporation (which is an energy-limiting stage) until the soil moisture content in the top 30 cm of the profile reaches



M (I,J,K = Moisture levels in each block of soil
I = Depth
J = X Direction
K = Y Direction

I_{1-4} = ellipsoid shell number direction of water flow

Figure 1. The dynamics of soil - water relationships in a typical soil profile.

a threshold value and then the model changes to stage-two evaporation, which is based upon a time function (Jensen 1973). Soil evaporation is calculated separately for both the rainfall and the trickle irrigated soil moisture areas.

The trickle irrigation flow is modeled as a point source filling the root zone in ellipsoids of increasing size as shown in figure 1. Rectangular boxes are sized as input data and the boxes associated with each ellipsoid are determined at the beginning of the program. The z and y ratio of the ellipsoids are specified as input. Water fills the boxes in the first ellipsoid and then the boxes in the next ellipsoid shell until water from the adjacent point source starts to fill boxes at which time water moves vertically. Rainfall initially fills all surface boxes with excess additional rainfall moving vertically to deeper boxes. This approach was used instead of solving the three-dimensional solution of Richard's equation because of time and memory size limitation associated with an IBM PC.

Extraction of water by transpiration from each box in an ellipsoid shell is based on an exponential decay function with depth measured along the vertical radial of the ellopsoid. Root growth depth is based on a root-coefficient-growth function times growing-degree-days. Depth is measured along the vertical radial and roots grow horizontally at the same ratio as the vertical to horizontal ellipsoid.

Deep drainage water goes out the bottom boxes representing maximum root growth.

DESCRIPTION OF MODEL OPERATION

The IRRSCH model was principally designed to fulfill two functions. The model can provide the user with an optimum irrigation schedule, based on user inputs, for a crop currently in production or it can be used to evaluate past irrigation scheduling practices. The eventual destination of all water inputs to the crop are modeled and displayed in an output file. Crop evapotranspiration is separated into an evaporation and transpiration component.

The model has the capability of determinig non-limiting crop water requirements (called non-stressed transpiration and evapotranspiration) from soil and climate variables, and can provide, accordingly, an optimal irrigation schedule.

Additionally the model can irrigate using information supplied by the user and calculates evapotranspiration, transpiration (called stressed transpiration) deep drainage losses, and yield based on the user's irrigation schedule, and on soil and climate variables.

About Your Present Version

At present this program has been implemented for alfalfa, corn, sorghum, winter wheat, winter barley, spring barley, cotton, chile, spring lettuce, fall lettuce, onions, beans, potatoes and pecans. The irrigation scheduling module is on a single disk and operates on an IBM or IBM compatible computer with 640K of memory. The program is compiled for a math co-processor, and it is recommended that a computer with a six, eight, or twelve megahertz clock be used.

The diskette contains the executable program IRRSCH along with a sample crop file (WHEAT82.CRO), irrigation file (WHEAT82.IRR) and climate file (CLOV8182.CLM). The diskette also contains a group of fortran modules (FORTRAN <DIR>). These modules have been compiled and linked into the executionable program called IRRSCH. The irrigation scheduling program consists of 15 modules with MAIN being the driving module for each one of the sub-modules (fig. 2) and Appendix B. A large portion of the variables in the irrigation scheduling module are described as functions so that global access of the variables can be acquired from each one of the modules. If you wish to make changes in the code of irrigation scheduling module it will be necessary to have a FORTRAN compiler and linker on your computer in order to recompile and link the FORTRAN modules. The disk also contains a basic program used to create the crop file (DRINPUT.BAS) and another basic program (UPDATE.EXE) used to update the climate file.

First, in case of disk failure, make a copy of the program using the disk copy command on the operating system. Put the original in a safe place and use the copy. Since sufficient space does not exist on a single diskette to run the program it will be necessary to make two working diskettes from this copy. On the first working disk, copy the example Crop, Irrigation, and Climate files. On the second working disk copy the remaining files. When you create your own data files it will, likewise, be necessary to separate your files from the program files.

Program Start Up

See the section entitled "Creating Your Own Files" later in the text for creating your own data files. The procedure described here to begin operation using the sample files will be identical to that you will use to begin operation using your own data files. To begin operation of the scheduling program the following steps are taken.

Put the diskette containing the IRRSCH.EXE file in drive A and the diskette containing the Climate, Crop, and Irrigation files in drive B. With the operator in drive A type IRRSCH. The computer will then come back and ask

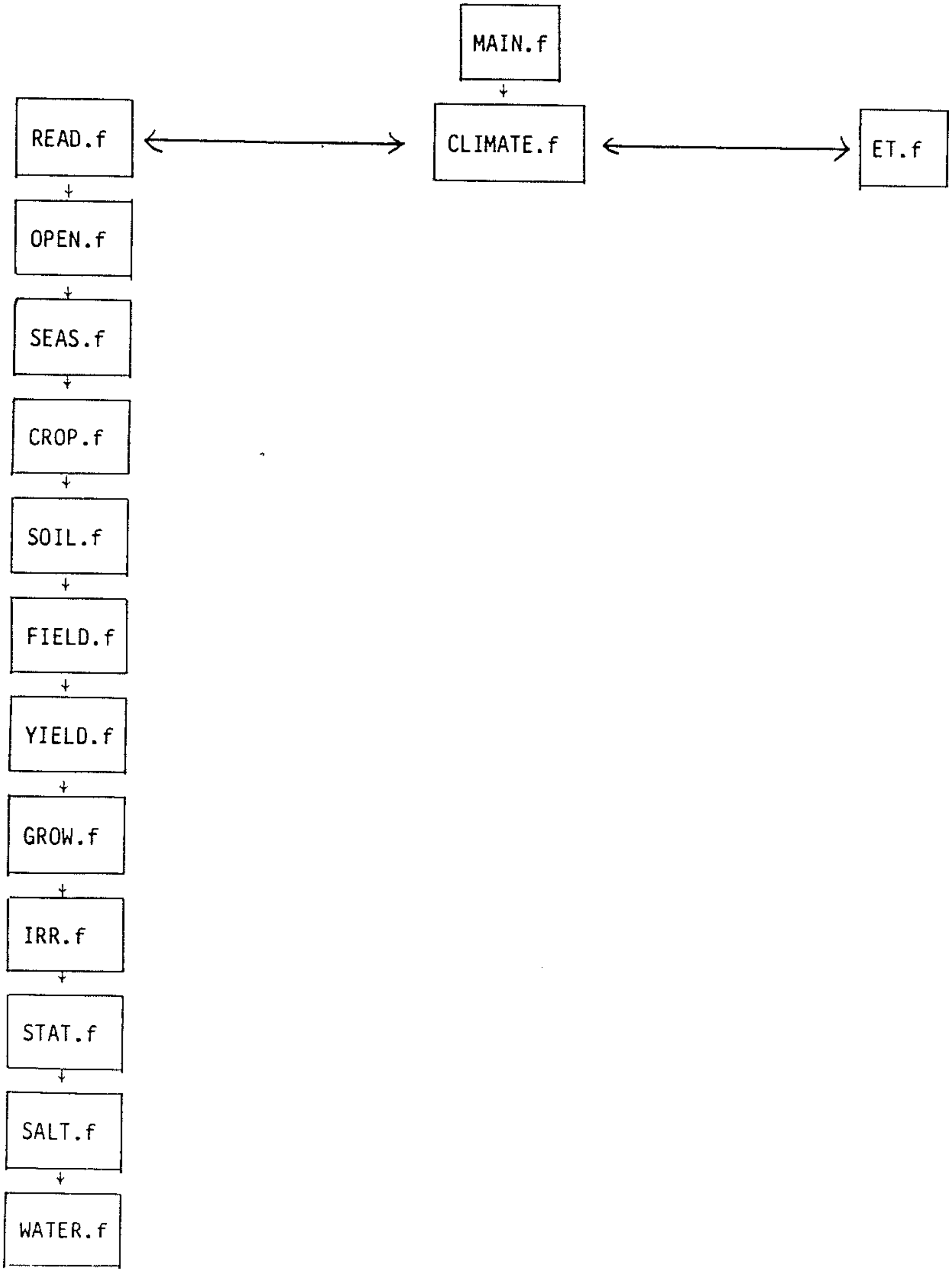


Figure 2. A flow chart of the trickle irrigation scheduling model.

you for the name of the crop and irrigation file. This is a file with the .CRO and .IRR extensions. Do not, however, write the extension, just specify the proper name of the file. For the purpose of our example the sample filers are called WHEAT82.CRO, WHEAT82.IRR, WHEAT82.WTH and WHEAT82.OUT. Remember that the crop and irrigation files have to be created first before the program will run. However, the program will create two output files with extensions .OUT (the irrigation scheduling output) and .WTH (the climate data and potential evapotranspiration output). The irrigation scheduling module will then ask for a climate file (for our example CLOV8182.CLM). Again, give only the proper name.

The program will then run and print out into the output files the results of the run. The results may be observed on the screen by using the type command which has the form: TYPE (file name). You can also print the output file on a printer using the DOS print command or you may look at the file using an editor, such as Wordstar.

Creating Your Own Data Files

The Climate File. The program operates for one complete year, consequently, it is necessary to have a complete year of climate data available before the model can be run at your location. The climate file should consist of the current climate data from the beginning of the year to the current date and an average climate data base from that date to the end of the year. In New Mexico, this complete climate data can be acquired from the state climatologist office, but the climate file will have to be put in the right units and format needed by the irrigation scheduling model. The climate file consists of a date, location, maximum and minimum temperature in Celsius, maximum and minimum humidity, solar radiation in langleys per day, wind speed in miles per day and rainfall in inches using the following fortran format statement. (F6.0, 11A, 5(F5.1), F5.0, 2(F5.2)). The climate is read in the module CLIM in subroutine RDCLM.

A climate file can be created and updated using the program UPDATE.EXE. This program allows creating a climate file, updating a climate file, and mixing a current climate file with an average climate file. The current climate file should be updated on a timely basis. If this is not possible because some of the climate inputs are not available, then, as a minimum, precipitation should be updated.

<u>The Crop File</u>. The crop file contains a large amount of information about the specific crop. The irrigation scheduling model is generic in nature, but the crop file is specific for that individual crop. Each module contains a subroutine that reads in information from the crop file. An example of the crop file is presented on the disk with extension CRO and in Appendix C. Information on the coefficients needed by that crop file are presented in the program COMMENT on the diskette and in Appendix C. A brief description of each input variable is given in the example crop file next to the variable. Variables must be entered into the crop file using the same format (i.e. with decimal points) as shown on the example crop file. A crop file can be created by changing the example crop file or by running the program DRINPUT.EXE (see below) which will ask the user for the value of each input data and put it in the correct format in a crop file.

The irrigation scheduling model has the capability of determining when an irrigation should occur based upon two input parameters in the crop file that either set the plant available water level before irrigation occurs or set the level to which relative transpiration must decrease before an irrigation occurs. To select one of these two options, set the other option to the -1.

The model can also irrigate by reading an irrigation schedule from an Irrigation File having extension IRR.

To run DRINPUT use the working diskette containing the DRINPUT file. Using a basic compiler load and run DRINPUT.BAS. Type 'drinput' and the program will sequentially prompt the user for necessary data inputs. The COMMENTS file, the WHEAT82.CRO file, and the following discussion have been provided to assist the user in making the crop file.

If a printing of daily output from the model is not desired place an 0 at the "daily output printing" prompt. If this output is desired in addition to the seasonal output place a 1 at this location. If a weather output printing is desired place a 1 at the "weather printing" prompt, an 0 if not.

Perennial crops are treated somewhat differently from annual crops by the model. The input "perennial crop" requires that an 0 be entered for an anuual crop and a 1 for a perennial crop. The planting date ("calendar plant date") and the emergence date ("calendar emerge date") for the second year and beyond of a perennial should be input as 0101 and the last two digits of the year. The harvest date should be 1231 and the last two digits of the same year, unless of course, a run over several years is desired. An additional difference for the perennial is that when the crop file is being created it is necessary to initially set the starting root depth at 0.0 for a new crop and at max roots depth for a mature crop. If certain inputs are not applicable to the crop place a 0.0 in that location. For example, for trees, one input is the diameter of the stem. If you are not working with a tree crop, place a 0.0 at this location. Other inputs have been provided with the expectation that the existing default value would be used to run the model, but the option does exist to change them if desired. For example the "ks a coefficient", the "ks b coefficient" the "sc a coefficient" and the "sc b coefficient" are inputs of this type. The ks coefficients are parameters for the function relating crop transpiration to plant available water (Abdul-Jabbar et al., 1983) and the sc coefficients are parameters relating to water application uniformity (Jensen 1981.)

The model estimates yield based on transpiration in two ways. With both methods yield is based on transpiration as calculated by the model. Method 1 uses a water production function (the parameters of which are listed in the COMMENTS file or which can be chosen by the user based on local conditions) in which yield is calculated as a function of transpiration as follows:

$$\text{yield} = a + b(T) \tag{1}$$

where a is the y-intercept, b is the slope and T is the modeled transpiration. A reduction in T as a result of stress reduces yield according to the water production function. The "yield 1-4 coefficients" are the parameters of the water production function with the "yield1 coefficient" being the intercept, "yield2 coefficient" the linear parameter, etc., so the option exists to input a curvilinear water production function if necessary. Values for the water production functions can be obtained from the COMMENT file. Method 2 produces a normalized functional relationship between yield and transpiration based on the input variable "given max yield LB/AC", the input variable "yield reduction coeff Ky", and the maximum transpiration as calculated by the model. Yield by Method 2 is calculated by the model as follows:

$$\text{yield} = (Ym \times Ky \times T/Tm) + (Ym \times (1-Ky)) \tag{2}$$

where Ym is maximum yield, Ky is the yield reduction coefficient, and T/Tm is the ratio of the calculated T to maximum T. The Ky coefficient has values from 0.7-1.4 depending upon the crop (For applicable values see Doorenbos and

Kassam 1979). If the Ky value is unknown it can be approximated by the default value of 1.0.

The model calculates transpiration by multiplying potential evapotranspiration by a crop coefficent (AKC). The crop coefficient used at a given stage of crop development is functionally related to the growing degree day accumulation of the crop by one or two polynomials. For a crop, like winter wheat, two polynomials are required because winter wheat has an initial cycle of growth in the fall, prior to winter, and a second cycle beginning in the spring and ending at maturity and each cycle requires separate coefficients. For crops requiring two polynomials "the grow degree days test value" (TSTGDD) is the growing degree day accumulation at which the second cycle of growth begins and the point at which the model switches to the second polynomial. For crops having two cycles of growth, shaping coefficients for the polynomial functions for the first cycle are input into the crop file as "akc1 coefficients a-d" and for the second cycles as "akc2 coefficients a-d" Crops that have one cycle of growth will have only one set of polynomial coefficents which are to be entered as the second polynomial (i.e. akc2 coefficients a-d). Appropriate polynomial coefficients for each crop are given in the COMMENTS file.

Growing degree days (G) are accumulated based on the equation:

$$G = \Sigma \frac{(\text{daily max temp.} + \text{daily min temp.})}{2} - \text{base temp.} \qquad (3)$$

where the maximum and minimum cutoff temperatures (see COMMENTS file) are substituted into the equation in place of daily maximum and minimum values above or below the cutoff temperatures, respectively.

The following paragraph describes input values for the Leaf Area Index (LAI) subroutine of the model (Appendix A). If it is not desired that the model be run using the LAI concept input a "0.0" for "max leaf area index"). For alfalfa a "0.0" must be entered for "max leaf area index" and for the other three variables in this section and the corresponding values in the irrigation scheduling output file should be ignored. The "max leaf area index" is the maximum leaf area index achieved by the crop. The "Day count for max akc" is the number of days that pass before the maximum AKC coefficient is used by the model to calculate transpiration and this will vary with the rate at which growing degree days are accumulated. The "transp. at max akc IN" is the cumulative transpiration in inches which has occurred up to the point in the season when the model uses the maximum AKC coefficent to calculate transpiration. The input values for "Day count for max akc", and "transp. at max akc IN" must be obtained by initially running the program with an estimated values. For this initial run these values do not need to be accurate. The program, in the irrigation scheduling output file, will return accurate values which the operator will need to place in the crop file for the actual run. The "final stressed transp." is the ratio of the final transpiration divided by the maximum transpiration achieved during the program run. It is suggested that the default value of 0.6 be used but can be changed as required.

The "application coeff 1-7" and the "weight coeff 1-7" are coefficients relating to the uniformity of water application to the field. If the Christian uniformity coefficient ("cs uniformity coeff") is set at 100.0 (100%) the model will assume that water is evenly distributed throughout the field. However, if the "cs uniformity coeff" is set at less than 100.0, the model will vary the water application uniformity at seven different locations over the field and present the user with a weighted ET and yield result based on the non-uniformity. Values for these coefficients depend upon the user's method of irrigation (sprinkler, surface or trickle) and appropriate coefficients are provided in the COMMENTS file for trickle irrigation. To obtain the modeled output at the seven locations, when a Christian uniformity coefficient less than 100 is chosen, "daily output printing" must be set to 1. Selecting this option significantly increases the running time of the model.

At this point in the crop file the user must make a decision as to whether irrigations will be scheduled by the model or whether irrigation scheduling will be based on an Irrigation File.

1. For those irrigating using an irrigation file the crop file should be specified as follows: The "number of iterations" refers to the number of irrigation scenarios in the irrigation file. Some users may want to experiment with different dates and depths of irrigation water may do so by placing various scenarios in the irrigation file (See irrigation file below). The amount to irrigate ("amount to irr (in)") should be set at a minimum value (example 0.2 in) so that if sufficient irrigation is not specified in the crop file, the model can supply a minimum irrigation to keep the crop alive. If it is necessary for the model to irrigate, these samll irrigations in the output file will alert the user to a potential problem. Variability in determining the volume of water to be applied is specified as a standard deviation ("std. dev amt to irr"). Again the Christian uniformity coefficient ("cs uniformity coeff") is the distribution efficiency. The model irrigates based on one of two parmaters that either force an irrigation when plant available water drops below a specified value ("% h2o before forced") or schedules an irrigation when the percentage of maximum relative ET falls below a specified

value ("% rel et before h2o"). One of these two options is specified by placing a -1 in the option not desired. If the irrigation file is being used the chosen option should be set sufficiently low so that the model will irrigate only as a last resort to prevent crop death.

2. For those users allowing the model to determine the timing of irrigations an irrigation file with 0 as the number of irrigaions must be made. The other inputs are similar to those described in Number I above except that inputs for "amount to irr (in)", and the option for determining the threshold for when the model will irrigate, either "% h2o before forced" or "% rel et before h2o" should be based on reasonable figures for proper crop growth and development. If the user does not require a measure of the uniformity of water application or a measure of the variability in the quantity of water applied to the field the "cs uniformity coefficient" should be set to 100.0 and the "std. dev amt to irr" to 0.00. The "seed for rand variant" is a large number input by the user which initiates a computer generated sequence of random numbers that will be used by the model to mimic variability in the average depth of water to be applied to the field as governed by the standard deviation of the irrigation ("std. dev. amt to irr").

The "sal a coefficient" and "sal b coefficient" are the parameters of a linear regression equation expressing yield as a function of salinity limited transpiration and are not active in the current version. Because modeling salinity is not required set "sal a coefficient" to 1.0 and "sal b coefficient to 0.0.

The "initial water depth 1" is the percent by volume of water in the cube.

Irrigation File. As discussed above the irrigation scheduling model has the capability of determining when an irrigation should occur based upon two input parameters in the crop file. The model can also irrigate by reading an irrigation schedule from an irrigation file having the extension .IRR. The first parameter read is the number of irrigation events, followed by the dates and the amounts irrigated. Each irrigation data and amount should occupy a separate line. The unit used, either inches or cm, is specified earlier in the crop file. The irrigation file continues until a minus one is encountered at the end of the file which rewinds the irrigation file to repeat the irrigation sequence for the next year's run. It is possible to place a number of scenarios or iterations in one irrigation file by following the first scenario (iteration) by a second iteration, etc. using the same format as the first iteration. If the user requires that the model determine when irrigations should occur it is necessary to creat an irrigation file with an 0 as the number of irrigation events and an 0 should be specified for "amount to irr (in)" in the crop file. An example of an irrigation file, called WHEAT82.IRR, which contains two scenarios is presented on the diskette.

Output Files.

The irrigation program places data into a weather output file and into an irrigation scheduling output file.

Climate data from the climate file is used to calculate daily potential evapotranspiration using the Penman equation. Weather output consists of the climate data and the calculated potential evapotranspiration.

The output file consists of a short yearly summary version and a daily version. An example of an irrigation scheduling output file called

WHEAT82.OUT will be created when the model is run and is presented in Appendix D. This example will display both the daily version and the summary version. The daily version can be deleted from the file by turning off the print command at the beginning of the crop file to 0. The beginning of the output file contains the data read from the input file. The variable abbreviation for the daily print out version are:

root zn = root zone

shell depth = root zone shell number times root zone depth in the z direction

lai = leaf area index

trration = ratio of transpiration/non-stressed transpiration

pet = potential evapotranspiration in/day

ns.tr = non-stress transpiration in/day

st.tr = stress transpiration in/day

evapo = soil evaporation in/day

evratio = evaporation/potential evaporation

akc = crop coefficient (expressed as a ratio of T to potential evapotranspiration)

gdday = growing degree days

pavw = plant available water (the ratio of actual plant available water to maximum plant available water)

Managing Your Files

The disk only holds so much space, therefore, care is needed when managing your files. The options open to you are to erase old unneeded files, or to transfer them to another disk. Some simple guidelines and commands are listed below:

1. Erase old files by typing in: ERASE filename.

2. Write new information over the old files by entering the old file name when the new corresponding file name is prompted for during processing. This method is recommended for the following files:
   a) combined climate file
   b) irrigation scheduling output file
3. Copy files to another disk by putting a formatted disk into drive B: and typing: COPY filename B: This command should be used when creating the working diskettes.

Appendix A

Effect of Soil Moisture Stress on Leaf Area Index Evapotranspiration and Modeled Soil Evaporation and Transpiration

This article is reprinted from the TRANSACTIONS of the ASAE (Vol. 29, No. 4, pp. 956-961, 1986)
Published by the American Society of Agricultural Engineers, St. Joseph, Michigan

Effect of Soil Moisture Stress on Leaf Area Index, Evapotranspiration and Modeled Soil Evaporation and Transpiration

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ABSTRACT

LEAF area index (L) development of a crop decreases with increased soil moisture stress. This affects the amount of soil evaporation that occurs through the growing season. Leaf area index of winter wheat *(Triticum aestivum* L.) and spring barley *(Hordeum volgare* L.) were measured during the growing season on plots receiving different irrigation levels to develop a functional model to predict L under soil moisture stress and non-soil-moisture-stress conditions based on measurement of evapotranspiration or modeled transpiration. The wheat study was conducted for 2 years on Pullman clay loam (fine-loamy, mixed, thermic Torrertic Paleustoll). The barley study was conducted for 1 year on a Wall sandy loam (Typic Camborthid, coarse, loamy, mixed, calcarous, Mesic family). Leaf area index was linearly related to cumulative evapotranspiration (E_{tcum}) up to maximum L. The wheat and barley functions relating relative L (L/L_{max}) to relative cumulative evapotranspiration (E_{tcum}/E_{tcumm} where $E_{tcumm} = E_{tcum}$ at L_m) up to maximum L where statistically ($P \leq 0.05$) the same. Relative L from the time maximum L occurred to harvest was linearly related to the relative cumulative evapotranspiration that occurred from maximum L to harvest time. The linear functions presented in this paper were used to model L in an irrigation scheduling model and thus in turn, model the evaporation process based on L. The irrigation scheduling model also modeled evaporation using crop coefficients. Modeling soil evaporation using modeled L improved the predictibility of the model in the low moisture range for barley. The model was insensitive as to the method of modeling evaporation when predicting wheat yield and evapotranspiration.

INTRODUCTION

Leaf area index (L) is used in computer simulation models as a state variable to model evapotranspiration and grain yield of different crops (Arkin et al., 1976; Holt et al., 1975). These models, along with irrigation scheduling models (Hanks, 1974; Hanks and Puckridge, 1980; contain water balance submodels which separate evapotranspiration into evaporation and transpiration, based on calculated L. In the physiologically based model of corn *(Zea mays* L.) growth by Stapper and Arking (1980), leaf size increases as a function of the size of the previous leaf with the initial leaf size specified. Total leaf area is calculated based on the number of leaves on the plant. However, the model does not account for the smaller size of leaves resulting from soil moisture stress which occurs when plant available water in the root zone becomes less than 50%. Hanks and Puckridge (1980) modeled L in wheat *(Triticum aestivum* L.) based on a sine function describing L for an average climatic year, and a reduction in their computer L caused by soil moisture stress based on the ratio of accumulated daily transpiration to potential transpiration. Maas and Arkin (1980) modeled the leaf area of wheat plants based on the number of leaves per shoot but did not adjust leaf size due to soil moisture stress. The purpose of this experiment was to determine how soil moisture stress effects the development of L of winter wheat and spring barley *(Hordeum volgare* L.) and to determine a functional relationship between accumulated transpiration and L that could be used in an irrigation scheduling model to predict L and soil evaporation. Another objective was testing the sensitivity of the irrigation scheduling model to predict grain yield and transpiration using two different soil evaporation models.

MATERIALS AND METHODS

Wheat was grown near Clovis and barley near Farmington, N. M. The Clovis study site is located 24 km north of Clovis at the Plains Branch Experiment Station. The soil type at the site is a Pullman clay loam (fine-loamy, mixed, thermic Torrertic Paleustoll). Wheat Variety 'Tamax' was planted in rows 0.2 m apart on 1.02 m spaced beds on 14 October 1980 and 1981. Anhydrous ammonia was applied to the field before planting at a rate of 112 kg/ha of N in 1980 and 168 kg/ha of N in 1981. Following planting the top 1.0 m of the soil profile was irrigated to field capacity based on neutron probe readings. Subsequent irrigations were applied using a sprinkler-line-source (Hanks et al.1976) when the plant available soil moisture at the spinkler line had been depleted by no more than 50% as determined from

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Article was submitted for publication in October, 1985; reviewed and approved for publication by the Soil and Water Div. of ASAE in May, 1986.

Journal article 1064 of the New Mexico Agricultural Experiment Station, Las Cruces, NM

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Acknowledgements: The work upon which this publication was supported in part by funds provided through the New Mexico Water Resources Institute by the United States Department of the Interior, Office of Water Research and Technology, as authorized upon the Water Research and Development Act of 1978, P. L. 95-467, under Project No. C-90229; by the Bureau of Reclamation; and by the State of New Mexico through state appropriations.

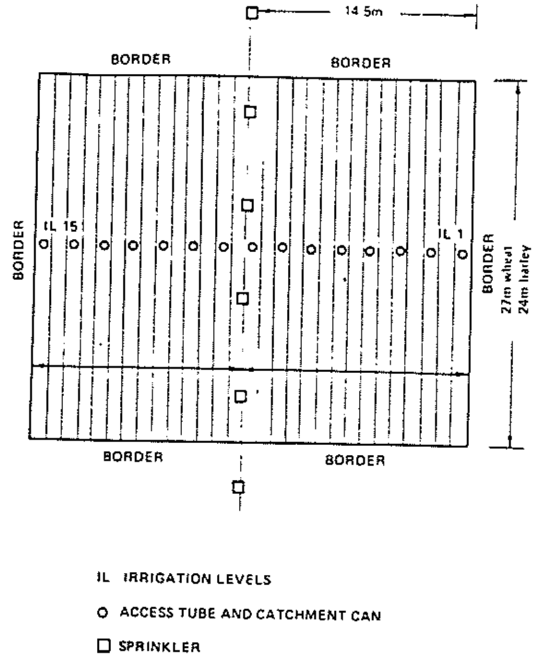

Fig. 1—Details of the layout of the sprinkler-line-source.

neutron probe data. The sprinkler-line-source provided adequate water near the sprinkler line throughout the growing season while applying a decreasing quantity of water with increasing distance perpendicular to the line. The system was operated in late evening when the wind speed was less than 1.4 m/sec. Five irrigations were applied each year. Plots 1 and 15 were located 15 m on either side of the sprinkler line. Plot 8 was located immediately adjacent to the sprinkler line (Fig. 1).

Evapotranspiration was determined from the water balance equation:

$$E_t = I + R - D + \Delta S_m \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots [1]$$

where

E_t = evapotranspiration, mm
I = irrigation, mm
R = rainfall, mm
D = drainage, mm
ΔS_m = change in soil moisture, mm

Catchment cans installed across the field at a spacing of 2.0 m were read after each irrigation. Rainfall was measured with a standard 20 cm rain gauge located next to the site. Change in soil moisture adjacent to the catchment cans was measured every 30 cm to a depth of 1.5 m using a Troxler model 1255 neutrol probe. Irrigation amounts, based on weekly soil moisture measurement directly under the sprinkler line, returned the soil moisture under the sprinkler line to field capacity. Drainage was therefore assumed to be negligible. Weather data collected at the site to drive the irrigation model included daily total solar radiation (Star Pyronometer Weathrmeasure Model R413), maximum and minimum temperature and relative humidity (Hydrothermograph Weathermeasure Model H311A), 24 hr wind run (Totalizing Anemometer Science Assoc Model 403), and rainfall.

A single sample (0.5 m^2) of wheat green leaf blades was harvested 5 times from 21 December to 23 June from each irrigation level 1, 3, 5, 7, and 9 in 1981. Four random samples (0.25 m^2) of green leaf blades were harvested biweekly from irrigation levels 9, 11, 13, and 15 in 1982. Irrigation level 8 was not measured because of excess water received in part of the plot by leakage of the irrigation pipe. Leaf area was obtained by relating dry weight of collected green leaf material to leaf area which was determined by tracing the leaves on heavy construction paper and weighting the paper cut-out and a piece of paper of a known area. A specific leaf area was determined for each irrigation level each time a clipping occurred throughout the growing season. Leaf area index was determined by dividing the total leaf area by the ground area harvested. The average coefficient of variation of the 1982 L was 0.27 based on the four samples at each irrigation level sampled.

Wheat was harvested 23 June 1981 and 7 July 1982. The wheat was hand-harvested in 1981 using a sickle mower and machine threshed to determine grain yield. The area of the plot harvested was 1.0 m wide by 27 m long. In 1982, a plot combine was used to harvest the wheat.

Barley was grown at the San Juan Agricultural Experiment Station, 11 km southwest from Farminton, N. M. The soil type was classified as a Wall sandy loam (Typic Camborthid, coarse, loamy, mixed, calcarous, Mesic farmily). Spring barley cultivar Steptoe was drilled in rows about 0.2 m apart on 3 April 1981, and harvested using a combine on 28 July. Ammonium nitrate at a rate of 180 kg/ha was broadcast and disked in prior to planting. Plots were irrigated with a sprinkler-line-source similar to the one described for the wheat experiment. Fifteen irrigations were applied, one every 3-4 days, to the field during the growing season because of the low water holding capacity of the sandy soil. Evapotranspiration and L were determined in the same manner as in the wheat experiment except that the harvest area clipped weekly was only 0.1 m^2 and the specific leaf area was determined after jointing, but before heading for the barley, and averaged over all irrigation levels. leaf are index was determined at irrigation levels 2, 4, 8, 12 and 14. Grain yield was determined at the end of the growing season for each plot (1 m wide by 24 m long) using a plot combine.

MODEL DESCRIPTION

The irrigation schedule model is a modification of that described by Hanks (1974) and Hanks and Puckridge (1980). Potential transpiration (T_p) is estimated from potential evapotranspiration (E_p) and crop coefficients (k) where:

$$T_p = k\,E_p \quad \text{mm Day}^{-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots [2]$$

Potential evapotranspiration is estimated by a modified Penman's equation referenced to grass with the coefficient given by Sammis et al. (1985). In calculating Penman's equation net radiation (mm/day) was determined by a linear relationship between solar radiation and net radiation with the equation having a slope of 0.95 (1-α) and an intercept of -1.09 mm/day with α equal to 0.21. Crop coefficients (Sammis et al., 1985) were based on equation [3]:

$$k = B_0 + B_1\,\Sigma G + B_2\,\Sigma G^2 + B_3\,\Sigma G^3 \quad \ldots\ldots\ldots [3]$$

TABLE 1. THIRD ORDER POLYNOMIALS ($k = B_0 + B_1 EG + B_2 EG^2 + B_3 EG^3$) RELATING CROP COEFFICIENTS (k) TO GROWING DEGREE DAYS (G) FOR WINTER WHEAT AND BARLEY

Crop	Wheat	
	Polynomial 1*	
$B_0 =$	1.44 E - 2	$r^2 = 0.85$
$B_1 =$	3.38 E - 3	
$B_2 =$	1.03 E - 5	
$B_3 =$	7.90 E - 9	
	Polynomial 2*	
$B_0 =$	2.79 E - 0	$r^2 = 0.89$
$B_1 =$	−6.29 E - 3	
$B_2 =$	4.72 E - 6	
$B_3 =$	−1.02 E - 9	
	Barley	
$B_0 =$	0.02 E - 0	$r^2 = 0.91$
$B_1 =$	1.54 E - 3	
$B_2 =$	2.95 E - 6	
$B_3 =$	3.86 E - 9	

*All coefficients are significant ($P \leq 0.5$)

where

ΣG = Accumulated growing degree days starting at planting
B_i = are regression coefficients

Two polynomials for wheat and one polynomial for barley were used to describe the coefficients with the first polynomial for wheat used until the accumulated G reach 830 (Table 1). Growing-degree-days (G) were calculated using the following formula:

$$G = \frac{(\text{daily max temp} + \text{daily min temp})}{2} - \text{Base Temp} \quad \ldots\ldots [4]$$

Maximum and minimum air temperatures, measured at the nearby climate station, above or below which no further G are accumulated were set to the cut-off temperature. There were no temperature limits set for wheat and the base temperature was set at 0°C (Maas and Arkin, 1980). Barley G was calculated with a base temperature of 5°C and a maximum cut-off temperature of 30°C, and a minimum cut-off temperature of 5°C (Williams 1974).

Potential transpiration (T_p) is reduced to actual transpiration (T) based on plant available water (Abdul-Jabber et al., 1983) where:

$$T = T_p 2.0 S_w \text{ for } S_w \leq 0.5 \quad \ldots\ldots [5]$$

$$T = T_p \text{ for } S_w > 0.5$$

where

S_w = available water in the root's zone divided by potential water storage in the root zone between field capacity and permanent wilting point.

The soil reservoir is divided into 20 compartments with the thickness of each compartment specified by the User. Root growth (Tubaileh et al., 1986) was calculated as:

$$R_d = k_R G \qquad R_d \leq R_m \quad \ldots\ldots [6]$$

$$R_d = R_m \qquad R_d > R_m$$

where

R_d = rooting depth, mm
k_R = empirical growth coefficient, mm GDD^{-1}
R_m = maximum rooting depth, mm

Daily soil evaporation (E_s) is modeled by separating it into two stages, where stage one (evaporation under energy limiting conditions (E_{s1}) is described by:

$$E_{s1} = E_{tp} - T_p \text{ mm day}^{-1} \quad \ldots\ldots [7]$$

or by

$$E_{s1} = E_{tp}\, e^{-0.623\, L} \text{mm day}^{-1} \quad \ldots\ldots [8]$$

(Alkhafaf et al., 1978)

where:

E_{tp} = potential evapotranspiration
L = leaf area index

Stage two evaporation (limited by soil water hydrualic conductivity) occurs when the available soil water content in the top 30 cm becomes less than 80% then:

$$E_{s2} = C_s (T)^{1/2} \text{ (Jensen, 1973)} \quad \ldots\ldots [9]$$

where

E_{s2} = a accumulative stage two evaporation, mm
T = time since stage two evaporation begins, days
C_s = empirical coefficient dependent on soil type (Jensen 1973), mm $\text{days}^{-1/2}$

Soil evaporation is equal to E_{s1} during stage one evaporation and equal to the difference in the cummulative E_{s2} over a one day time period during stage two evaporation. Water is added to the soil profile by irrigation and rain, filling each discrete soil depth with the excess passing to the next depth. Deep drainage is the amount of water passing the last discrete soil depth equal to the maximum rooting depth. The rate of infiltration is assumed to occur within 1 day, the time step of the model. Transpiration is extracted from each soil layer based on an exponential decay function with root depth, and soil evaporation is extracted from the top 30 cm. Yield in the model is predicted by using a linear water production function relating seasonal transpiration to yield.

RESULTS AND DISCUSSION

Winter wheat showed no leaf area index difference with respect to irrigation treatments until 150 days after planting (Table 2). Maximum leaf area index (L_{wm}) for wheat occurred, on the average for the 2 years, after 1799 G (212 days after planting) (Table 2). Leaf area index of wheat (L_w) increases linearly with cummulative evapotranspiration for all irrigation levels up to maximum L (L_{wm}) after which senescence occurs and L

CUMULATIVE EVAPOTRANSPIRATION (E_{tcum}) DURING THE GROWING SEASON
AT 5 IRRIGATION LEVELS FOR WHEAT, 1980-1981 and 1981-1982

1980-1981

Date	Days after planting	Growing degree days	Irrigation level 1 L	1 E_{tcum}	3 L	3 E_{tcum}	5 L	5 E_{tcum}	7 L	7 E_{tcum}	9 L	9 E_{tcum}
				cm		cm		cm		cm		cm
12/21	68	523	0.10	3.90	0.10	4.20	0.10	3.90	0.10	4.70	0.10	4.30
03/20	157	1032	0.20	8.30	0.20	11.00	0.20	10.20	0.20	13.00	0.20	13.30
04/20	188	1421	0.66	16.20	0.98	16.10	1.14	18.40	1.06	22.20	1.80	21.50
05/08	206	1749	0.98	19.40	1.13	21.80	1.52	26.70	1.92	31.50	2.12	30.10
05/18	216	1901	0.76	22.20	1.11	25.20	1.61	31.20	2.40	37.50	2.84	35.50
06/23	Harvest		0.00*	28.5	0.00*	33.7	0.00*	46.8	0.00*	55.8	0.00*	55.2

1981-1982

Date	Days after planting	Growing degree days	Irrigation level 9 L	9 E_{tcum}	11 L	11 E_{tcum}	13 L	13 E_{tcum}	15 L	15 E_{tcum}
				cm		cm		cm		cm
12/07	54	543	0.12	3.90	0.18	3.90	0.09	3.90	0.15	3.90
01/28	106	782	0.28	7.20	0.29	6.30	0.24	7.10	0.34	5.50
02/24	133	910	0.44	8.80	0.56	7.50	0.47	8.10	0.56	6.60
03/08	145	972	0.55	9.95	0.45	8.37	0.55	8.80	0.73	7.10
03/17	154	1069	0.77	10.70	0.69	9.00	0.58	9.30	0.68	9.90
03/30	167	1183	0.84	15.10	0.68	12.40	0.66	11.90	0.71	11.30
04/15	183	1377	1.46	19.90	1.51	15.90	1.15	14.40	1.02	14.20
04/29	197	1532	2.05	23.30	1.97	17.70	1.05	17.70	0.94	16.30
05/11	209	1698	2.77	28.40	1.45	22.60	1.12	21.20	1.12	19.50
05/28	226	1986	1.81	40.40	1.16	33.70	0.75	25.60	0.43	25.80
06/05	234	2142	1.65	46.40	0.89	38.30	0.58	27.20	0.16	28.70
07/07	Harvest		0.00*	61.5	0.00*	49.8	0.00*	38.5	0.00*	38.0

*Estimated not measured

decreases (Table 2). The relationship is given by equation [10].

$$L_w = -0.16 + 0.071\ E_{tcum} \quad \cdots\cdots\cdots\cdots\cdots\cdots [10]$$

where

L_w = leaf area index of wheat up to the maximum value at 1799 G
E_{tcum} = cumulative evaporation of wheat, cm

The coefficient of determination (r^2) is 0.80.

The wheat crop was observed to be under slight moisture stress based on neutron probe readings next to the sprinkler line during the last part of the winter growing period. Freezing weather prevented operation of the sprinkler system at this time. Measured yield at the sprinkler line was 3616 kg ha^{-1}. In irrigated yield trials from 1976-1985, the average yield for wheat variety 'Tomax' was 5015 kg ha^{-1} (Finker et al., 1986). In a previous study where late winter irrigations were applied (Sammis et al., 1979), seasonal evapotranspiration, for wheat planted September 1, measured in lysimeters was 103 cm and accumulated evapotranspiration at L_{wm} was 73 cm resulting in a L_{wm} of 5.0 based on equation [10].

The spring barley at Farmington began to show a difference in L, 32 days after planting (Table 3). Maximum leaf area index (L_{bm}) of 4.2 at irrigation level 8 occured for the spring barley on 8 July 1981, 618 G after planting. Leaf area index of barley (L_b) was linearly related to E_{tcum} (cm) as described by equation [11] with an (r^2) of 0.77.

$$L_b = -0.09 + 0.21\ E_{tcum} \quad \cdots\cdots\cdots\cdots\cdots\cdots [11]$$

Equations [10] and [11] indicate that L up to maximum L is linearly related to evapotranspiration and the equations pass very close to the origin. When these

TABLE 3. LEAF AREA INDEX (L) AND CUMULATIVE EVAPOTRANSPIRATION (E_{tcum}) DURING THE 1981 GROWING SEASON AT 5 IRRIGATION LEVELS FOR BARLEY GROWN AT FARMINGTON

Date	Days after planting	Growing degree days	Irrigation level 2 L	2 E_{tcum}	4 L	4 E_{tcum}	8 L	8 E_{tcum}	12 L	12 E_{tcum}	14 L	14 E_{tcum}
				cm		cm		cm		cm		cm
04/28	25	200	0.06	1.68	0.10	2.31	0.24	3.78	0.26	2.73	0.10	1.89
05/05	32	283	0.22	2.80	0.38	3.64	0.42	5.04	0.58	3.99	0.29	4.13
05/12	39	342	0.54	4.34	0.48	5.53	1.30	7.70	1.19	5.60	1.59	5.32
05/19	46	395	0.86	6.16	0.86	7.70	2.94	10.29	1.86	7.56	1.28	7.56
05/26	53	455	2.52	7.49	2.56	9.80	3.20	13.44	4.00	9.73	2.56	9.10
06/02	60	593	2.18	9.31	2.72	13.37	3.04	19.95	2.94	13.65	1.76	12.18
06/08	66	618	2.02	10.93	3.87	16.61	4.21	26.01	4.20	17.25	2.62	13.06
06/23	81	842	0.32	14.98	0.96	24.71	1.72	41.16	0.50	26.25	0.78	22.26
06/30	88	968	0.13	17.36	1.95	29.54	1.36	49.42	0.03	31.36	0.13	26.32
07/07	95	1080	0.29	18.41	0.32	31.50	0.42	53.64	0.22	33.67	0.68	28.00
07/12	100	1165	0.00	19.01	0.00	32.55	0.00	55.06	0.00	34.97	0.00	28.90

equations are expressed in relative terms using a potential L of 5.0 (for wheat) and 4.2 (for barley), the resulting equations are statistically ($P \leq 0.05$) the same equation given by:

$$L_r = -0.03 + 1.03\, E_{tr} \quad \text{[12]}$$

where

L_r = relative wheat and barley leaf area index
E_{tr} = relative what and barley cumulative evapotranspiration

The coefficient of determination is 0.81.

Equations [10] and [11] include data over time and irrigation level, indicating that L up to maximum L (L_m) is directly related to the cumulative E_t. However, the rate of decrease in L from L_m to harvest time will depend upon the maximum L the plant achieves under the soil moisture regime in which it has grown, and the evapotranspiration rate that occurs from that point to harvest time.

Consequently for wheat from Table 2

$$L = L_m\,(0.01 + 0.97\, E_{tra}),\ r^2 = 0.85 \quad \text{[13]}$$

and for barley from Table 3

$$L = L_m\,(0.01 + 0.93\, E_{tra}),\ r^2 = 0.83 \quad \text{[14]}$$

where

$$E_{tra} = \frac{E_{tcum} - E_{tcumm}}{E_{tcums} - E_{tcumm}} \quad \text{[15]}$$

where

E_{tcums} = cumulative seasonal evapotranspiration, cm
E_{tcum} = cumultive evapotranspiration, cm
E_{tcumm} = cumultive evapotranspiration at maximum L, cm

Because the slope of equation [12] is near 1 and the intercept near 0, it is not unreasonable to assume if equation [12] were expressed in terms of relative cumulative transpiration (T_r) instead of the measured (E_{tr}) it would be of the form

$$L = L_{mp}\, T_r \quad \text{[16]}$$

where L_{mp} is the maximum potential L under non-soil-moisture-stress conditions and T_r is the ratio of cummulative transpiration (T_{cum}) to cumulative non-soil-moisture-stress transpiration (T_{mcumm}) at L_{mp}. Equation [16] is defined by a single measurement of L_{mp} and an estimate of T_{mcumm} based on a measurement of E_t under non-soil-moisture-stress conditions for the climatic condition under which the wheat or barley crop is grown.

Equations [13] and [14] would also take the form

$$L = L_m\, T_{ra} \quad \text{[17]}$$

where

T_{ra} = relative cumulative transpiration between transpiration at L_m and seasonal transpiration

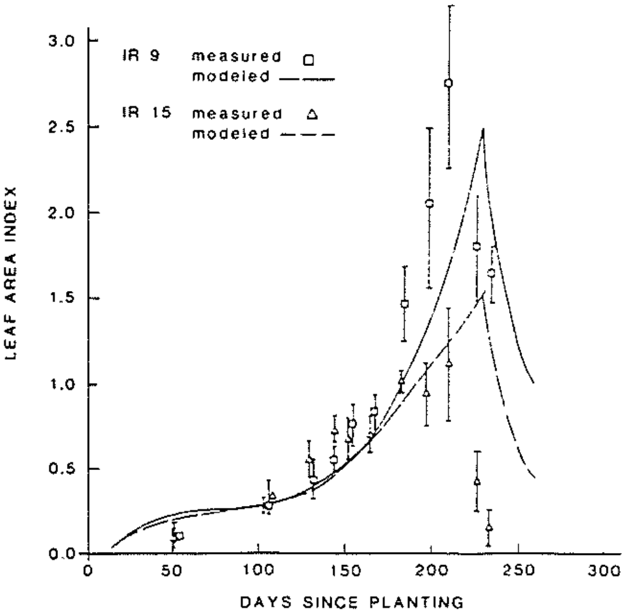

Fig. 2—Measured and modeled leaf area index during the growing season of winter wheat for two irrigation levels (IR) grown at Clovis, NM, 1981. Bars represent two standard errors of the mean.

Model Testing

In order to model stage one evaporation using equation [8] assuming relative L is proportional to relative transpiration, an estimate of L_{mp} and accumulative transpiration (T_{mcumm}) under non-soil-moisture-stress conditions must be known or estimated along with seasonal transpiration.

The model was first run using equations [7] and [9] to estimate E_s. The accumulated non-soil-moisture-stress transpiration predicted by the model at the point in time the crop coefficients reached their peak value was used to estimate T_{mcumm}. The assumption is that maximum L occurs at the same time the crop cofficient peaks. The model was then run again with the model predicting L using equations [16] and [17] throughout the growing season and soil evaporation based on equations [8] and [9]. Seasonal cumulative transpiration in the model was estimted for the diffeent irrigation levels by dividing the modeled accumulative transpiration at L_m by 0.6 based on data in Table 2 and 3.

The model tends to predict maximum L occurs at a later date than the measured values under soil moisture stress conditions (Figs. 2 and 3). The model does not account for the increased rate of senescence that occurs under soil moisture stress conditions and consequently over-estimates the peak L of wheat under soil moisture stress conditions compared to measured values (Table 4). The barley L did not decrease as much under soil moisture stress as the wheat L and consequently the model does an excellent job of modeling peak L for barley under soil moisture stress conditions (Table 4). The model over-estimates seasonal evapotranspiration and yield under severe soil moisture stress compared to the measured values (Table 4) using either equation [7] or equation [8] and equation [9] to model soil evaporation. The model's ability to accurately predict wheat seasonal evapotranspiration and yield is not improved by estimating stage one soil evaporation using equation [8] compared to the simplified approach using equation [7] (Table 4). The model's ability to predict barley seasonal E_t and yield is improved when stage one

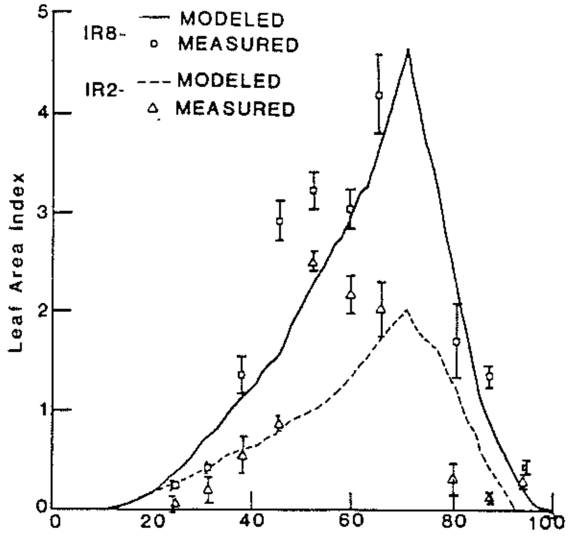

Fig. 3—Measured and modeled leaf area index during the growing season of spring barley for two irrigation levels (IR) at Farmington, NM. Bars represent two standard errors of the mean.

soil evaporation is modeled using equation [8] compared to the simplified approach modeled using equation [7] (Table 4). The model's ability to predict barley seasonal E_t and yield is improved when stage one soil evaporation is modeled using equation [8] (Table 4).

Soil evaporation estimate increases using equation [8] compared to equation [7] and seasonal transpiration of barley decreased under severe soil moisture stress. The increase in soil evaporation is due to a decrease in L under severe soil moisture stress conditions.

CONCLUSION

Soil evaporation can be computed based on leaf area index (L) and L can be satisfactorily estimated based on cumulative transpiration up to maximum L. The senescence process that decreases L can be estimated by the relative cumulated transpiration between transpiration at L_m and seasonal transpiration. However, in this simplified methodology of modeling L the increased rate of senescence under soil moisture stress was not modeled. Consequently, the time that maximum L occurs may be over-estimated in the model by 10 or 15 days. Improved estimate of soil evaporation occur when stage one evaporation is based on L calculations.

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TABLE 4. COMPARISON BETWEEN SIMULATED (L_{ms}) AND MEASURED MAXIMUM LEAF AREA INDEX (L_m) SEASONAL EVAPOTRANSPIRATION E_t AND YIELD FOR WHEAT AND BARLEY

Irrigation level	Planting year	Measured E_t	Measured L_m	Model evapotranspiration Using eq. [7] E_s	Model evapotranspiration Using eq. [7] T	Model evapotranspiration Using eq. [8] E_s	Model evapotranspiration Using eq. [8] T	L_{ms}	Measured yield	Model yield Using eq. [7]	Model yield Using eq. [8]	Total water application includ. rainfall*
		mm		mm	mm	mm	mm		kg/ha	kg/ha	kg/ha	mm
					Wheat							
1	1980	285	0.98	94	243	96	243	1.68	1204	1732	1725	526
3	1980	337	1.13	109	279	109	277	1.91	1692	2090	2079	619
5	1980	468	1.52	135	347	132	347	2.28	2612	2826	2821	730
7	1980	558	1.92	172	370	170	370	2.37	2718	3058	3050	799
9	1980	552	2.12	172	378	175	375	2.41	3025	3152	3045	814
9	1981	615	2.77	187	383	190	378	2.52	3616	3202	3152	402
11	1981	498	1.97	162	340	157	335	2.32	3320	2740	2689	321
13	1981	385	1.15	122	273	127	274	1.77	1860	2095	2051	235
15	1981	380	1.12	119	246	124	243	1.56	1214	1756	1723	199
					Barley							
2	1981	190	2.52	55	144	71	132	2.03	1534	2101	1917	146
4	1981	327	3.87	78	238	104	216	3.00	3260	3634	3280	268
8	1981	573	4.21	78	371	81	373	4.64	6626	5785	5809	479
12	1981	349	4.20	76	266	104	243	3.22	3893	4071	3713	296
14	1981	289	2.62	81	218	104	198	2.88	2322	3305	2962	240

*A preplant surface irrigation was applied to the wheat that brought the soil moisture to near field capacity and is not included in the water application.

Appendix B

Description of IRRSCH Model Modules, Subroutines and Functions

DESCRIPTION OF IRRSCH MODEL MODULES, SUBROUTINES, AND FUNCTIONS

The model consists of sub-modules and each module is linked together to form one large-compiled-scheduling model. A brief description of each module follows.

Module Main

Module MAIN calls an input module (read), reads input data and then initiates an irrigation loop that runs for the duration of the number of possible irrigation scenarios supplied. Module MAIN initiates a year loop that runs for the number of years with each year running the irrigation scenario. MAIN then calls a whole series of reports subroutines to report the status of each one of the components of each module.

MAIN calls subroutines to calculate the crop curves and growing-degree-days along with the subroutines that grow the roots, add rainfall and irrigation water to the profile and subroutines to determine if irrigation is necessary. The module MAIN also calls the evapotranspiration subroutine to calculate water used by evaporation and transpiration and the extract subroutine to remove this water from the soil profile. Main module accomplishes a series of bookkeeping processes to keep track of the accumulated evapotranspiration at each one of the seven field sites that represent the lack of uniform water application with the result from each site weighted according to the area of the field receiving that depth of water application.

Module Read

Module READ reads in the working environment of the irrigation-scheduling model by calling all subsequent modules except CLIMATE and ET. The READ module is a bookkeeping module.

Module Open

Module OPEN contains the subroutine open and subroutine closed. Both subroutines set up the input and output files needed by the program.

Module SEAS

This module contains subroutine RDSEAS, which reads in the relevant crop information including planting, emergence and harvest dates. Module SEAS also contains a series of functions concerned with determining Julian dates.

Module CROP

This module contains the subroutine RDCROP, which reads in the coefficients associated with crop development. The module contains subroutine SETRD, which sets the rooting-depth values in the program. The Module CROP also contains subroutine SETDIA, which sets the stem diameter for the trees. The module contains a subroutine REPCROP, which reports on root-growth dynamics and subroutine INITRD, which specifies intitial-rooting depth.

Module Soils

This module contains the subroutine RDSOIL to read in the soil characteristics including soil type and the dimensions for the cube, which describes the dimensions of the irrigation system. Module SOIL calls a series of functions to get field capacity and a permanent wilting point for the cube in terms of volume measurement. The mapping procedure for the trickle irrigations shells is done in a subroutine MAPIT whereby the model determines which boxes fit in which ellipsoid shells.

Module Field

This module contains subroutine RDFIELD, which reads in information about field identification, elevation, and the number of the field.

Module Yield

Module yield contains subroutine RDYIELD, which reads in the water production function coefficients. This module also computes the yield based upon the cumulative transpiration.

Module Grow

Module GROW contains the subroutine RDGROW, which reads in the growing-degree-day coefficients to compute a crop curve. It calculates the growing degree days in subroutine CALGDD and the crop curve in the CALAKC. Leaf area index is also calculated in this module.

Module IRR

The module IRR contains subroutine RDSETT to read in the coefficients associated with the weighting of the irrigation at the seven locations around the field. RDSETT also reads in the amount to irrigate, the Christian uniformity coefficient, the standard deviation of the distribution describing the irrigation application and the desired soil water ratio at which the irrigation program will irrigate. This module then reads the irrigation file containing the dates and the amount of water application that was externally applied to the crop outside the control of the model.

Module Stat

Module STAT calls subroutine STAT which is a subroutine that generates at random variant used in the module IRR to determine the depth of water application as a random variant with the mean and standard deviation of the population specified earlier.

Module Salt

The salt module reads in the initial salt value of the water and soil and calculates the salt balance. This module is not currently active in the trickle-irrigation program.

Module Water

This is one of the larger modules that reads in the initial water content and maintains the soil-water accounting procedure. The module works on the principles of running two balances, one is the balance of volume of water within the ellipsoid shells and the second component of the module is to maintain a water balance within the boxes, calculating and distributing water in terms of transpiration into each one of the boxes within any given shell. Evaporation is handled in this module by one-dimensional flow with each column switching from stage-one evaporation to stage-two evaporation when the top foot reach an average 80 percent depletion. The calculation of that point is accomplished in module ET. The total evaporation is the sum of evaporation from each column.

Module Climate

Module CLIMATE is called after the READ module and all subsequent modules that were described. This module reads in the climate on a daily time set necessary to compute potential evapotranspiration, which is subsequently computed by module ET and which also computes transpiration and returns daily stressed or non-stressed evapotranspiration. Module ET also determines when soil evaporation switches from stage-one to stage-two evaporation.

A list of the subroutines and functions and a statement of their use is presented in table 1.

Table 1. Descriptions of subroutines (sub.) and functions (fun.) in each module (.f) of the irrigation schedule model.

CLIM.f	
sub.plant	searches through weather file for starting date
sub.rdclim	reads current climate data
sub.wthrpt	monthly accumulator of climate and potential evapotranspiration
sub.zeroclm	zeroes climate counters
fun.getdate	returns calendar date
fun.gettrn	returns rain up to iday
fun.getrain	returns today's rain
fun.getmax	returns today's maximum temperature
fun.getmnt	returns today's minimum temperature
fun.getmxh	returns today's maximum humidity
fun.getmnh	returns today's minimum humidity
fun.getsol	returns today's solar radiation
fun.getwin	returns today's wind run
ET.f	
sub.zeroet	initializes evaporation and transpiration counters
sub.calpet	calculates potential evaporation using Penman's equation
sub.et	calculated daily stressed and non-stressed evapotranspiration
sub.acumet	accumulates daily evaporation and transpiration
sub.setsti	bookkeeping
sub.setdtr	bookkeeping
sub.setdev	bookkeeping
fun.getpet	defines daily pet as function for global access
fun.getapet	defines accumulative pet for global access
fun.getdif	defines difference in accumulative transpiration and seasonal non-stressed evapotranspiration
fun.getaev	defines daily evapotranspiration for global access
fun.getsev	defines seasonal evapotranspiration for global access
fun.getatr	defines season transpiration for global access
fun.gettrns	defines non-stressed evapotranspiration for global access
fun.getdtr	defines daily transpiration for global access
fun.getdev	defines daily evapotranspiration for global access
fun.getmat	returns accumulated non-stressed transpiration value at max akc
READ.f	
sub.input	reads in working environment from files by calling other modules
OPEN.f	
sub.openn	opens reads and write files
sub.cclose	closes all open files
SEAS.f	
ksub.rdseas	reads in relevant crop dates
fun.julian	converts from month day year to julian date
fun.inqnyr	defines number of years read in sub.rdseas for global access
fun.inqjpl	defines planting date for global access
fun.inqjem	defines emergence date for global access
fun.inqharv	defines harvest date for global access
fun.inqbem	defines emergence date for global access

Table 1 cont.

fun.ingngrow	defines number of growing days in season for global access
fun.inggtst	calculated test date for converting from one polynomial to the next that describes the crop coefficient curves
CROP.f	
sub.rdcrop	reads in crop information - annual or perennial, root max depth, etc.
sub.setrd	sets root depth
sub.setdia	sets initial diameter of a tree
sub.repcrop	computes root diameter increase
sub.initrd	set initial root depth
sub.rgroot	calculates root growth
fun.getpcr	calculates percent root depth
SOILS.f	
sub.rdsoil	reads information on size and shape of shells
sub.setsin	returns index on shell based on root growth in z direction
sub.setsoil	computes field capacity and permanent wilting point for soil type
sub.mapit	maps the boxes in each ellipsoid
sub.unitv	returns unit vector in direction of vector to center of box
fun.getfc	defines field capacity for global access
fun.getpwp	defines permanent wilting point for global access
fun.inqdel	defines interval for ellopsoil shell
fun.inqnpart	booking
fun.inqsty	defines soil type for global access
fun.tshell	defines shell parameter for locating boxes in shells
fun.inqnsh	defines number of shells in the soil
fun.inqnqbs	returns number of cubes in shell as some radius
fun.inqnx	returns x coordinate of shell
fun.inqny	returns y coordinate of shell
fun.inqnz	returns z coordinate of shell
FIELD.f	
sub.rdfield	reads in field information
fun.inqelev	defines site elevation for global access
fun.inqnfld	defines number of fields for global access
YIELD.f	
rdyield	reads in yield information for water production functions
fun.getymax	defines maximum yield based on accumulated et
fun.getyac	defines actual yield based on accumulated et
fun.getymax	defines max yield as read in
GROW.f	
sub.rdgrow	reads in grow data including temperature limits for growing degree days
sub.calgdd	calculates growing degree days
sub.calakc	calculates crop curves (akc) for each crop by calling appropriate subroutines
sub.genakc	generic crop curve calculator
sub.whtack	wheat crop curve calculator
sub.zerogr	initializes growing degree days and akc accumulators
sub.mdhvst	determines if mid-harvests are necessary for alfalfa when operating
sub.repgrw	reports when date and amount of non-stress transpiration at maximum akc
fun.calklai	calculates relative leaf area index

Table 1 cont.

fun.getlai	defines relative leaf area index for global access
fun.getakc	defines crop curve coefficients (akc) for global access
fun.getgdd	defines growing degree days for global access
fun.getdgdd	defines daily growing degree days for global access
fun.inqmakc	defines index when maximum akc occurs
IRR.f	
sub.rdsett	reads in application coefficients for linear or normal distributed water applications
sub.rdirr	reads in irrigation amounts and dates
sub.addirr	computes the amount of irrigation water that is applied at each site
sub.irdec	decides if irrigation water is needed based on plant available water then call subroutine to add water to soil
sub.repirr	reports on irrigation decision
fun.getirr	defines irrigation for global access
fun.gettirr	defines accumulative irrigation amount
fun.getwght	defines weighting amounts
STAT.f	
sub.rdstat	reads in random seed and computes random variant
SALT.f	NOT ACTIVE IN TRICKLE MODEL
sub.rdsinit	reads in initial salt content of soil and salt coefficients
sub.dilsalt	dilutes salt based on water application
sub.wsinit	sets wsinit at current salt level
sub.initwsal	sets salt profile to initial
sub.repsalt	reports salt level
fun.getscf	determines effect of salt on transpiration
fun.gettwsal	accumulates salt
fun.getwsal	defines salt for global access
fun.getacsal	defines average salt in soil profile
WATER.f	
sub.rdwinit	reads in initial soil moisture content
sub.storew	stores and inputs water into soil from point source and one dimensional flow
sub.sortcubes	sorts cubes in shell according to x,y,z and radius coordinates
sub.adrnwatr	adds rain water to soil
sub.adirwatr	adds irrigation water to soil
sub.extrct	extracts water from soil
sub.dalyevap	computes daily evaporation
sub.zerodr	zeros drainage parameters
sub.awcinit	replaces initial water content with current water content
fun.calrat	calculates ratio of plant available water in soil surface 12 inches
fun.calshrat	calculates ratio of plant available water in soil shells
fun.getadtr	defines accumulative transpiration for global access
fun.getrdr	defines drainage for global access
fun.getadev	defines accumulative evaporation by volume for global access
fun.getsdtr	defines accumulative transpiration by volume for global access
fun.getsdtns	defines accumulative non-stress transpiration by volume
fun.getair	defines accumulative irrigation by volume
fun.getdeep	defines deep drainage for global access
fun.getawac	defines actual water in cube for global access

Table 1 cont.

fun.getshiaw	defines initial water content for specified radius for global access
fun.getawc	defines actual water content for global access
fun.gettapw	defines actual applied water irrigated by model
fun.gettapw	defines plant average available water for cubes
fun.gettiw	defines total initial water in all boxes

Appendix C

```
trickle shell irrigation

printing for site#      =              1      1 makes it print 0 no
weather printing        =              0      1 makes it print 0 no

season dates
number of crop years    =              1
calender plant   date   =         101481      for pernial use 0101
calender emerg   date   =         102381      and the year.
calender harvest date   =         062382      for pernial use 1231
                                              and the year.
crop information
crop name               =          wheat
crop id #               =              4
perinial crop           =              0      1 if pernial crop.
diameter of stem        =            0.0      for trees only else 0.
root growth coeff       =           0.04      rootcf
starting root depth     =            0.0      inches
maximum rooting depth   =           48.0      inches
number of trees per ac  =           0.00      use for pecans else 0.
ks  a coefficient       =            0.0      intercept (for relative
ks  b coefficient       =            2.0      slope  T vs pavw).
sc  a coefficient       =           1.25      conversion from christian
sc  b coefficient       =          -25.0      to stastical uniformity.

soil information
soil type               =              4      see table in comments file
xy radius delta         =            8.0
z to xy ellipse ratio   =            1.0
spout distance          =           48.0
line distance           =           48.0
soil cube depth         =           48.0
grid x partition        =              6
grid y partition        =              6
grid z partition        =             12

field information
site id#                =              0      for user identification.
elevation of site m     =           1304
number of fields        =              1

crop yield information
given max yield         =         3893.9      see COMMENTS and READ.ME.
yield reduction coef Ky=            1.00      values from 0.7-1.4.
yield1 coefficient      =          238.2      parameters for water
yield2 coefficient      =         -742.6      production function.
yield3 coefficient      =            0.0
yield4 coefficient      =            0.0

growing information
grow degree test value  =          830.0      Level to switch to second
base temp (celsius)     =            0.0      polynomial for some crops,
maximum cutoff          =          999.9      and temp. Input for calu-
minimum cutoff          =         -999.9      lating growing degree days.
day of pernial cut  1   =              0      Only used by alfalfa model
```

```
day of pernial cut  2  =             0      otherwise leave as zero.
day of pernial cut  3  =             0
day of pernial cut  4  =             0      With alfalfa use cutting
day of pernial cut  5  =             0      date or leave as zero's to
day of pernial cut  6  =             0      use the model's default
day of pernial cut  7  =             0      values.
day count for max akc  =           242      Days until max AKC use.
max leaf area index    =           3.0      See READ.ME file.
final stressed transp. =           0.6      Ratio of final T to max T.
transp. at max akc     =          17.7      See READ.ME file.
akc1   coeff  a        =  0.789614e-08      Polynomial 1 coefficients
akc1   coeff  b        = -0.103107e-04      See COMMENTS file for
akc1   coeff  c        =  0.338057e-02      values and READ.ME for an
akc1   coeff  d        =  0.144179e-01      explanation.
akc2   coeff  a        = -0.102193e-08      Ploynomial 2 coeficients
akc2   coeff  b        =  0.472945e-05
akc2   coeff  c        = -0.629657e-02
akc2   coeff  d        =  0.279122e+01

irrigation application and settings
application coeff 1    =           0.0      Standard deviation
application coeff 2    =           1.0      Governs distribution
application coeff 3    =          -1.0      efficiency.  See COMMENTS
application coeff 4    =           2.0      for values and READ.ME for
application coeff 5    =          -2.0      an explanation.
application coeff 6    =           3.0
application coeff 7    =          -3.0
weight      coeff 1    =        0.3830      Weighting coefficient for
weight      coeff 2    =        0.2470      standard deviation.
weight      coeff 3    =        0.2470
weight      coeff 4    =        0.0600      See COMMENTS file for
weight      coeff 5    =        0.0600      values and READ.ME file
weight      coeff 6    =        0.0062      for explanation.
weight      coeff 7    =        0.0062
number of iterations   =             1      Number of scenarios in
irr units cm=0, in=1   =             1      irrigation file.
amount to irr (in)     =           0.5      See READ.ME file.
cs uniformity coeff    =         100.0      Christian uniformity.
std. dev. amt to irr   =           0.1      See READ.ME file.
%  h2o before forced   =          40.0      Set to -1 to turn off.
% rel et before h20    =          -1.0      set to -1 to turn off.
                                            See READ.ME file.
random seed
seed for rand variant  =         10000      See READ.ME file.

initial salt content                        See READ.ME file.
sal a coefficient      =          1.00      Set coefficient a to 1
sal b coefficient      =           0.0      and b to 0 to turn off.
well salinity          =        1000.0      PPM

initial water content
initial water depth 1  =          46.6      See READ.ME file.
```

```
C-----SUBROUTINE COMMENTS---------------------------------------------
C     1  - ELECTRICAL CONDUCTIVITY (SIMPLE SALINITY MODEL IN PPM )
C---------------------------------------------------------------------
C     INPUT PARAMETERS ACCORDING TO IDCROP
C
C     BASET  = BASE TEMPERATURE USED IN SELECTING CURRENT AKC
C     CUTMAX = MAX CUTOFF TEMP USED IN SELECTING CURRENT AKC
C     CUTMIN = MIN CUTOFF TEMP USED IN SELECTING CURRENT AKC
C     NOTE: FOR THOSE CROPS NOT REQUIRING CUTOFFS INSERT A LARGE VALUE
C           FOR CUTMAX AND A LARGE NEGATIVE NUMBER FOR CUTMIN
C
C     ROOTCF = ROOT COEFFICIENT USED TO CALCULATE ROOT DEPTH  ACCORDING
C              TO GROWING DEGREE DAYS (GDD)
C     ONE OTHER NOTE.  THE CROPS CHILE, SPRING AND FALL LETTUCE, FALL
C                   ONIONS ARE VALID FOR THE LAS CRUCES AREA.  THEY
C                   HAVE NOT BEEN VALIDATED IN THE OTHER AREAS OF THE
C                   STATE AND SHOULD THUS BE USED WITH CAUTION.  THE
C                   SAME IS TRUE OF POTATOES AND PINTO BEANS.  THEY WERE
C                   DERIVED USING THE FARMINGTON AREA CLIMATE FILE
C  ID  1   ALFALFA
C      2   CORN
C      3   SORGHUM
C      4   WHEAT   WINTER
C      5   PECANS
C      6   BARLEY  WINTER
C      7   COTTON
C      8   CHILE
C      9   SPRING LETTUCE
C      10  FALL LETTUCE
C      11  ONIONS
C      12  BEANS
C      13  POTATOES
C      14  BARLEY SPRING
C IF IDCROP = 1 ROOTCF = 0.11  BASET = 5.0  CUTMAX = 999.9 CUTMIN = -999
C IF IDCROP = 2 ROOTCF = 0.064 BASET = 10.0 CUTMAX = 30.0  CUTMIN = 10.0
C IF IDCROP = 3 ROOTCF = 0.042 BASET = 7.0  CUTMAX = 999.9 CUTMIN = -999
C IF IDCROP = 4 ROOTCF = 0.043 BASET = 0.0  CUTMAX = 999.9 CUTMIN = -999
C IF IDCROP = 5 ROOTCF = 0.90  BASET = 15.5 CUTMAX = 999.9 CUTMIN = -999
C IF IDCROP = 6 ROOTCF = 0.043 BASET = 5.0  CUTMAX = 30.0  CUTMIN = 5.0
C IF IDCROP = 7 ROOTCF = 0.03  BASET =12    CUTMAX =30     CUTMIN =12
C IF IDCROP = 8 ROOTCF = .064  BASET = 5    CUTMAX = 30    CUTMIN= 5
C IF IDCROP = 9 ROOTCF = .04   BASET =10    CUTMAX = 20    CUTMIN=10
C IF IDCROP =10 ROOTCF=.03     BASET = 10   CUTMAX=20      CUTMIN=20
C IF IDCROP= 11 ROOTCF=.012    BASET = 7    CUTMAX=25      CUTMIN=7
C IF IDCROP  12 ROOTCF=.04     BASET = 5    CUTMAX=25      CUTMIN =5
C IF IDCROP =13 ROOTCF=.04     BASET = 2    CUTMAX=21      CUTMIN=2
C IF IDCROP =14 ROOTCF = 0.043 BASET = 5.0   CUTMAX = 30.0  CUTMIN = 5.0
C
C     CONTINUING  yield= yldcf1*transpiration +yldcf2
C IF IDCROP = 1 YLDMAX = 7.0t/ac YLDCF1 =   0.14  wri    191 t/ac/in
                                 YLDCF2=    0.026
C IF IDCROP = 2 YLDMAX = 12000.0 YLDCF1 =   440.7 CLOVIS 1980 wri 191
                                 YLDCF2 =   -5079.0
C IF IDCROP = 3 YLDMAX =  7000.0 YLDCF1 =   339.0 wri 191
                                 YLDCF2=    146.0
```

```
C IF IDCROP = 4 YLDMAX =  5000.0 YLDCF1 =   238.2  CLOVIS 81,82
C                                YLDCF2 =  -742.60 wri 191
C IF IDCROP = 5 YLDMAX =  2500.0 YLDCF1 =   50.0  98.6    SLOPE
C                                YLDCF2 =  -60.0 -884.7   INTERCEP
C                                YLDCF3          -0.605   T**2
C                                YLDCF4          -.002097 T**3
C IF IDCROP = 6 YLDMAX =  6000.0 YLDCF1 =   535.62  wri 191
C                                YLDCF2 =  -3428.0
C IF IDCROP = 7 YLDMAX =   700.0 YLDCF1 =    36.16  wri 191
C                                YLDCF2 =    27.67
C
C IF IDCROP =8  YLDMAX =32000    YLDCF1 =    0.52   wri 191
C                                YLDCF2 =   -4.01
C IF IDCROP=9   YLDMAX=40000     YLDCF1 =  1892.0    MODELED
C                                YLDCF2 = -4057.0
C IF IDCROP=10  YLDMAX=30000     YLDCF1=  1887.8   MODELED
C                                YLDCF2= -1355.5
C IF IDCROP=11  YLDMAX=30000     YLDCF1=  2916.54  MODELED
C                                YLDCF2= -1547.9
C IF IDCROP=12  YLDMAX= 5000     YLDCF1=   194.54
c                                YLDCF2=  -140.16
C IF IDCROP=13   YLDMAX=50000    YLDCF1=  1207.63  MODELED
C                                YLDCF2=   638.96
C IF IDCROP 14   YLDMAX=6500     YLDCF1    363.1
C                                YLDCF2   -198.2
C AKC COEFFIENTS ARE READ INTO COEF VARIABLE
C    YIELD=COEF5GDD3+COEFF6GDD2+COEF7GDD+COEF8
C   IF IDCROP = 1      TSTGDD = 0.0    ALFALFA
C      COEF(a) = 0.000000E-00 COEF(b) =  0.000000E-00
C      COEF(c) = 0.000000E-00 COEF(d) =  0.000000E-00
C      COEF(a) = 3.563039E-11 COEF(b) = -4.252780E-07
C      COEF(c) = 1.110234E-03 COEF(d) =  4.054830E-01
C   IF IDCROP = 2      TSTGDD = 0.0       CORN
C      COEF(a) = 0.000000E-00 COEF(b) =  0.000000E-00
C      COEF(c) = 0.000000E-00 COEF(d) =  0.000000E-00
C      COEF(a) =-4.376590E-10 COEF(b) = -2.460800E-07
C      COEF(c) = 1.681085E-03 COEF(d) =  1.200090E-01
C   IF IDCROP = 3      TSTGDD = 0.0       SORGHUM
C      COEF(a) = 0.000000E-00 COEF(b) =  0.000000E-00
C      COEF(c) = 0.000000E-00 COEF(d) =  0.000000E-00
C      COEF(a) = 8.357460E-13 COEF(b) = -7.457840E-07
C      COEF(c) = 1.594611E-03 COEF(d) =  8.926230E-02
C   IF IDCROP = 4      TSTGDD = 830   WHEAT CLOV PLANT NOV 14
C    THE SECOND POLYNIMAL USES ACCUMULATED DEGREE DAYS FROM START
C      COEF(a) = 7.896139E-09 COEF(b) = -1.031069E-05
C      COEF(c) = 3.3805695-03 COEF(d) =  1.441792E-02
C      COEF(a) =-1.021934E-09 COEF(b) = 4.7294460E-06
C      COEF(c) =-6.296573E-03 COEF(d) =  2.791223E-00
C   IF IDCROP = 4      TSTGDD = 2161  WHEAT CLOV PLANTED AUG 18
C      COEF(a) = 5.311709E-10 COEF(b) = -2.149063E-06
C      COEF(c) = 2.266462E-03 COEF(d) =  4.663963E-03
C      COEF(a) =-2.529599E-10 COEF(b) = 1.3680070E-06
C      COEF(c) =-1.197444E-03 COEF(d) =-0.9720703E-00
C   IF IDCROP = 5      TSTGDD = 0.0   PECANS
C      COEF(a) = 0.000000E-00 COEF(b) =  0.000000E-00
```

```
C      COEF(c) = 0.000000E-00 COEF(d) =  0.000000E-00
C      COEF(a) = 0.000000E-00 COEF(b) =  0.000000E-00
C      COEF(c) = 0.000000E-00 COEF(d) =  0.000000E-00
C  IF IDCROP = 6     TSTGDD = 818.0 BARLEY WINTER
C  THE SECOND POLYNOMIAL RESETS GDD TO 0 AT THE TSTGDD
C      COEF(a) =-3.350198E-09 COEF(b) =  3.021112E-06
C      COEF(c) = 1.388876E-04 COEF(d) =  1.464570E-01
C      COEF(a) =-3.287240E-09 COEF(b) =  2.623170E-06
C      COEF(c) = 7.916980E-04 COEF(d) =  4.457150E-01
C  IF IDCROP = 7     TSTGDD = 0.0   COTTON
C      COEF(a) = 0.000000E-00 COEF(b) =  0.000000E-00
C      COEF(c) = 0.000000E-00 COEF(d) =  0.000000E-00
C      COEF(a) =-5.773080E-10 COEF(b) =  4.620190E-07
C      COEF(c) = 1.204242E-03 COEF(d) =  4.241236E-04
C IF   IDCROP =8 CHILE TSTGDD = 0.0
C      COEF(a) = 0.000000E-00 COEF(b) =  0.000000E-00
C      COEF(c) = 0.000000E-00 COEF(d) =  0.000000E-00
C      COEF(a) =-1.900000E-10 COEF(b) =  6.200000E-07
C      COEF(c) = 6.000000E-05 COEF(d) =  9.800000E-02
C IF IDCROP=9  FALL ONION  TSTGDD = 0.0
C      COEF(a) = 0.000000E-00 COEF(b) =  0.000000E-00
C      COEF(c) = 0.000000E-00 COEF(d) =  0.000000E-00
C      COEF(a) =-7.100000E-10 COEF(b) =  1.600000E-06
C      COEF(c) =-2.600000E-04 COEF(d) =  2.800000E-02
C IF IDCROP=10 FALL LETTUCE TSTGDD = 0.0
C      COEF(a) = 0.000000E-00 COEF(b) =  0.000000E-00
C      COEF(c) = 0.000000E-00 COEF(d) =  0.000000E-00
C      COEF(a) =-1.173080E-08 COEF(b) =  7.000000E-06
C      COEF(c) = 5.700000E-04 COEF(d) =  2.010000E-01
C IF IDCROP=11 SPRING LETTUCE  TSTGDD = 0.0
C      COEF(a) = 0.000000E-00 COEF(b) =  0.000000E-00
C      COEF(c) = 0.000000E-00 COEF(d) =  0.000000E-00
C      COEF(a) =-1.100000E-08 COEF(b) =  5.300000E-06
C      COEF(c) = 1.300000E-03 COEF(d) =  2.030000E-01
C IF IDCROP=12 PINTO BEANS   TSTGDD = 0.0
C      COEF(a) = 0.000000E-00 COEF(b) =  0.000000E-00
C      COEF(c) = 0.000000E-00 COEF(d) =  0.000000E-00
C      COEF(a) =-1.900000E-09 COEF(b) =  3.400000E-06
C      COEF(c) =-5.900000E-04 COEF(d) =  3.710000E-01
C IF IDCROP=13 POTATO   TSTGDD = 0.0
C      COEF(a) = 0.000000E-00 COEF(b) =  0.000000E-00
C      COEF(c) = 0.000000E-00 COEF(d) =  0.000000E-00
C      COEF(a) = 8.600000E-11 COEF(b) = -1.100000E-06
C      COEF(c) = 2.000000E-03 COEF(d) =  1.400000E-01
C IF IFCROP= 14  TSTGDD = 0.0  FARMINGTON 1980 1981  SPRING BARLEY R.91
C      COEF(a) = 0.000000E-00 COEF(b) =  0.000000E-00
C      COEF(c) = 0.000000E-00 COEF(d) =  0.000000E-00
C      COEF(a) =-3.856746E-09 COEF(b) =  2.950449E-06
C      COEF(c) = 1.540113E-03 COEF(d) =  0.0219854-00
C   COMPUTED BY SAMMIS P 67 WRI 159 FARMING 7000KG ADD 0 0
C  APPLICATION COEFFICIENTS APLCF1-7
C      SPRINKLER 0  1.00  -1.00  2.00  -2.00  3.00  -3.00
C      SURFACE   0  0.50  -0.50  1.00  -1.00  1.53  -1.53
C      TRICKLE   0  1.00  -1.00  2.00  -2.00  3.00  -3.00
C
```

```
C  WEIGHT COEFFICIENTS WGHT1-7
C     SPRINKLER  0.3830 0.2417 0.2417 0.0606 0.0606 0.0062 0.0062
C     SURFACE    0.1380 0.1380 0.1380 0.1380 0.1380 0.1560 0.1560
C     TRICKLE    0.3830 0.2417 0.2417 0.0606 0.0606 0.0062 0.0062
C
C     NUMBER     SOIL TYPE    PERCENT VOL
C                             FIELD CAPACITY   PERMANENT WILTING POINT
C       1        SAND               14.8           6.6
C       2        SANDY LOAM         21             12
C       3        LOAM               30.8           14
C       4        CLAY LOAM          36.5           17.5
C       5        SILTY CLAY         40.3           19.5
C       6        CLAY               43.7           18.7
```

Appendix D

Example of Output from IRRSCH

```
trickle shell irrigation
print irrigation site  #             1
print weather flag     =             0

season dates
number of crop years   =             1
calender plant   date  =       101481.
calender emerg   date  =       102381.
calender harvest date  =        62382.
julian planting  date  =           287
julian emergence date  =           296
julian harvest   date  =           174
# of growing days      =           253
# of days before emerg =            10
count for heat units   =           322

crop information
crop name              =         wheat
crop id #              =             4
perinial crop          =             0
diameter of stem       =      .0000000
root growth coeff      =      .0400000
starting root depth    =      .0000000
maximum rooting depth  =    48.0000000
ks  a coefficient      =      .0000000
ks  b coefficient      =     2.0000000
sc  a coefficient      =     1.2500000
sc  b coefficient      =   -25.0000000

soil information
soil type              =             4
xy delta radius shell  =          8.00
z to xy ellipse ratio  =          1.00
distance betweem spouts=         48.00
distance between lines =         48.00
surface depth          =         48.00
spout partitions       =             6
line partitions        =             6
depth partitions       =            12
grid dist., spout direc=          4.00
grid dist., line direc =          4.00
grid dist., depth      =          4.00
maximum rooting shell  =             6
soil is clay loam
field capacity          (vol) =             23.328
permament wilting point (vol) =             11.232

field information
site id#               =             0
elevation of site      =          1304
number of fields       =             1

crop yield information
given max yield        =       3893.90
yield reduction coef ky=          1.00
yieldl coefficient     =        238.20
```

```
yield2 coefficient     =        -742.60
yield3 coefficient     =            .00
yield4 coefficient     =            .00
et for projected yield =          19.46

growing information
grow degree test value =        830.000
base temp (celsius)    =           .000
maximum cutoff         =        999.900
minimum cutoff         =       -999.900
alfalfa cut dates   1  =        .000000
alfalfa cut dates   2  =        .000000
alfalfa cut dates   3  =        .000000
alfalfa cut dates   4  =        .000000
alfalfa cut dates   5  =        .000000
alfalfa cut dates   6  =        .000000
alfalfa cut dates   7  =        .000000
day count for max akc  =            242
max leaf area index    =          3.000
final stressed transp. =           .600
transp. at max akc     =         17.700
akc1   coeff  a        =    .789614E-08
akc1   coeff  b        =   -.103107E-04
akc1   coeff  c        =    .338057E-02
akc1   coeff  d        =    .144179E-01
akc2   coeff  a        =   -.102193E-08
akc2   coeff  b        =    .472945E-05
akc2   coeff  c        =   -.629657E-02
akc2   coeff  d        =    .279122E+01

irrigation application and settings
application coeff 1    =            .00
application coeff 2    =           1.00
application coeff 3    =          -1.00
application coeff 4    =           2.00
application coeff 5    =          -2.00
application coeff 6    =           3.00
application coeff 7    =          -3.00
weight      coeff 1    =          .3830
weight      coeff 2    =          .2470
weight      coeff 3    =          .2470
weight      coeff 4    =          .0600
weight      coeff 5    =          .0600
weight      coeff 6    =          .0062
weight      coeff 7    =          .0062
number of iterations   =              1
irr units in-1, cm-0   =              1
amount to irr (in)     =            .50
cs uniformity coeff    =         100.00
std. dev. amt to irr   =            .10
% h2o before forced    =          40.00
% rel et before h20    =          -1.00
random seed
seed for rand variant  =         10000.
```

```
initial salt content                             See READ.ME file.
sal a coefficient      =           1.00
sal b coefficient      =            .00
well salinity          =        1000.00

initial moisture (by volume h20) for cubes :     20.00
total initial h2o (in*3) =           12.80

processing irrigation #  1
processing year #  1
number of irrigations =   1
irrigation schedule
   date      inches

   20381.      .01
processing site #     1
searching file for planting date...
irrigation appl eff=  .245 apply=   .66 deep=     285.75 deepd=        .00




       root lai trratio  pet ns.tr st.tr  evap st.et  ns.et evratio  akc  gdd
  date  zn    %         (in)  (in)  (in)  (in)  (in)  (in)    %       %   days
------------------------------------------------------------------------------------
101481.  1  .000  .902  .222  .000  .000  .045  .045  .045  .010  .000   18.
rain appl eff= 1.000 apply=   .07 deep=     285.75 deepd=        .00
101581.  1  .000  .962  .022  .000  .000  .009  .009  .009  .010  .072   29.
rain appl eff= 1.000 apply=   .15 deep=     285.75 deepd=        .00
101681.  1  .000  .960  .090  .000  .000  .033  .033  .033  .010  .103   44.
101781.  1  .000  .874  .196  .000  .000  .039  .039  .039  .010  .143   57.
101881.  1  .000  .801  .165  .000  .000  .033  .033  .033  .010  .174   67.
101981.  1  .000  .727  .168  .000  .000  .032  .032  .032  .010  .196   77.
102081.  1  .000  .639  .260  .000  .000  .034  .034  .034  .010  .216   92.
102181.  1  .000  .603  .085  .000  .000  .020  .020  .020  .010  .244   98.
102281.  1  .000  .587  .041  .000  .000  .014  .014  .014  .010  .254  104.
102381.  1  .000  .414  .056  .013  .013  .014  .027  .027  .010  .263  108.
102481.  1  .002  .010  .237  .057  .033  .015  .048  .072  .010  .268  118.
irrigation appl eff=  .124 apply=   .68 deep=     627.73 deepd=        .00
102581.  1  .008  .478  .150  .038  .038  .038  .076  .076  .010  .283  125.
102681.  1  .014  .010  .234  .061  .032  .053  .085  .114  .010  .291  136.
irrigation appl eff=  .204 apply=   .41 deep=     816.19 deepd=        .00
102781.  1  .020  .198  .218  .059  .059  .056  .115  .115  .010  .303  150.
102881.  1  .030  .010  .225  .064  .009  .055  .064  .119  .010  .316  167.
irrigation appl eff=  .138 apply=   .61 deep=    1118.44 deepd=        .00
102981.  1  .031  .269  .185  .055  .055  .057  .112  .112  .010  .328  182.
103081.  1  .041  .010  .223  .067  .015  .066  .081  .133  .010  .336  194.
rain appl eff= 1.000 apply=   .24 deep=    1118.44 deepd=        .00
103181.  1  .043  .000  .125  .038  .016  .057  .073  .095  .010  .340  198.
```

```
        root  lai  trratio   pet  ns.tr  st.tr   evap  st.et   ns.et  evratio   akc    gdd
  date   zn    %             (in)  (in)   (in)   (in)   (in)   (in)     %        %     days
------------------------------------------------------------------------------------------
110181.  2  .046   .665   .186   .057   .057   .048   .105   .105   .010   .341   208.
110281.  2  .056   .562   .151   .047   .047   .036   .083   .083   .010   .343   219.
110381.  2  .063   .509   .090   .028   .028   .019   .047   .047   .010   .343   229.
110481.  2  .068   .396   .212   .065   .065   .026   .091   .091   .010   .343   240.
110581.  2  .079   .326   .152   .047   .037   .022   .059   .068   .010   .341   251.
rain appl eff= 1.000 apply=    .01 deep=     1118.44 deepd=         .00
110681.  2  .086   .296   .065   .020   .013   .020   .033   .040   .010   .338   261.
rain appl eff= 1.000 apply=    .07 deep=     1118.44 deepd=         .00
110781.  2  .088   .257   .177   .053   .035   .032   .067   .085   .010   .335   275.
110881.  2  .094   .212   .148   .044   .022   .017   .039   .061   .010   .329   285.
110981.  2  .098   .171   .162   .047   .020   .016   .036   .063   .010   .323   291.
111081.  2  .101   .137   .164   .047   .016   .015   .031   .062   .010   .320   299.
irrigation appl eff= 1.000 apply=   .43 deep=     1118.44 deepd=          .00
111181.  2  .104   .644   .140   .040   .040   .028   .068   .068   .010   .315   307.
111281.  2  .110   .515   .227   .063   .063   .039   .102   .102   .010   .309   318.
111381.  2  .121   .451   .123   .033   .033   .020   .054   .054   .010   .301   330.
111481.  2  .127   .364   .198   .052   .047   .023   .069   .074   .010   .291   344.
irrigation appl eff=  .916 apply=   .51 deep=     1143.25 deepd=          .00
111581.  2  .135   .882   .181   .045   .045   .052   .097   .097   .010   .279   359.
111681.  2  .142   .761   .202   .048   .048   .052   .100   .100   .010   .265   375.
111781.  2  .151   .645   .217   .049   .049   .048   .097   .097   .010   .249   389.
irrigation appl eff= 1.000 apply=   .50 deep=     1143.25 deepd=          .00
111881.  3  .159   .010   .272   .057   .001   .073   .074   .131   .010   .234   404.
irrigation appl eff= 1.000 apply=   .54 deep=     1143.25 deepd=          .00
111981.  3  .159   .169   .139   .027   .009   .047   .056   .074   .010   .218   410.
irrigation appl eff= 1.000 apply=   .41 deep=     1143.25 deepd=          .00
112081.  3  .160   .311   .144   .027   .019   .051   .070   .079   .010   .211   416.
irrigation appl eff= 1.000 apply=   .69 deep=     1143.25 deepd=          .00
112181.  3  .164   .555   .171   .032   .032   .076   .108   .108   .069   .205   428.
112281.  3  .169   .495   .237   .041   .041   .104   .144   .144   .008   .192   442.
112381.  3  .176   .455   .172   .027   .027   .070   .097   .098   .010   .177   452.
112481.  3  .180   .404   .235   .035   .032   .091   .122   .125   .010   .165   467.
112581.  3  .186   .377   .220   .030   .024   .041   .065   .070   .010   .149   479.
irrigation appl eff= 1.000 apply=   .54 deep=     1143.25 deepd=          .00
112681.  3  .190   .587   .061   .008   .008   .029   .036   .036   .099   .136   482.
112781.  3  .191   .576   .042   .005   .005   .021   .026   .026   .088   .133   485.
112881.  3  .192   .567   .038   .004   .004   .018   .023   .023   .078   .129   491.
rain appl eff= 1.000 apply=    .47 deep=     1143.25 deepd=         .00
112981.  3  .193   .635   .039   .004   .004   .024   .028   .028   .206   .123   498.
113081.  3  .193   .613   .100   .010   .010   .045   .056   .056   .182   .116   503.
```

```
        root  lai  trratio   pet  ns.tr  st.tr   evap  st.et   ns.et  evratio   akc    gdd
  date   zn    %             (in)  (in)   (in)   (in)   (in)   (in)     %        %     days
------------------------------------------------------------------------------------------
120181.  3  .195   .590   .107   .011   .011   .046   .057   .057   .157   .112   503.
120281.  3  .197   .556   .155   .015   .015   .066   .082   .082   .122   .111   509.
120381.  3  .200   .504   .247   .023   .023   .102   .125   .125   .069   .106   519.
120481.  3  .204   .495   .102   .009   .009   .014   .023   .023   .060   .096   522.
120581.  3  .205   .474   .124   .010   .010   .041   .051   .052   .039   .093   529.
120681.  3  .207   .456   .167   .013   .012   .032   .045   .045   .022   .086   540.
```

```
120781.  3  .209  .441  .142  .010  .009  .028  .037  .038  .009  .077  551.
120881.  3  .211  .429  .121  .007  .007  .025  .032  .032  .010  .068  560.
120981.  3  .212  .417  .138  .008  .006  .023  .029  .030  .010  .061  569.
121081.  3  .213  .404  .283  .014  .012  .021  .033  .035  .010  .054  581.
121181.  3  .215  .395  .051  .002  .002  .020  .022  .022  .010  .047  591.
irrigation appl eff= 1.000 apply=   .42 deep=   1143.25 deepd=        .00
121281.  3  .215  .561  .051  .002  .002  .022  .024  .024  .118  .041  593.
121381.  3  .215  .543  .118  .004  .004  .040  .044  .044  .099  .040  600.
irrigation appl eff= 1.000 apply=   .43 deep=   1143.25 deepd=        .00
121481.  4  .216  .010  .098  .003  .000  .048  .048  .051  .189  .036  605.
irrigation appl eff= 1.000 apply=   .53 deep=   1143.25 deepd=        .00
121581.  4  .216  .056  .111  .003  .000  .061  .062  .065  .344  .034  610.
irrigation appl eff= 1.000 apply=   .63 deep=   1143.25 deepd=        .00
121681.  4  .216  .272  .124  .004  .002  .072  .073  .075  .422  .032  617.
irrigation appl eff= 1.000 apply=   .57 deep=   1143.25 deepd=        .00
121781.  4  .216  .381  .072  .002  .001  .044  .045  .046  .454  .030  617.
irrigation appl eff= 1.000 apply=   .34 deep=   1143.25 deepd=        .00
121881.  4  .217  .441  .102  .000  .000  .061  .061  .061  .474  .000  617.
121981.  4  .217  .417  .184  .000  .000  .109  .109  .109  .438  .000  624.
122081.  4  .217  .394  .175  .004  .003  .104  .107  .108  .403  .028  633.
irrigation appl eff= 1.000 apply=   .59 deep=   1143.25 deepd=        .00
122181.  4  .217  .490  .214  .005  .005  .132  .137  .137  .482  .026  648.
122281.  4  .218  .481  .065  .001  .001  .041  .042  .042  .468  .024  653.
rain appl eff= 1.000 apply=   .02 deep=   1143.25 deepd=        .00
122381.  4  .218  .482  .020  .000  .000  .014  .015  .015  .470  .024  653.
122481.  4  .218  .469  .102  .000  .000  .063  .063  .063  .449  .000  653.
122581.  4  .218  .452  .132  .000  .000  .079  .079  .079  .423  .000  656.
122681.  4  .218  .436  .121  .003  .002  .075  .077  .077  .397  .024  658.
122781.  4  .219  .431  .159  .003  .003  .017  .020  .020  .391  .024  666.
122881.  4  .219  .428  .090  .002  .002  .015  .017  .017  .385  .025  666.
122981.  4  .220  .418  .154  .000  .000  .045  .045  .045  .370  .000  668.
123081.  4  .220  .409  .175  .004  .003  .038  .042  .042  .357  .025  675.
123181.  4  .220  .401  .081  .002  .002  .034  .036  .036  .345  .027  682.


        root  lai  trratio  pet  ns.tr  st.tr  evap  st.et  ns.et  evratio  akc   gdd
  date   zn    %           (in)   (in)   (in)  (in)   (in)   (in)    %       %   days
-----------------------------------------------------------------------------------------
 10182.  4  .220  .394  .124  .003  .003  .031  .034  .034  .334  .029  685.
irrigation appl eff= 1.000 apply=   .45 deep=   1143.25 deepd=        .00
 10282.  4  .221  .470  .157  .004  .004  .083  .087  .087  .452  .030  694.
 10382.  4  .222  .454  .137  .004  .004  .070  .074  .074  .428  .034  695.
 10482.  4  .222  .438  .148  .005  .004  .072  .076  .077  .403  .034  696.
 10582.  4  .223  .412  .245  .008  .006  .113  .119  .121  .364  .035  705.
 10682.  4  .224  .407  .155  .006  .004  .020  .024  .026  .356  .040  712.
rain appl eff= 1.000 apply=   .01 deep=   1143.25 deepd=        .00
 10782.  4  .225  .406  .043  .002  .001  .012  .013  .014  .355  .045  712.
 10882.  4  .225  .398  .103  .000  .000  .039  .039  .039  .342  .000  712.
irrigation appl eff= 1.000 apply=   .53 deep=   1143.25 deepd=        .00
 10982.  4  .225  .491  .174  .000  .000  .103  .103  .103  .482  .000  718.
 11082.  4  .225  .484  .048  .002  .002  .030  .032  .032  .472  .049  718.
 11182.  4  .225  .476  .062  .000  .000  .038  .038  .038  .459  .000  718.
 11282.  4  .225  .465  .084  .000  .000  .051  .051  .051  .442  .000  718.
rain appl eff= 1.000 apply=   .02 deep=   1143.25 deepd=        .00
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 11382.  4  .225  .461  .066  .000  .000  .041  .041  .041  .436  .000  718.
 11482.  4  .225  .445  .126  .000  .000  .075  .075  .075  .411  .000  718.
 11582.  4  .225  .422  .175  .008  .007  .100  .106  .107  .376  .049  724.
 11682.  4  .226  .419  .072  .003  .003  .009  .012  .012  .372  .054  724.
 11782.  4  .227  .407  .266  .000  .000  .057  .057  .057  .353  .000  728.
 11882.  4  .227  .396  .212  .011  .009  .044  .053  .055  .336  .057  738.
irrigation appl eff= 1.000 apply=   .51 deep=   1143.25 deepd=        .00
 11982.  4  .228  .484  .127  .008  .008  .076  .083  .083  .475  .067  744.
 12082.  4  .230  .470  .103  .007  .006  .059  .065  .066  .454  .074  754.
 12182.  4  .231  .452  .142  .011  .009  .078  .088  .089  .425  .086  762.
 12282.  4  .232  .428  .183  .016  .013  .098  .110  .114  .389  .097  765.
 12382.  4  .234  .421  .202  .018  .014  .020  .035  .039  .378  .102  768.
 12482.  4  .237  .406  .231  .022  .017  .054  .070  .076  .356  .106  776.
 12582.  4  .240  .395  .120  .013  .009  .042  .052  .055  .339  .119  782.
irrigation appl eff= 1.000 apply=   .63 deep=   1143.25 deepd=        .00
 12682.  4  .241  .494  .242  .028  .028  .146  .174  .174  .465  .129  790.
 12782.  4  .246  .462  .206  .026  .026  .119  .145  .146  .418  .142  800.
irrigation appl eff= 1.000 apply=   .39 deep=   1143.25 deepd=        .00
 12882.  5  .250  .126  .117  .017  .004  .071  .075  .088  .445  .162  805.
irrigation appl eff= 1.000 apply=   .71 deep=   1143.25 deepd=        .00
 12982.  5  .251  .218  .142  .022  .009  .092  .102  .114  .552  .172  815.
rain appl eff= 1.000 apply=   .01 deep=   1143.25 deepd=        .00
irrigation appl eff= 1.000 apply=   .48 deep=   1143.25 deepd=        .00
 13082.  5  .253  .285  .059  .010  .005  .041  .047  .052  .649  .194  815.
irrigation appl eff= 1.000 apply=   .71 deep=   1143.25 deepd=        .00
 13182.  5  .254  .376  .149  .000  .000  .117  .117  .117  .785  .000  816.
irrigation appl eff= 1.000 apply=   .33 deep=   1143.25 deepd=        .00



      root  lai  trratio   pet  ns.tr  st.tr   evap  st.et   ns.et  evratio   akc   gdd
 date   zn    %           (in)   (in)   (in)   (in)   (in)    (in)     %        %    days
-------------------------------------------------------------------------------------------
 20182.  5  .254  .415  .076  .013  .010  .061  .072  .075  .842  .197  818.
rain appl eff= 1.000 apply=   .01 deep=   1143.25 deepd=        .00
 20282.  5  .255  .401  .108  .019  .015  .087  .102  .106  .818  .201  818.
irrigation appl eff= 1.000 apply=   .01 deep=   1143.25 deepd=        .00
 20382.  5  .258  .399  .026  .000  .000  .021  .021  .021  .815  .000  818.
irrigation appl eff= 1.000 apply=   .50 deep=   1143.25 deepd=        .00
 20482.  5  .258  .469  .038  .000  .000  .032  .032  .032  .920  .000  818.
 20582.  5  .258  .463  .046  .000  .000  .038  .038  .038  .910  .000  818.
 20682.  5  .258  .455  .068  .000  .000  .056  .056  .056  .895  .000  818.
 20782.  5  .258  .438  .131  .000  .000  .108  .108  .108  .866  .000  818.
rain appl eff= 1.000 apply=   .02 deep=   1143.25 deepd=        .00
 20882.  5  .258  .435  .044  .000  .000  .037  .037  .037  .862  .000  818.
rain appl eff= 1.000 apply=   .04 deep=   1143.25 deepd=        .00
 20982.  5  .258  .435  .053  .000  .000  .044  .044  .044  .861  .000  818.
 21082.  5  .258  .416  .145  .000  .000  .120  .120  .120  .829  .000  820.
rain appl eff= 1.000 apply=   .03 deep=   1143.25 deepd=        .00
 21182.  5  .258  .415  .041  .008  .006  .034  .040  .042  .826  .207  821.
rain appl eff= 1.000 apply=   .03 deep=   1143.25 deepd=        .00
 21282.  5  .259  .397  .149  .028  .021  .121  .142  .149  .796  .210  824.
irrigation appl eff= 1.000 apply=   .51 deep=   1143.25 deepd=        .00
 21382.  5  .262  .446  .180  .035  .030  .148  .179  .184  .881  .217  829.
 21482.  5  .268  .412  .233  .048  .039  .186  .225  .234  .822  .228  838.
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 21582.  5  .274  .387  .166  .035  .026  .135  .161  .170  .779  .235  847.
irrigation appl eff= 1.000 apply=   .48 deep=    1143.25 deepd=          .00
 21682.  5  .279  .436  .166  .034  .029  .136  .165  .171  .863  .230  858.
 21782.  5  .284  .411  .179  .036  .029  .133  .162  .170  .820  .225  868.
 21882.  5  .288  .393  .127  .025  .019  .097  .115  .122  .790  .221  875.
irrigation appl eff= 1.000 apply=   .64 deep=    1143.25 deepd=          .00
 21982.  5  .292  .463  .183  .036  .032  .148  .180  .184  .881  .218  882.
 22082.  5  .297  .425  .250  .049  .041  .202  .243  .251  .816  .216  892.
 22182.  5  .304  .389  .247  .047  .037  .196  .232  .243  .755  .212  905.
irrigation appl eff= 1.000 apply=   .40 deep=    1143.25 deepd=          .00
 22282.  5  .310  .417  .228  .043  .035  .180  .215  .223  .805  .209  918.
 22382.  5  .316  .384  .301  .056  .042  .169  .211  .225  .749  .206  932.
irrigation appl eff= 1.000 apply=   .53 deep=    1143.25 deepd=          .00
 22482.  5  .323  .449  .133  .024  .021  .100  .121  .124  .857  .204  938.
 22582.  5  .327  .442  .054  .010  .008  .042  .050  .052  .844  .203  938.
 22682.  5  .328  .436  .050  .000  .000  .039  .039  .039  .834  .000  938.
 22782.  5  .328  .419  .156  .000  .000  .110  .110  .110  .805  .000  941.
 22882.  5  .328  .397  .172  .031  .024  .120  .144  .151  .767  .202  949.
irrigation appl eff= 1.000 apply=   .45 deep=    1143.25 deepd=          .00




        root  lai  trratio  pet  ns.tr  st.tr  evap  st.et  ns.et  evratio  akc  gdd
  date   zn    %           (in)  (in)   (in)   (in)  (in)   (in)     %       %   days
-------------------------------------------------------------------------------------
 30182.  5  .332  .440  .202  .037  .031  .142  .173  .179  .841  .202  959.
 30282.  5  .337  .413  .209  .038  .030  .142  .172  .179  .795  .201  971.
 30382.  5  .343  .389  .198  .036  .027  .128  .155  .164  .754  .201  981.
irrigation appl eff= 1.000 apply=   .57 deep=    1143.25 deepd=          .00
 30482.  5  .347  .446  .224  .041  .035  .163  .198  .204  .852  .201  984.
rain appl eff= 1.000 apply=   .02 deep=    1143.25 deepd=          .00
 30582.  5  .353  .444  .033  .006  .005  .025  .030  .031  .849  .201  984.
 30682.  5  .354  .431  .121  .000  .000  .088  .088  .088  .826  .000  984.
 30782.  5  .354  .406  .231  .000  .000  .163  .163  .163  .783  .000  990.
irrigation appl eff= 1.000 apply=   .50 deep=    1143.25 deepd=          .00
 30882.  6  .354  .177  .193  .035  .012  .144  .156  .179  .801  .201 1002.
irrigation appl eff= 1.000 apply=   .70 deep=    1143.25 deepd=          .00
 30982.  6  .356  .241  .203  .037  .017  .158  .175  .195  .808  .202 1013.
irrigation appl eff= 1.000 apply=   .53 deep=    1143.25 deepd=          .00
 31082.  6  .359  .273  .293  .054  .028  .228  .256  .282  .790  .204 1026.
irrigation appl eff= 1.000 apply=   .44 deep=    1143.25 deepd=          .00
 31182.  6  .364  .304  .204  .038  .021  .158  .180  .196  .807  .206 1038.
irrigation appl eff= 1.000 apply=   .38 deep=    1143.25 deepd=          .00
 31282.  6  .367  .324  .237  .044  .027  .184  .211  .228  .801  .208 1052.
rain appl eff= 1.000 apply=   .10 deep=    1143.25 deepd=          .00
irrigation appl eff= 1.000 apply=   .50 deep=    1143.25 deepd=          .00
 31382.  6  .372  .381  .130  .025  .018  .101  .119  .125  .830  .211 1062.
irrigation appl eff= 1.000 apply=   .47 deep=    1143.25 deepd=          .00
 31482.  6  .375  .416  .196  .038  .030  .151  .181  .189  .825  .214 1071.
 31582.  6  .380  .391  .230  .045  .034  .172  .206  .217  .780  .217 1080.
irrigation appl eff= 1.000 apply=   .49 deep=    1143.25 deepd=          .00
 31682.  6  .386  .419  .269  .053  .044  .206  .250  .260  .811  .220 1089.
 31782.  6  .393  .394  .227  .046  .035  .169  .204  .214  .766  .223 1100.
irrigation appl eff= 1.000 apply=   .42 deep=    1143.25 deepd=          .00
 31882.  6  .399  .418  .254  .052  .043  .193  .236  .245  .808  .227 1118.
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rain appl eff= 1.000 apply=   .08 deep=    1143.25 deepd=        .00
 31982.  6  .406  .397  .266  .056  .044  .202  .246  .258  .772  .235 1128.
irrigation appl eff= 1.000 apply=   .66 deep=    1143.25 deepd=        .00
 32082.  6  .414  .441  .301  .065  .057  .226  .283  .291  .804  .240 1139.
 32182.  6  .424  .406  .304  .067  .054  .226  .281  .293  .743  .245 1150.
 32282.  6  .433  .385  .185  .042  .031  .136  .167  .177  .706  .251 1156.
irrigation appl eff= 1.000 apply=   .64 deep=    1143.25 deepd=        .00
 32382.  6  .438  .424  .362  .083  .071  .260  .330  .342  .775  .254 1167.
 32482.  6  .450  .393  .291  .068  .053  .197  .250  .265  .721  .260 1178.
irrigation appl eff= 1.000 apply=   .42 deep=    1143.25 deepd=        .00
 32582.  6  .459  .424  .178  .043  .035  .119  .153  .161  .779  .266 1182.
 32682.  6  .465  .418  .056  .013  .010  .040  .050  .053  .768  .268 1185.
 32782.  6  .467  .404  .124  .030  .023  .078  .101  .108  .747  .270 1190.
 32882.  6  .470  .393  .103  .025  .019  .065  .084  .091  .728  .273 1196.
rain appl eff= 1.000 apply=   .02 deep=    1143.25 deepd=        .00
irrigation appl eff= 1.000 apply=   .58 deep=    1143.25 deepd=        .00
 32982.  6  .474  .438  .283  .071  .061  .201  .262  .271  .803  .277 1207.
 33082.  6  .484  .389  .432  .110  .089  .300  .389  .410  .718  .284 1217.
irrigation appl eff= 1.000 apply=   .55 deep=    1143.25 deepd=        .00
 33182.  6  .499  .423  .315  .082  .069  .216  .285  .298  .778  .291 1228.



        root lai trratio  pet ns.tr st.tr  evap st.et  ns.et evratio  akc  gdd
  date   zn    %          (in)  (in)  (in)  (in)  (in)  (in)   %       %   days
------------------------------------------------------------------------------
 40182.  6  .511  .386  .353  .095  .074  .221  .295  .316  .714  .298 1240.
irrigation appl eff= 1.000 apply=   .55 deep=    1143.25 deepd=        .00
 40282.  6  .523  .420  .332  .092  .077  .208  .285  .300  .774  .307 1252.
 40382.  6  .536  .384  .347  .098  .076  .208  .284  .307  .712  .316 1264.
irrigation appl eff= 1.000 apply=   .57 deep=    1143.25 deepd=        .00
 40482.  6  .549  .415  .378  .110  .092  .232  .324  .342  .768  .324 1276.
 40582.  6  .565  .385  .290  .087  .066  .176  .243  .263  .715  .334 1287.
irrigation appl eff= 1.000 apply=   .64 deep=    1143.25 deepd=        .00
 40682.  6  .576  .431  .284  .088  .075  .188  .263  .276  .799  .343 1293.
 40782.  6  .589  .401  .274  .086  .068  .175  .243  .261  .746  .348 1304.
 40882.  6  .600  .372  .265  .085  .063  .163  .226  .248  .697  .357 1313.
irrigation appl eff= 1.000 apply=   .48 deep=    1143.25 deepd=        .00
 40982.  6  .611  .396  .273  .089  .071  .171  .242  .261  .751  .364 1323.
irrigation appl eff= 1.000 apply=   .46 deep=    1143.25 deepd=        .00
 41082.  6  .623  .430  .257  .086  .073  .163  .236  .249  .801  .372 1331.
 41182.  6  .635  .390  .365  .125  .099  .226  .325  .351  .731  .379 1345.
irrigation appl eff= 1.000 apply=   .33 deep=    1143.25 deepd=        .00
 41282.  6  .652  .379  .409  .144  .114  .250  .364  .394  .725  .392 1367.
irrigation appl eff= 1.000 apply=   .65 deep=    1143.25 deepd=        .00
 41382.  6  .671  .421  .369  .136  .117  .237  .353  .373  .789  .411 1383.
 41482.  6  .691  .383  .313  .120  .093  .198  .290  .318  .726  .426 1400.
irrigation appl eff= 1.000 apply=   .62 deep=    1143.25 deepd=        .00
 41582.  6  .707  .414  .396  .157  .133  .248  .382  .405  .779  .441 1415.
 41682.  6  .729  .382  .262  .107  .082  .157  .239  .265  .728  .455 1426.
irrigation appl eff= 1.000 apply=   .60 deep=    1143.25 deepd=        .00
 41782.  6  .743  .431  .237  .099  .084  .143  .227  .242  .811  .466 1436.
 41882.  6  .757  .394  .315  .135  .106  .182  .289  .317  .748  .475 1448.
irrigation appl eff= 1.000 apply=   .38 deep=    1143.25 deepd=        .00
 41982.  6  .775  .401  .300  .132  .107  .173  .280  .305  .773  .487 1460.
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 42082.  6  .793  .374  .210  .095  .070  .118  .188  .213  .732  .499 1466.
irrigation appl eff= 1.000 apply=   .57 deep=    1143.25 deepd=         .00
 42182.  6  .805  .433  .182  .083  .069  .106  .175  .188  .819  .505 1471.
 42282.  6  .817  .418  .127  .058  .046  .072  .118  .130  .794  .510 1479.
 42382.  6  .825  .402  .145  .068  .052  .082  .134  .149  .765  .517 1484.
rain appl eff= 1.000 apply=   .01 deep=    1143.25 deepd=         .00
 42482.  6  .833  .364  .320  .150  .111  .169  .280  .319  .707  .522 1496.
irrigation appl eff= 1.000 apply=   .46 deep=    1143.25 deepd=         .00
 42582.  6  .852  .371  .371  .178  .137  .202  .340  .381  .736  .535 1511.
irrigation appl eff= 1.000 apply=   .48 deep=    1143.25 deepd=         .00
 42682.  6  .876  .409  .292  .144  .118  .159  .276  .303  .783  .549 1526.
rain appl eff= 1.000 apply=   .15 deep=    1143.25 deepd=         .00
 42782.  6  .895  .405  .193  .098  .077  .103  .180  .201  .777  .564 1538.
 42882.  6  .908  .376  .229  .119  .088  .113  .201  .231  .734  .577 1554.
irrigation appl eff= 1.000 apply=   .38 deep=    1143.25 deepd=         .00
 42982.  6  .923  .373  .361  .192  .149  .177  .326  .369  .747  .592 1570.
rain appl eff= 1.000 apply=   .02 deep=    1143.25 deepd=         .00
irrigation appl eff= 1.000 apply=   .22 deep=    1143.25 deepd=         .00
 43082.  6  .949  .399  .021  .011  .008  .011  .020  .023  .795  .608 1580.
irrigation appl eff= 1.000 apply=   .17 deep=    1143.25 deepd=         .00



       root  lai  trratio  pet  ns.tr  st.tr  evap  st.et  ns.et  evratio  akc   gdd
 date   zn    %           (in)  (in)   (in)   (in)  (in)   (in)     %       %    days
------------------------------------------------------------------------------------------
 50182.  6  .950  .418  .142  .079  .063  .072  .135  .151  .803  .618 1592.
 50282.  6  .961  .399  .169  .096  .074  .082  .155  .178  .770  .630 1606.
irrigation appl eff= 1.000 apply=   .40 deep=    1143.25 deepd=         .00
 50382.  6  .973  .422  .212  .123  .101  .110  .211  .233  .812  .644 1625.
 50482.  6  .990  .386  .279  .166  .129  .139  .268  .305  .755  .663 1644.
irrigation appl eff= 1.000 apply=   .47 deep=    1143.25 deepd=         .00
 50582.  6 1.012  .406  .321  .197  .162  .162  .324  .359  .789  .681 1659.
 50682.  6 1.040  .370  .275  .172  .129  .126  .254  .298  .735  .696 1668.
irrigation appl eff= 1.000 apply=   .48 deep=    1143.25 deepd=         .00
 50782.  6 1.061  .389  .323  .205  .162  .159  .320  .363  .772  .704 1681.
irrigation appl eff= 1.000 apply=   .43 deep=    1143.25 deepd=         .00
 50882.  6 1.089  .396  .394  .254  .209  .194  .403  .448  .779  .716 1697.
irrigation appl eff= 1.000 apply=   .41 deep=    1143.25 deepd=         .00
 50982.  6 1.124  .396  .385  .253  .207  .186  .393  .439  .781  .731 1716.
irrigation appl eff= 1.000 apply=   .51 deep=    1143.25 deepd=         .00
 51082.  6 1.159  .408  .375  .253  .213  .178  .390  .430  .782  .749 1736.
 51182.  6 1.195  .357  .350  .241  .181  .153  .333  .394  .711  .767 1753.
irrigation appl eff= 1.000 apply=   .59 deep=    1143.25 deepd=         .00
 51282.  6 1.226  .380  .361  .254  .201  .164  .364  .418  .763  .782 1770.
irrigation appl eff= 1.000 apply=   .76 deep=    1143.25 deepd=         .00
 51382.  6 1.260  .434  .282  .202  .175  .125  .300  .327  .801  .796 1780.
 51482.  6 1.290  .390  .289  .209  .167  .119  .286  .329  .740  .805 1794.
irrigation appl eff= 1.000 apply=   .73 deep=    1143.25 deepd=         .00
 51582.  6 1.318  .427  .362  .266  .233  .155  .388  .421  .782  .816 1811.
 51682.  6 1.357  .383  .291  .217  .170  .115  .285  .332  .722  .830 1830.
irrigation appl eff= 1.000 apply=   .51 deep=    1143.25 deepd=         .00
 51782.  6 1.386  .398  .297  .225  .184  .121  .304  .346  .769  .844 1844.
irrigation appl eff= 1.000 apply=   .56 deep=    1143.25 deepd=         .00
 51882.  6 1.417  .429  .326  .250  .218  .131  .349  .381  .791  .854 1861.
```

```
 51982.  6 1.454  .368  .397  .309  .243  .147  .391  .457  .708  .866 1882.
irrigation appl eff= 1.000 apply=   .48 deep=   1143.25 deepd=        .00
 52082.  6 1.496  .367  .401  .317  .248  .152  .399  .469  .728  .880 1900.
irrigation appl eff= 1.000 apply=   .48 deep=   1143.25 deepd=        .00
 52182.  6 1.538  .395  .327  .263  .211  .122  .334  .385  .763  .892 1919.
irrigation appl eff= 1.000 apply=   .55 deep=   1143.25 deepd=        .00
 52282.  6 1.573  .428  .285  .231  .198  .104  .303  .336  .801  .902 1938.
 52382.  6 1.607  .392  .236  .194  .153  .080  .233  .274  .751  .913 1955.
rain appl eff= 1.000 apply=   .77 deep=   1143.25 deepd=        .00
 52482.  6 1.633  .445  .257  .213  .188  .090  .279  .303  .781  .921 1972.
rain appl eff= 1.000 apply=   .42 deep=   1143.25 deepd=        .00
 52582.  6 1.665  .475  .132  .110  .100  .049  .149  .159  .796  .929 1987.
rain appl eff= 1.000 apply=  1.00 deep=   1143.25 deepd=        .00
 52682.  6 1.682  .549  .320  .270  .248  .109  .356  .378  .802  .935 2006.
rain appl eff= 1.000 apply=   .04 deep=   1143.25 deepd=        .00
 52782.  6 1.724  .529  .140  .119  .109  .048  .157  .166  .777  .943 2024.
 52882.  6 1.742  .465  .403  .344  .315  .117  .433  .461  .686  .948 2043.
 52982.  6 1.796  .417  .386  .331  .283  .101  .384  .433  .609  .953 2062.
 53082.  6 1.843  .373  .397  .342  .262  .101  .363  .444  .538  .957 2082.
irrigation appl eff= 1.000 apply=   .43 deep=   1143.25 deepd=        .00
 53182.  6 1.888  .393  .303  .262  .204  .063  .267  .325  .581  .960 2098.
irrigation appl eff= 1.000 apply=   .54 deep=   1143.25 deepd=        .00


       root  lai  trratio  pet  ns.tr st.tr  evap  st.et  ns.et evratio  akc   gdd
  date  zn    %           (in)  (in)  (in)  (in)  (in)  (in)    %        %    days
-------------------------------------------------------------------------------------

 60182.  6 1.922  .413  .383  .331  .278  .089  .366  .420  .626  .961 2115.
 60282.  6 1.969  .372  .409  .354  .268  .075  .343  .428  .556  .962 2134.
irrigation appl eff= 1.000 apply=   .49 deep=   1143.25 deepd=        .00
 60382.  6 2.015  .388  .411  .355  .281  .070  .351  .426  .593  .961 2155.
irrigation appl eff= 1.000 apply=   .32 deep=   1143.25 deepd=        .00
 60482.  6 2.063  .395  .309  .267  .209  .057  .266  .324  .611  .959 2173.
irrigation appl eff= 1.000 apply=   .57 deep=   1143.25 deepd=        .00
 60582.  6 2.098  .422  .386  .332  .283  .062  .345  .394  .666  .955 2198.
 60682.  6 2.146  .385  .387  .331  .256  .052  .308  .383  .601  .949 2222.
irrigation appl eff= 1.000 apply=   .47 deep=   1143.25 deepd=        .00
 60782.  6 2.189  .406  .350  .296  .240  .053  .293  .349  .644  .940 2246.
 60882.  6 2.230  .365  .466  .390  .291  .053  .344  .443  .572  .929 2271.
irrigation appl eff= 1.000 apply=   .36 deep=   1143.25 deepd=        .00
 60982.  6 2.279  .383  .264  .217  .163  .042  .205  .260  .607  .914 2289.
irrigation appl eff= 1.000 apply=   .39 deep=   1143.25 deepd=        .00
 61082.  6 2.307  .407  .229  .186  .147  .038  .185  .224  .653  .902 2309.
rain appl eff= 1.000 apply=   .76 deep=   1143.25 deepd=        .00
 61182.  6 2.332  .463  .260  .207  .188  .060  .248  .267  .759  .887 2328.
 61282.  6 2.284  .432  .285  .223  .190  .066  .256  .289  .709  .871 2346.
 61382.  6 2.236  .403  .283  .218  .173  .068  .240  .285  .662  .854 2367.
rain appl eff= 1.000 apply=   .03 deep=   1143.25 deepd=        .00
 61482.  6 2.192  .368  .406  .304  .227  .093  .320  .397  .601  .832 2392.
irrigation appl eff= 1.000 apply=   .54 deep=   1143.25 deepd=        .00
 61582.  6 2.134  .403  .313  .226  .180  .066  .245  .292  .670  .804 2411.
 61682.  6 2.088  .379  .285  .200  .148  .057  .205  .257  .630  .780 2430.
rain appl eff= 1.000 apply=   .23 deep=   1143.25 deepd=        .00
 61782.  6 2.051  .373  .371  .252  .188  .092  .280  .344  .625  .754 2453.
```

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irrigation appl eff= 1.000 apply=   .49 deep=    1143.25 deepd=        .00
 61882.  6 2.003  .420  .126  .081  .064  .035  .100  .117  .713  .720 2472.
rain appl eff= 1.000 apply=   .82 deep=    1143.25 deepd=        .00
 61982.  6 1.987  .499  .199  .124  .114  .057  .171  .181  .816  .690 2487.
 62082.  6 1.958  .475  .236  .141  .129  .066  .196  .208  .776  .664 2505.
 62182.  6 1.925  .448  .291  .166  .145  .081  .226  .247  .731  .633 2524.
 62282.  6 1.888  .421  .306  .164  .135  .086  .220  .250  .687  .596 2548.
rain appl eff= 1.000 apply=   .04 deep=    1143.25 deepd=        .00
 62382.  6 1.854  .392  .422  .208  .163  .113  .275  .321  .639  .548 2572.
 62482.  1  .000  .010  .259  .000  .000  .195  .195  .195  .538  .000 2593.
 62582.  1  .000  .010  .290  .000  .000  .146  .146  .146  .474  .000 2615.
rain appl eff= 1.000 apply=   .06 deep=    1143.25 deepd=        .00
 62682.  1  .000  .010  .227  .000  .000  .092  .092  .092  .510  .000 2634.
 62782.  1  .000  .010  .272  .000  .000  .055  .055  .055  .485  .000 2656.
 62882.  1  .000  .010  .330  .000  .000  .047  .047  .047  .465  .000 2680.
rain appl eff= 1.000 apply=   .18 deep=    1143.25 deepd=        .00
 62982.  1  .000  .023  .315  .000  .000  .165  .165  .165  .615  .000 2705.
 63082.  1  .000  .010  .249  .000  .000  .039  .039  .039  .598  .000 2728.
rain appl eff= 1.000 apply=   .67 deep=    1143.25 deepd=        .00



          root  lai  trratio  pet  ns.tr  st.tr  evap  st.et  ns.et  evratio  akc  gdd
  date    zn    %             (in)  (in)  (in)   (in)  (in)   (in)     %       %   days
-------------------------------------------------------------------------------------
 70182.  1  .000  .636  .182  .000  .000  .170  .170  .170  .913  .000 2749.
 70282.  1  .000  .623  .378  .000  .000  .138  .138  .138  .853  .000 2773.
 70382.  1  .000  .611  .383  .000  .000  .063  .063  .063  .825  .000 2798.
 70482.  1  .000  .600  .313  .000  .000  .050  .050  .050  .803  .000 2822.
 70582.  1  .000  .589  .314  .000  .000  .043  .043  .043  .784  .000 2845.
 70682.  1  .000  .578  .383  .000  .000  .039  .039  .039  .766  .000 2869.
 70782.  1  .000  .567  .201  .000  .000  .036  .036  .036  .751  .000 2893.
rain appl eff= 1.000 apply=   .31 deep=    1143.25 deepd=        .00
 70882.  1  .000  .632  .294  .000  .000  .235  .235  .235  .896  .000 2917.
rain appl eff= 1.000 apply=   .90 deep=    1143.25 deepd=        .00
 70982.  1  .000  .872  .278  .000  .000  .274  .274  .274  .879  .000 2941.
 71082.  1  .000  .862  .254  .000  .000  .194  .194  .194  .793  .000 2964.
rain appl eff= 1.000 apply=   .94 deep=    1143.25 deepd=        .00
 71182.  1  .000  .902  .193  .000  .000  .194  .194  .194  .914  .000 2984.
 71282.  1  .000  .873  .221  .000  .000  .187  .187  .187  .832  .000 3003.
 71382.  1  .000  .857  .252  .000  .000  .204  .204  .204  .742  .000 3026.
 71482.  1  .000  .843  .330  .000  .000  .163  .163  .163  .670  .000 3050.
 71582.  1  .000  .831  .400  .000  .000  .071  .071  .071  .639  .000 3077.
 71682.  1  .000  .819  .392  .000  .000  .055  .055  .055  .615  .000 3103.
 71782.  1  .000  .808  .338  .000  .000  .047  .047  .047  .594  .000 3130.
 71882.  1  .000  .798  .336  .000  .000  .042  .042  .042  .575  .000 3156.
 71982.  1  .000  .788  .337  .000  .000  .038  .038  .038  .558  .000 3183.
rain appl eff= 1.000 apply=   .18 deep=    1143.25 deepd=        .00
 72082.  1  .000  .888  .262  .000  .000  .137  .137  .137  .723  .000 3207.
rain appl eff= 1.000 apply=   .52 deep=    1143.25 deepd=        .00
 72182.  1  .000  .899  .228  .000  .000  .228  .228  .228  .899  .000 3232.
rain appl eff= 1.000 apply=   .03 deep=    1143.25 deepd=        .00
 72282.  1  .000  .856  .252  .000  .000  .067  .067  .067  .910  .000 3257.
 72382.  1  .000  .826  .270  .000  .000  .037  .037  .037  .893  .000 3281.
 72482.  1  .000  .802  .289  .000  .000  .034  .034  .034  .878  .000 3305.
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```
 72582.  1  .000  .781  .292  .000  .000  .031  .031  .031  .865  .000 3330.
 72682.  1  .000  .762  .322  .000  .000  .030  .030  .030  .852  .000 3357.
 72782.  1  .000  .746  .262  .000  .000  .028  .028  .028  .839  .000 3381.
rain appl eff= 1.000 apply=   .10 deep=    1143.25 deepd=        .00
 72882.  1  .000  .822  .102  .000  .000  .046  .046  .046  .950  .000 3401.
rain appl eff= 1.000 apply=   .48 deep=    1143.25 deepd=        .00
 72982.  1  .000  .956  .154  .000  .000  .151  .151  .151  .933  .000 3424.
rain appl eff= 1.000 apply=  1.17 deep=    1143.25 deepd=        .00
 73082.  1  .000  .956  .100  .000  .000  .100  .100  .100  .956  .000 3443.
 73182.  1  .000  .860  .217  .000  .000  .218  .218  .218  .860  .000 3464.



       root  lai trratio  pet ns.tr st.tr  evap st.et  ns.et evratio  akc  gdd
  date  zn    %           (in)  (in)  (in)  (in)  (in)  (in)   %       %   days
-----------------------------------------------------------------------------------
 80182.  1  .000  .753  .244  .000  .000  .244  .244  .244  .753  .000 3488.
 80282.  1  .000  .665  .253  .000  .000  .200  .200  .200  .665  .000 3513.
rain appl eff= 1.000 apply=   .01 deep=    1143.25 deepd=        .00
 80382.  1  .000  .636  .280  .000  .000  .088  .088  .088  .639  .000 3539.
 80482.  1  .000  .608  .298  .000  .000  .064  .064  .064  .611  .000 3563.
 80582.  1  .000  .584  .265  .000  .000  .054  .054  .054  .587  .000 3587.
 80682.  1  .000  .563  .268  .000  .000  .047  .047  .047  .567  .000 3612.
 80782.  1  .000  .544  .251  .000  .000  .043  .043  .043  .548  .000 3635.
rain appl eff= 1.000 apply=   .04 deep=    1143.25 deepd=        .00
 80882.  1  .000  .557  .262  .000  .000  .062  .062  .062  .574  .000 3657.
 80982.  1  .000  .541  .270  .000  .000  .037  .037  .037  .557  .000 3679.
 81082.  1  .000  .526  .299  .000  .000  .034  .034  .034  .542  .000 3701.
 81182.  1  .000  .511  .267  .000  .000  .033  .033  .033  .528  .000 3724.
 81282.  1  .000  .498  .328  .000  .000  .031  .031  .031  .514  .000 3749.
 81382.  1  .000  .485  .299  .000  .000  .030  .030  .030  .501  .000 3775.
 81482.  1  .000  .472  .377  .000  .000  .028  .028  .028  .489  .000 3801.
 81582.  1  .000  .460  .308  .000  .000  .027  .027  .027  .477  .000 3828.
rain appl eff= 1.000 apply=   .10 deep=    1143.25 deepd=        .00
 81682.  1  .000  .523  .250  .000  .000  .082  .082  .082  .573  .000 3853.
 81782.  1  .000  .512  .206  .000  .000  .025  .025  .025  .562  .000 3878.
 81882.  1  .000  .501  .183  .000  .000  .025  .025  .025  .551  .000 3900.
 81982.  1  .000  .491  .282  .000  .000  .024  .024  .024  .540  .000 3924.
 82082.  1  .000  .481  .288  .000  .000  .023  .023  .023  .530  .000 3949.
rain appl eff= 1.000 apply=   .88 deep=    1143.25 deepd=        .00
 82182.  1  .000  .990  .227  .000  .000  .023  .023  .023  .990  .000 3971.
 82282.  1  .000  .980  .252  .000  .000  .022  .022  .022  .980  .000 3995.
 82382.  1  .000  .970  .272  .000  .000  .022  .022  .022  .971  .000 4020.
 82482.  1  .000  .961  .294  .000  .000  .021  .021  .021  .961  .000 4044.
rain appl eff= 1.000 apply=   .63 deep=    1143.25 deepd=        .00
 82582.  1  .000  .954  .105  .000  .000  .105  .105  .105  .954  .000 4063.
 82682.  1  .000  .821  .302  .000  .000  .302  .302  .302  .821  .000 4087.
 82782.  1  .000  .683  .313  .000  .000  .313  .313  .313  .683  .000 4111.
 82882.  1  .000  .594  .266  .000  .000  .200  .200  .200  .594  .000 4134.
 82982.  1  .000  .558  .301  .000  .000  .083  .083  .083  .558  .000 4158.
 83082.  1  .000  .530  .325  .000  .000  .064  .064  .064  .530  .000 4184.
 83182.  1  .000  .506  .321  .000  .000  .053  .053  .053  .506  .000 4211.
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       root lai trratio  pet ns.tr st.tr  evap st.et  ns.et evratio  akc  gdd
  date  zn    %          (in)  (in)  (in)  (in)  (in)  (in)   %        %   days
------------------------------------------------------------------------------
  90182.  1  .000  .485  .336  .000  .000  .047  .047  .047  .485  .000 4237.
  90282.  1  .000  .467  .287  .000  .000  .043  .043  .043  .467  .000 4261.
  90382.  1  .000  .449  .286  .000  .000  .039  .039  .039  .449  .000 4285.
  90482.  1  .000  .433  .324  .000  .000  .037  .037  .037  .433  .000 4310.
  90582.  1  .000  .418  .338  .000  .000  .034  .034  .034  .418  .000 4335.
  90682.  1  .000  .404  .264  .000  .000  .033  .033  .033  .404  .000 4358.
rain appl eff= 1.000 apply=   .35 deep=    1143.25 deepd=        .00
  90782.  1  .000  .647  .266  .000  .000  .237  .237  .237  .762  .000 4379.
  90882.  1  .000  .634  .272  .000  .000  .030  .030  .030  .749  .000 4401.
  90982.  1  .000  .621  .298  .000  .000  .028  .028  .028  .737  .000 4425.
  91082.  1  .000  .609  .252  .000  .000  .027  .027  .027  .725  .000 4447.
  91182.  1  .000  .598  .326  .000  .000  .026  .026  .026  .713  .000 4470.
  91282.  1  .000  .586  .330  .000  .000  .025  .025  .025  .702  .000 4491.
  91382.  1  .000  .575  .331  .000  .000  .025  .025  .025  .691  .000 4510.
  91482.  1  .000  .565  .309  .000  .000  .024  .024  .024  .681  .000 4530.
  91582.  1  .000  .555  .047  .000  .000  .023  .023  .023  .670  .000 4544.
  91682.  1  .000  .545  .261  .000  .000  .023  .023  .023  .660  .000 4564.
  91782.  1  .000  .535  .291  .000  .000  .022  .022  .022  .651  .000 4585.
  91882.  1  .000  .525  .116  .000  .000  .022  .022  .022  .641  .000 4601.
  91982.  1  .000  .516  .164  .000  .000  .021  .021  .021  .632  .000 4621.
rain appl eff= 1.000 apply=   .30 deep=    1143.25 deepd=        .00
  92082.  1  .000  .764  .100  .000  .000  .080  .080  .080  .965  .000 4636.
rain appl eff= 1.000 apply=   .11 deep=    1143.25 deepd=        .00
  92182.  1  .000  .796  .125  .000  .000  .049  .049  .049  .978  .000 4651.
  92282.  1  .000  .788  .275  .000  .000  .020  .020  .020  .970  .000 4669.
  92382.  1  .000  .779  .324  .000  .000  .019  .019  .019  .961  .000 4690.
  92482.  1  .000  .771  .251  .000  .000  .019  .019  .019  .953  .000 4710.
  92582.  1  .000  .763  .256  .000  .000  .019  .019  .019  .944  .000 4727.
  92682.  1  .000  .754  .326  .000  .000  .018  .018  .018  .936  .000 4750.
  92782.  1  .000  .746  .326  .000  .000  .018  .018  .018  .928  .000 4773.
  92882.  1  .000  .739  .367  .000  .000  .018  .018  .018  .920  .000 4793.
  92982.  1  .000  .731  .263  .000  .000  .018  .018  .018  .913  .000 4811.
rain appl eff= 1.000 apply=   .11 deep=    1143.25 deepd=        .00
  93082.  1  .000  .801  .039  .000  .000  .023  .023  .023  .990  .000 4828.
rain appl eff= 1.000 apply=   .72 deep=    1143.25 deepd=        .00
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       root lai trratio  pet ns.tr st.tr  evap st.et  ns.et evratio  akc  gdd
  date  zn    %          (in)  (in)  (in)  (in)  (in)  (in)   %        %   days
------------------------------------------------------------------------------
100182.  1  .000  .990  .168  .000  .000  .023  .023  .023  .990  .000 4848.
100282.  1  .000  .982  .222  .000  .000  .017  .017  .017  .982  .000 4864.
100382.  1  .000  .975  .216  .000  .000  .016  .016  .016  .975  .000 4879.
100482.  1  .000  .968  .249  .000  .000  .016  .016  .016  .968  .000 4899.
100582.  1  .000  .961  .277  .000  .000  .016  .016  .016  .961  .000 4920.
100682.  1  .000  .954  .261  .000  .000  .016  .016  .016  .954  .000 4935.
100782.  1  .000  .947  .284  .000  .000  .016  .016  .016  .947  .000 4952.
rain appl eff= 1.000 apply=   .08 deep=    1143.25 deepd=        .00
100882.  1  .000  .971  .270  .000  .000  .066  .066  .066  .971  .000 4968.
100982.  1  .000  .964  .228  .000  .000  .015  .015  .015  .964  .000 4979.
101082.  1  .000  .957  .222  .000  .000  .015  .015  .015  .957  .000 4990.
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101182.  1  .000  .951  .206  .000  .000  .015  .015  .015  .951  .000 5000.
101282.  1  .000  .944  .015  .000  .000  .015  .015  .015  .944  .000 5005.
divide by  576.0 to convert from cubic inches to inches

tapw =  34367.820
tawc =   6889.777
tiw =     86.400
deepd =       .000
atr =   9101.076
aev =  18105.740
sev =  13606.410

water balance =            357.62450 inches

n-stress yield (water prod. func.) lb/ac =    3958.39
stressed yield (water prod. func.) lb/ac =    3021.07
max yield (read from input data)   lb/ac =    3893.90
stressed yield using ky,max yield  lb/ac =    3117.51
accumulative pet                   (in)   =      81.1
seasonal pet                       (in)   =      51.8
         soil        evaporation   (in)   =      23.6
         stressed    transpiration (in)   =      15.8
         stressed    evaptrans     (in)   =      39.4
         non-stress transpiration  (in)   =      19.7
         non-stress evaptrans      (in)   =      43.4

total water application            (in)   =      59.7
      due to irrigation            (in)   =      45.1
      due to rainfall (yr)         (in)   =      14.6
deep drainage loss
     past dynamic root zone        (in)   =       2.0
     past maximum root zone        (in)   =        .0
total evaporation                  (in)   =      47.2
      due to transpiration         (in)   =      15.8
      due to soil                  (in)   =      31.4
leaching fraction                  (in)   =       .00
salinity of deep drainage          ppm    =        0.

beginning content for year   1 field site                    1
         water    and   elec. cond.
depth   inches^3         ppm
    1       86.40             .0
    2       86.40             .0
    3       86.40             .0
    4       86.40             .0
    5       86.40             .0
    6       86.40             .0

ending content for year   1 field site #               1
        water   and    elec. cond.
depth   inches           ppm
    1     6889.78             .0
    2     6889.78             .0
    3     6889.78             .0
    4     6889.78             .0
    5     6889.78             .0
```

```
    6     6889.78                 .0
day count at maximum akc   =        232
accum. ns-trans at max akc =      14.85

irrigation date  amount

101481.             .66
102581.             .68
102781.             .41
102981.             .61
111181.             .43
111581.             .51
111881.             .50
111981.             .54
112081.             .41
112181.             .69
112681.             .54
121281.             .42
121481.             .43
121581.             .53
121681.             .63
121781.             .57
121881.             .34
122181.             .59
 10282.             .45
 10982.             .53
 11982.             .51
 12682.             .63
 12882.             .39
 12982.             .71
 13082.             .48
 13182.             .71
 20182.             .33
 20382.             .01
 20482.             .50
 21382.             .51
 21682.             .48
 21982.             .64
 22282.             .40
 22482.             .53
 30182.             .45
 30482.             .57
 30882.             .50
 30982.             .70
 31082.             .53
 31182.             .44
 31282.             .38
 31382.             .50
 31482.             .47
 31682.             .49
 31882.             .42
 32082.             .66
 32382.             .64
 32582.             .42
 32982.             .58
 33182.             .55
```

```
40282.          .55
40482.          .57
40682.          .64
40982.          .48
41082.          .46
41282.          .33
41382.          .65
41582.          .62
41782.          .60
41982.          .38
42182.          .57
42582.          .46
42682.          .48
42982.          .38
43082.          .22
50182.          .17
50382.          .40
50582.          .47
50782.          .48
50882.          .43
50982.          .41
51082.          .51
51282.          .59
51382.          .76
51582.          .73
51782.          .51
51882.          .56
52082.          .48
52182.          .48
52282.          .55
53182.          .43
60182.          .54
60382.          .49
60482.          .32
60582.          .57
60782.          .47
60982.          .36
61082.          .39
61582.          .54
61882.          .49


weighted averages

accumulated  difference    potential loss  difference     potential loss  average
 actual et    actual et    from projected   actual et     from maximum    irrigation
(inches)     projected et     (lb/ac)     non-stress et     (lb/ac)       (inches)
  49.043        .000           .000          -29.140          .000          5.086
```

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