PECAN NUT YIELD AND TREE GROWTH
AS INFLUENCED BY IRRIGATION

by

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DISCLAIMER

ABSTRACT

The objective of this study was to develop methods to schedule irrigations on pecan orchards. The first section of this report presents a description of an irrigation scheduling model for pecans that is based on a water balance approach. In the model a crop curve is used to reduce potential evapotranspiration (E_o) calculated from Penman's Equation down to non-stress transpiration. The model then reduces transpiration as soil moisture stress occurs. Evaporation and transpiration are extracted from the soil and irrigation and rainfall are added and the new soil moisture content determined. Excess water application goes to deep drainage. The model was tested on a border at Salopek's Farm and the model tracked the measured soil moisture very closely. It showed that the application exceeded the evapotranspiration (E_t) requirement and resulted in an irrigation application efficiency of 0.76 and 0.87 in 1983 and 1984 respectively. The model has the capability of utilizing actual time weather data or simulated weather data and the model simulated seasonal rainfall over 20 years within 14 percent of measured values. When used to simulate seasonal potential evapotranspiration, the model was within 7 percent of the computed E_o using 1983-1984 weather data. The irrigation scheduling model uses a water production function to convert seasonal evapotranspiration to nut yield. All irrigation scheduling procedures that are based on a computer simulation process need to be verified in the field through direct observations. Data is presented on infrared measurements which are used to determine the crop water stress index and relative evapotranspiration which is another method used to schedule irrigations. The relative E_t computed with the infrared measurements are linearly related to the measured values in pecan trees growing in small barrels with a coefficient of determination of 0.78. The infrared measurements indicated a greater relative evapotranspiration compared to the water balance technique on drip irrigated pecan trees receiving different irrigation levels. Information is presented to show how leaf diffusion resistance measurements change throughout the day during the growing season under moisture stress conditions. Also information on, and how leaf area index is related to the basal area of the pecan trees, is presented. This information can be used in understanding the growth rate of the tree under irrigation.

Keywords: Evapotranspiration, pecans, leaf diffusion resistance, leaf temperature.

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INTRODUCTION

Jensen (1981) defines irrigation scheduling as planning and decision making by the water manager or operator of an irrigation farm before and during most of the growing season for any crop that is grown. Irrigation scheduling involves two interdependent decisions, when to irrigate and how much to irrigate. These decisions require that the scheduler has the extensive experience necessary to identify an optimal choice (English et al. 1980). Irrigation timing can be based upon soil moisture measurements, plant measurements, a soil moisture accounting procedure or some combination of these. Irrigation quantities are normally based upon irrigation system capacity, soil infiltration rate and water holding capacity. However, when using irrigation scheduling for a drip system, water is normally applied at frequent intervals. The amount of water applied is sufficient to satisfy the crop's evapotranspiration needs since the previous irrigation.

At the farm level, the most promising form of irrigation scheduling is a computer based scheduling model. The model uses micro-meteorological data and a soil water budget accounting procedure implemented by the farmer on his home micro-computer. Irrigation scheduling, on a commercial basis, has been demonstrated to be economically feasible (English et al. 1980) due to derived water conservation, energy conservation, crop production improvement, and environmental benefits. The first irrigation scheduling model, proposed by Jensen et al. (1970), has 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 adjusting 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 by using tensiometers to measure soil moisture tension and neutron probes to measure soil moisture content. In addition, pressure bombs can assess plant water status, infrared thermometry can measure leaflet minus air temperature differences, or gravimetric sampling can measure the soil moisture in the field.

Computer irrigation scheduling models developed by the U.S. Bureau of Reclamation, and other models developed by universities, have been operated on large main frame computers. A limited number of irrigation scheduling models have been developed for micro-computers (Stegman 1984, Miyamoto 1984, Hulsman 1985).

The purpose of the research was to develop an irrigation scheduling model with the flexibility to meet the irrigation needs of a pecan orchard as it increased in size from a newly planted orchard to a mature 25-year-old closed canopy orchard. The objectives were to:

1. Develop the parameters for the climate simulation model so that a 30-year simulated weather file could be generated to act as driving variables in the irrigation scheduling model.
2. Develop an irrigation scheduling model that would predict the growth, yield, and daily and seasonal evapotranspiration rate of pecan trees under different spacings.
3. Test the model's predicted yield, evapotranspiration and soil moisture regime against those measured in the field.
4. Measure the plant parameters: leaflet diffusion resistance, crop water stress index and the relationship between transpiration and soil water status.

DESCRIPTION OF MODEL

All water balance irrigation scheduling models consist of: (1) a climate estimated reference evapotranspiration (E_o), (2) an index for relating expected crop water use to reference E_t, (3) an index for estimating additional soil water evaporation from a wet soil surface, (4) an index for estimating the effect of soil water depletion on actual evapotranspiration, (5) an estimate of extractable soil water amount by specified crop from the specified soil, (6) and if yield is a component, the relationship between crop production yield and crop water use.

The irrigation scheduling model developed for pecans is based upon a model first described by Hanks (1974) and later modified by Rasmussen and Hanks (1978). In all models, the driving variables are climate data consisting of daily solar radiation, maximum daily temperature, minimum daily temperature, maximum relative humidity, minimum relative humidity and 24-hour wind run. This climate data is used to predict potential evapotranspiration based upon Penman's equation (Cuenca et al. 1982). In order to generate 35 years of climate data, a weather simulation model described by Lansford et al. (1983) was used. The approach is to generate rainfall events and amounts independent of the other variables and then to generate the other climate variables conditionally on a wet or dry status for that day. The model's parameters were based upon five years of climate data collected at the New Mexico Plant Science Center from 1978 to 1983. A basic assumption in the model is that dry matter yield and pecan yield can be related to seasonal transpiration (T) through a linear or curvilinear function. Linear water production functions have been demonstrated by many investigators to be applicable for field crops (Garrity et al. 1982, Sammis et al. 1979, Singh 1981, Kallsen et al. 1984). Consequently, the yield prediction of a model is directly proportional to the accuracy of the model's ability to predict the evapotranspiration process. The model assumes that the nonstressed transpiration (T) can be predicted from potential evapotranspiration (E_o) based upon Penman's Equation and a crop curve over the growing season that is a function of heat units and the size and spacing between trees as described by equation 1.

$$T_o = K \times E_o \qquad (1)$$

The crop coefficient (K) was presented by Miyamoto (1983) where:

$$K = 0 \quad \text{for Temperature} < 4\ C \qquad (2)$$

$$K = K_{max}/(1 + A\ e^{-B \cdot G_T/G_M}) \quad \text{for Temperature} > 4\ C$$

K_{max} = peak value of the crop coefficient

$$K_{max} = 1.43/(1 + 9e^{-1.22\ d \cdot N}) \qquad (3)$$

where:

d = Diameter of trees in cm

N = number of trees per ha

Growing degree day (G) is computed using eq (4)

$$G = \frac{T_{max} + T_{min}}{2} - \text{Base } T \qquad (4)$$

Base T = 15.5 C

T_{min} = minimum daily Temperature C

T_{max} = maximum daily Temperature C

Accumulated Growing degree days (G_T) is:

$$G_T = \Sigma G \qquad (5)$$

where:

G_T starts when bud break occurs and G is positive and

Maximum Accumulate Growing degree days (G_m) is:

$$G_m = G_T \text{ on August 30} \qquad (6)$$

For $G_T/G_m > 1$ (7)

$$G_T = G_m - \quad (T_a - T_{min}) \text{ for } T_{min} > -4 \text{ C} \tag{8}$$

where:

T_a = long term average mean temperature during the peak K August 30 equal to 25.0 C

Constants A and B in equation 2 are:

$$B = 6.5/(1 + 5.0\ e^{-d.N}) \tag{9}$$

$$A = 3.2/(1 + 4.0\ e^{-d.N}) \tag{10}$$

Because the crop curve developed by Miyamoto represented nonstress evapotranspiration it was reduced by 10 percent to represent potential transpiration (T_o). Transpiration (T) is further reduced by soil moisture stress:

$$T = T_o\ (a + b\ w) \quad \text{if } w \leq c \tag{11}$$

$$T = T_o \text{ if } w > c$$

$$w = AW/SWS$$

where:

SWS = Soil water stored in the root zone (cm) between permanent wilting point and field capacity

AW = Available water in the root zone equal to the difference between water content and permanent wilting point (cm)

c = Level of W equals 0.5

a,b = empirical constants assumed to equal 0 for a and 2 for b

Soil evaporation (E_s) in stage 1 where water is not limiting is modeled by:

$$E_s = E_o - T_o \tag{12}$$

Potential soil evaporation occurs until 20 percent of the plant available water in the top 30 cm of the root zone has been depleted. At this point stage two evaporation occurs causing soil evaporation, (E_s), to decrease. Stage two evaporation is related to the time since stage 1 evaporation has stopped by:

$$E_s = c \quad T^{0.5} \qquad (13)$$

where:

T = Time since stage two evaporation started (days)

c = empirical constant dependent on soil type

Because roots extract different amounts of water from different soil layers the model has up to 20 distinct moisture layers. The depth of each layer can be specified by the user. Water enters the top layer as precipitation or irrigation, filling each layer to field capacity and passing on to the subsequent layers until all of the applied water has been distributed (figure 1). After the water has been distributed, evaporation and transpiration deplete each of the soil layers. Fifty percent of evaporation is taken out of the top 15 cm depth and 50 percent out of the next 15 cm depth. Transpiration occurs from all depths with a percent extraction (E) determined by equation:

$$\sum_{I=1}^{n} E_I = (1 - e^{-3.0 \frac{I}{IDepth}}) \qquad (14)$$

where:

I = counter for the number of the depth

IDepth = total number of depths

E_I = cumulated extraction to Depth I

If no water is available at the depth at which extractions occurs, that extraction percentage is taken from the next lowest depth. Water passing

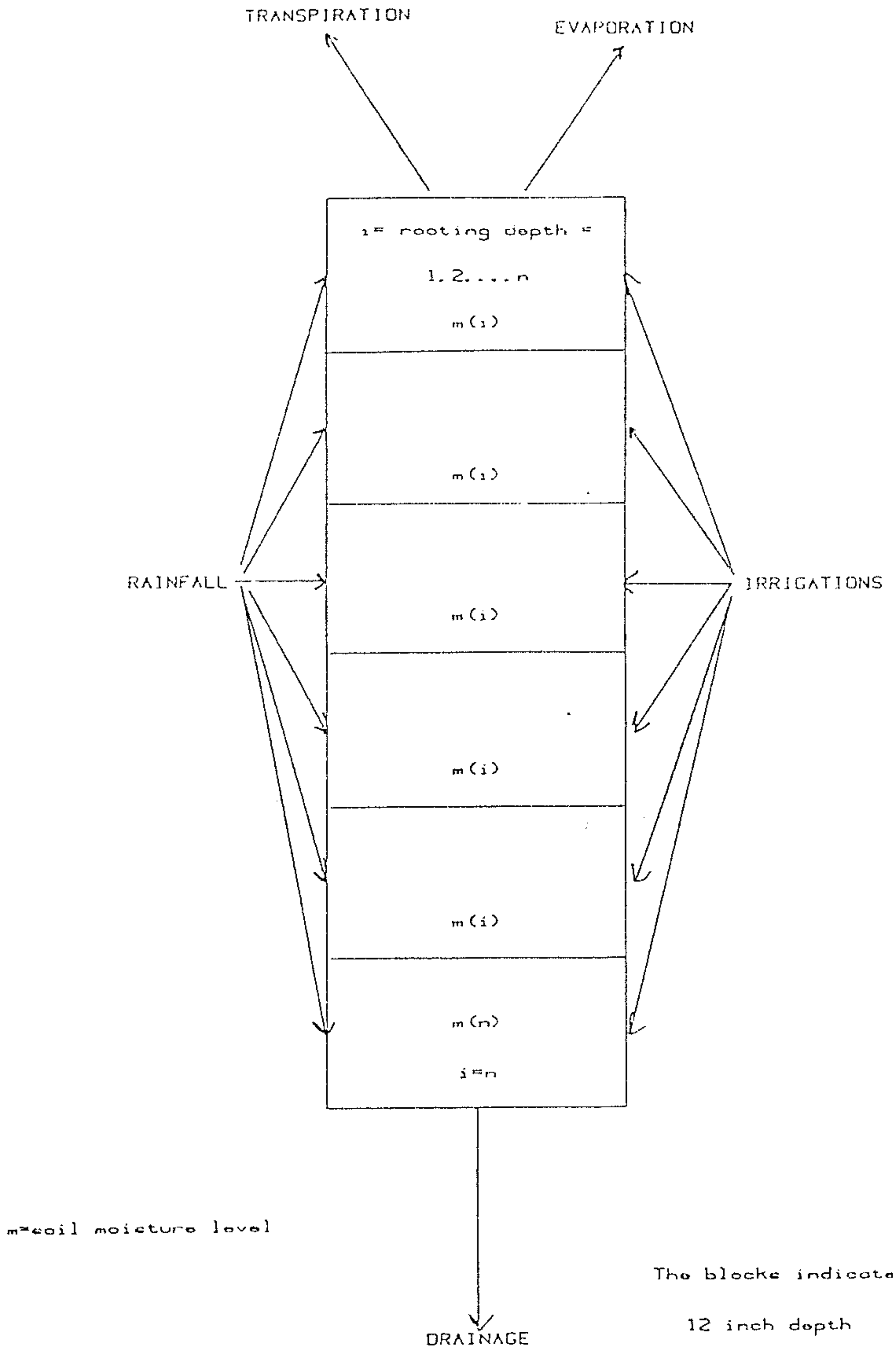


Figure 1. The Dynamics of Soil-Water Relationships in a Typical Soil Profile

below the root zone becomes deep drainage. The depth of root penetration is specified by a root growth function:

$$D = C\ G_T \tag{15}$$

where:

D = the depth of the roots

C = 2.28 cm/Growing degree day

A maximum rooting depth below which roots do not penetrate was set to 1.52 m for pecans.

The model can be operated at different locations in a field receiving different amounts of surface water. The depth at each location is dependent upon the application uniformity and a weighted mean value of deep perculation is calculated by the model along with the weighted E_t and yield from the field. Salinity effects were not incorporated into this version but were accounted for in a subsequent version of the model where relative T was a function of the average salinity in the root zone and the sensitivity of the crop to salinity stress (Lansford et al. (1985).

The cross sectional area of the tree trunk at 60 cm/height increases proportionally to the amount of transpiration that occurs from the tree for that year:

$$A_{I+1} = A_I + (C \times T) \tag{16}$$

where:

C = 0.635, a constant that converts transpiration to cross sectional area growth

A = cross section of the tree (cm^2)

T = seasonal transpiration (cm)

I = the period of growth, 1 year

MATERIALS AND METHODS

Experimental Sites

Research was conducted at two sites. Site one, Salopek's Farm, located on the mesa south of Las Cruces, New Mexico, consisted of a border (.837 hectars) that had Sparling flow meters on all of the irrigation turnouts to measure the water applied. The farmer determined the timing and amount of irrigation. Five neutron probe access tubes were installed in the orchard to measure changes in soil moisture (figure 2). The soil type at the site was Pajarito, fine sandy loam (coarse-loamy mixed thermic typic camborthids). The farmer measured yields at the end of the year using conventional harvesting equipment. The trees were 14 years old in 1984.

The second research plot was located south of Las Cruces, New Mexico at New Mexico State University (NMSU) Plant Science Research Center and consisted of four trickle irrigation treatments. The diameter of the trees at planting time in 1978 was 1.27 cm. In 1979 an additional row was planted with the diameter of trees ranging from 0.625 cm to 5.7 cm (figure 3). The trees were spaced on a 5.3 x 7.7 m grid with the expectation that they would have to be thinned to a 7.7 x 10.6 m spacing later on. Each treatment was replicated twice in a split plot design with each line containing 14 or 15 trees. Trickle irrigation treatment 1 consisted of applying a volume of water equal to the daily pan evaporation times the projected area of the tree crown plus 10 percent for advective energy. Treatments 2 through 4 consisted of applying a volume of water equaling 0.75, 0.5 and 0.25 of irrigation treatment 1. Until 1984, the trees were irrigated at a tensiometer reading of -40 Kpa. The tensiometers were placed at a depth of 30 cm and located 15 cm from an emitter in irrigation treatment 1. In 1984, the trees were irrigated three times a week. The trickle irrigated trees had four emitters per tree in treatment 1

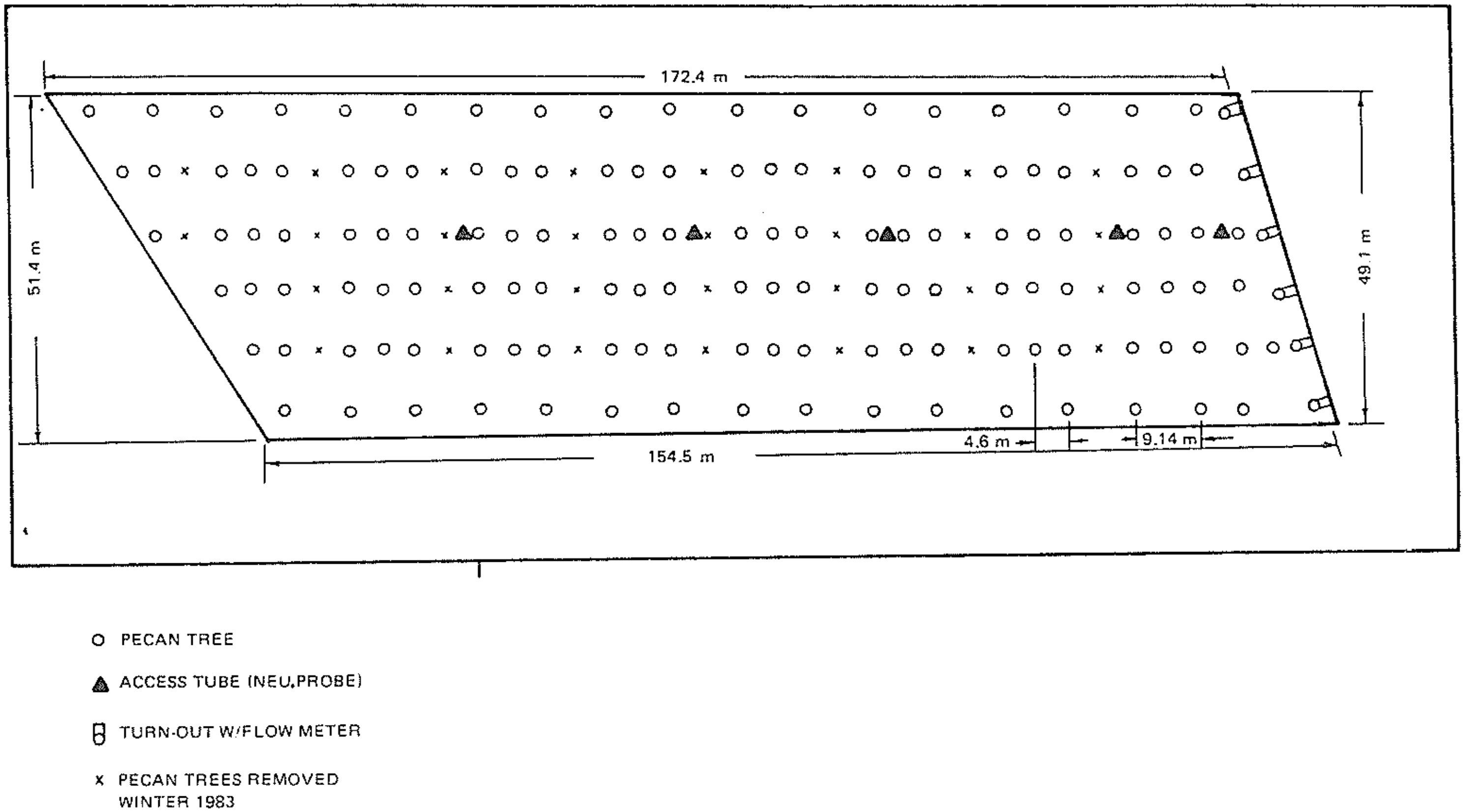


Figure 2. A plot diagram of the research at Salopek's Farm.

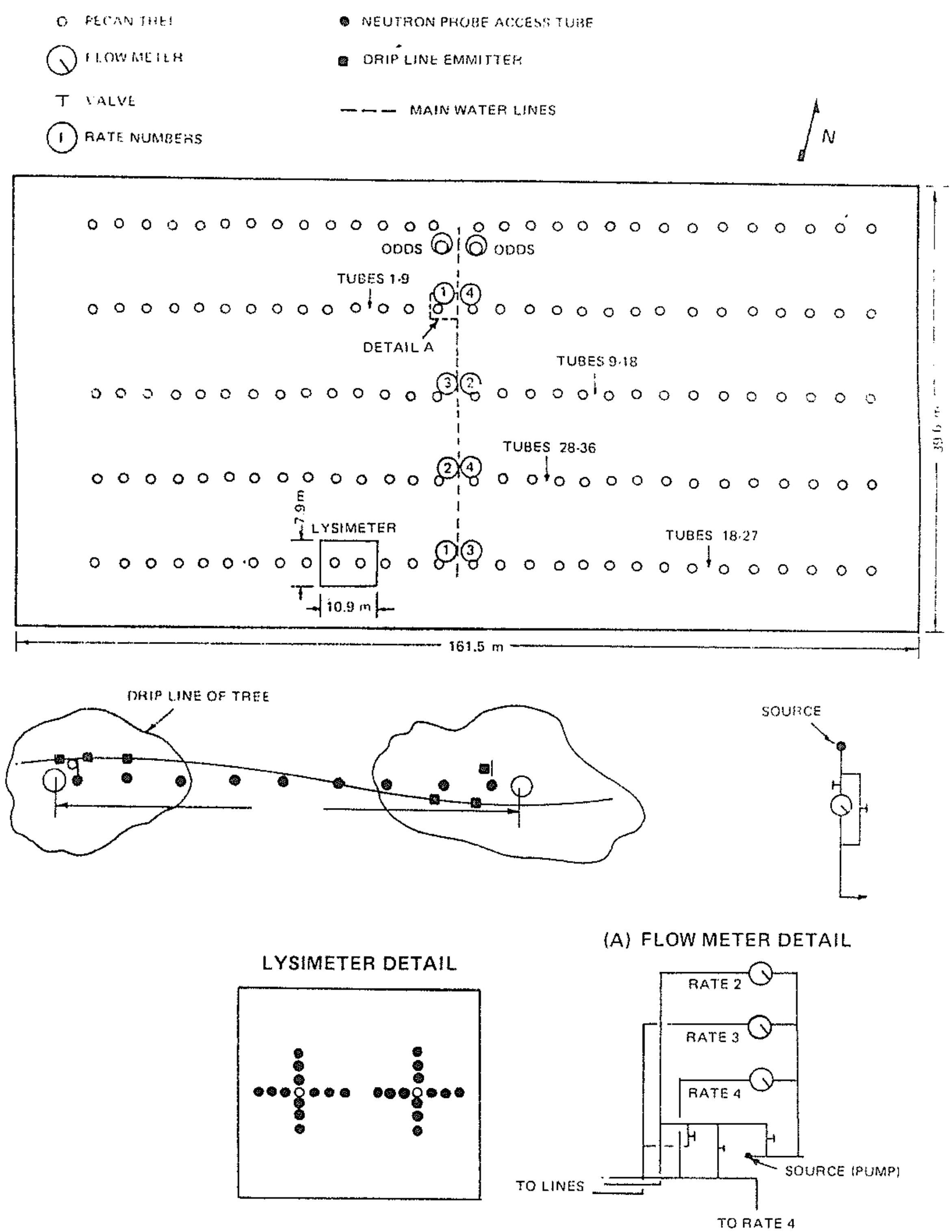


Figure 3. A plot diagram of the research at the Plant Science Center.

and two emitters per tree in treatments 2-4. The emitter rate was 3.78 liters per hour operated at a pressure of 100 kpa. The trunk diameter of the trees was measured at a height of 60 cm at the end of each growing season. Fertilizer was applied at the rate recommended by the New Mexico Fertilizer Guide, which is 0.15 kg of nitrogen per 2.5 cm of tree trunk diameter. Nitrogen fertilizer was broadcast around the trees and NZN was also sprayed on the leaflets of the tree to supply the zinc needs of the tree. The variety of the trees at the Plant Science Center and Salopek Farm is Western Schley.

Water application was measured at the Plant Science Center using flow meters. Neutron probe access tubes were installed in the plots as shown in figure 3. The location of the access tubes in relationship to the crown of the tree is also shown in figure 3. A non-weighing lysimeter was installed in irrigation treatment 1 to measure any deep drainage that might occur. The soil type was an Armijo clay loam (fine, montmorillonitic thermic Typic Torrert). A climate station, located adjacent to the pecan experiment at the Plant Science Center, collected weather data necessary to run the irrigation scheduling model. The 24-hour wind run, solar radiation, maximum and minimum relative humidity, and maximum and minimum temperatures were measured using a hydrothermograph, totalizing wind anemometer and Eppley model 50 precision pyranometer in 1983 and a Campbell automated weather station in 1984. A 20 cm diameter rain gauge was installed at Salopek Farm and at the Plant Science Center.

Tree Growth Rate Measurements From Selected Orchards

To test the pecan irrigation model, measurements were made on the diameter of trees from different age orchards in the Mesilla Valley of New Mexico. One-year-old trees were assumed to have tree trunk diameters equal to measurements made on newly transplanted trees. The tree trunk diameters of

13-year-old trees were measured at the Plant Science Research Center orchard, and 28-year-old trees were measured at the Salopek Farm orchard. The tree spacing of the measured orchards was 9.1 x 9.1 m. The tree trunk diameter measurements were made at a height of 60 cm from the ground. The trunk diameter was measured by determining the circumference of the tree trunk.

Leaflet Temperature Measurements

Infrared measurements of individual leaflet temperatures were made on the four trickle irrigation treatment plots in 1983 and 1984. In 1983, 40 samples per tree were measured by placing the infrared thermometer (Everest Interscience Model 210) approximately 15 cm away from the leaflet and measuring 10 leaflets each from the north, south, east and west. The measurements were taken on two trees in each treatment between 1200 and 1400 hours on leaflets at the outer edge of the canopy. The leaflets were located at a height of approximately 2 m and included sunlit and shaded leaflets.

In 1984, net radiation, relative humidity and infrared measurements were again made on the four trickle irrigation treatment plots. Relative humidity was determined using an Assmann psychrometer and net radiation was measured over the top of the tree using a Fritschen net radiometer. Fifteen samples per tree were taken randomly on the outer edge of three trees in each plot on both sunlit and shaded leaflets. Measurements were also made on July 19, July 26 and August 2 from 0700 until 1900 hours. In 1984, small limbs were cut from selected trees and wired back in place. After being allowed to desiccate, ten measurements of leaflet temperatures were taken while the leaflets were still green but were not transpiring. Measurements were also made with a steady state porometer (Li Cor Model 1600) verifying that the leaflets were not transpiring. On October 6, 1984, leaf temperature, air temperature and humidity measurements were taken on the closed canopy at Salopek's orchard from 1000 til/1600 hours.

Leaflet Diffusion Measurements

In 1983, leaflet diffusion resistance measurements were made on leaflets of two trees in each of the four trickle irrigated plots. Ten readings from the bottom side of the leaflets were made from 1130 to 1330 hours. The measurements were made using the Li-Cor steady state porometer. Only randomly selected sunlit leaflets around the outside of the canopy were measured.

In 1984, leaflet diffusion resistance measurements were measured again throughout July and August and three daily cycles from 0700 until 1900 hours were conducted on the nonstressed irrigation treatment (number 1). On October 1, 1984, and September 21, 1984, 50 leaflet diffusion resistance measurements were taken each day on the bottom and top of the leaflets to determine the amount of transpiration from the upper leaflet surfaces. In July and August, leaflet diffusion measurements were made on three large 15-year-old trees located adjacent to the trickle irrigated plots. Leaflet diffusion resistance measurements were made on the outside of the canopy representing sunlit leaflets and on the inside of the canopy representing shaded leaflets.

Leaflet Area Measurements

Total leaflet area of a tree is related to the cross sectional area of the tree trunk. In August 1984, three individual trees were selected in irrigation treatments 1, 3 and 4 and all leaflets were stripped from the trees. The total leaflet area was measured with a Li-Cor Model 300 leaf area meter. At the same time that total leaf area measurements were made, the effective diameter of the crown projection was measured by standing on the edge of the canopy and measuring the diameters with a tape measure. The cross sectional area of the tree trunk was determined by measurements of the circumference at a 60 cm height. In 1981 leaflet area was measured on selected trees by running the leaf area meter over all leaflets on the tree. Large trees (tree trunk diameter 16-28 cm) were covered with a net at the end of the growing season and all of the leaflet fall was caught, dried and weighed. A subsample was dried and passed through the leaf area meter to get a conversion from dry weight to leaf area which was 112.6 cm^2/g.

Relative Evapotranspiration asRelated to Relative Available Water

In 1976, pecan trees were transplanted in eight, 30-gallon barrels filled with a 1:1:1 mixture of peat moss , perlite and vermiculite. These trees were trimmed to maintain their size within manageable limits. The tree canopy diameters were approximately 91 cm. In 1984, dry down experiments were conducted on these trees. Four trees were watered until saturation, allowed to drain, and then placed on a weighing beam balance scale. Changes in weight were measured and relative water content was computed along with relative E_t rate. Two additional trees were maintained at near field capacity and used to measure the nonstress E_t. Two additional trees were allowed to dry down until no weight changes were recorded, which was assumed to be the weight at permanent wilting point. The relative water content was computed from the initial barrel weight minus the current barrel weight divided by the maximum weight change between field capacity and permanent wilting point. Relative evapotranspiration was determined by determining E_t of each tree based on the weight change on a daily time scale divided by the E_t computed for the non-moisture stressed trees.

Leaflet temperature measurements were made from 1200 to 1400 hours on the trees throughout the dry down cycles. Air temperatures and relative humidity were measured at the same time using the psychrometer mentioned earlier.

RESULTS AND DISCUSSIONS

Weather Simulation

In order to determine if the model was simulating weather similar to the climate of the area, the model was compared to the daily precipitation measured at the NMSU Climate Station (table 1, figures 4 and 5). Three simulation runs were made using a different random seed in each simulation to start the weather simulator. The mean daily rainfall over a 20-year period was 10 percent of the measured daily rainfall and one of the simulation runs was within 2 percent of the mean value. The coefficient of variation between the measured and simulated runs were similar with the simulated rainfall variation generally being slightly less than the measured rainfall variation for the 1959 to 1978 period. A long-term simulation was compared to measure values for the years 1892 to 1981. Figure 6 results show good agreement except for a dry period that occurred from 1950 to 1960. Figures 7 through 12 present a plot of the 20-year simulated weather parameters versus the four-year measured average, 1978 through 1981. In general the four-year average falls in the center of the simulated 20 years. The only weather parameter that seems to be simulated slightly different than the four-year average is the maximum humidity. Simulated maximum humidity in January, February, August, September and October appears to be lower than the four-year average. Potential evapotranspiration (E_o) computed by the model using simulated weather for 10 years was within 7 percent of the average E_o for 1983 and 1984.

Tree Growth Modeled and Measured

The irrigation model predicts the size of the tree under the irrigation schedule specified for the model. When the model was run with irrigations occurring at 50 percent soil moisture depletion, no moisture stress occurred and the model predicted maximum growth of the trees. Table 2 presents

Table 1. Comparison of measured and modeled precipitation for Las Cruces, N.M.

Year	Measured precipitation for 1959-1978	Sim 1/	Sim 2/	Sim3/
	mm	mm	mm	mm
1	145	277	212	228
2	196	254	222	372
3	226	185	433	257
4	162	294	337	217
5	155	313	171	150
6	92	312	173	202
7	211	210	304	258
8	250	247	311	200
9	214	192	328	266
10	335	180	180	224
11	303	250	183	194
12	87	169	170	232
13	147	194	157	232
14	310	226	342	206
15	232	271	228	210
16	351	317	234	185
17	205	319	381	237
18	197	318	210	186
19	222	237	137	320
20	377	323	223	120
Mean	221	254	247	225
2/S.D.	81	53	84	55
3/C.V.	0.367	0.210	0.340	0.244

1/ Sim is simulation run

2/ S.D. is standard deviation

3/ C.V. is coefficient of variance

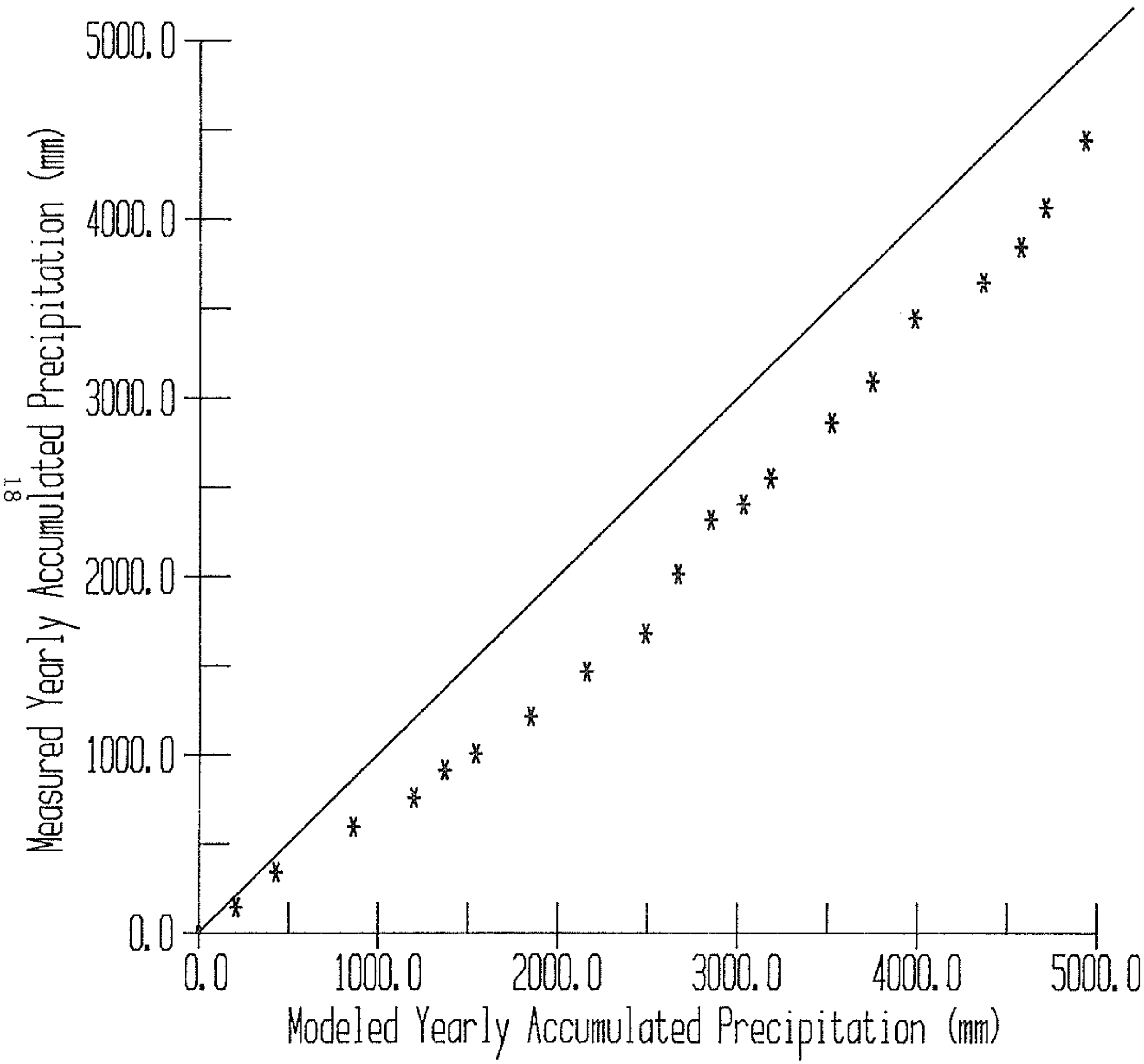


Figure 4. Measured and modeled precipitation simulation 1 (1959-1978) at Las Cruces, New Mexico.

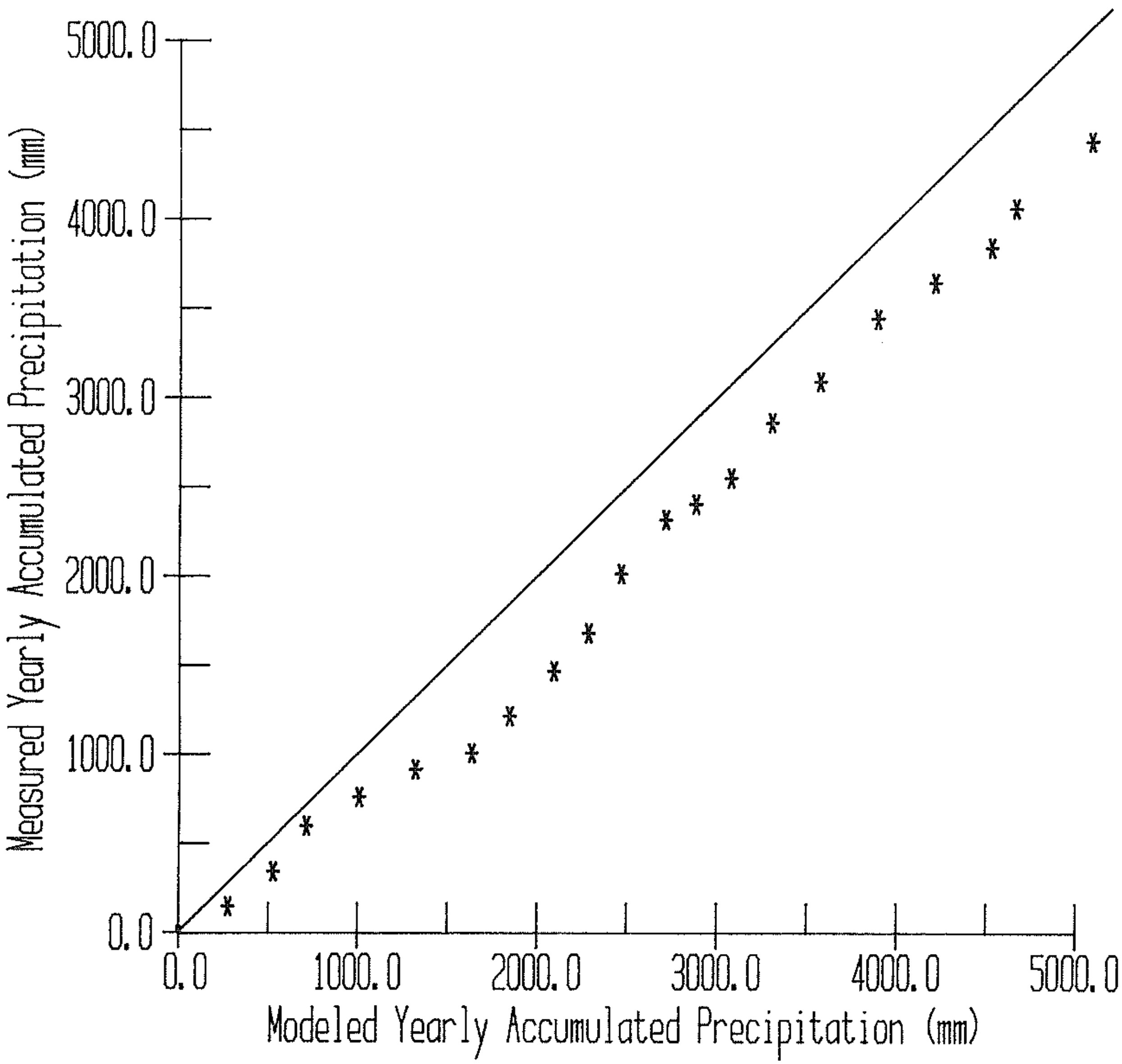


Figure 5. Measured and modeled precipitation simulation 2 (1959-1978) at Las Cruces, New Mexico.

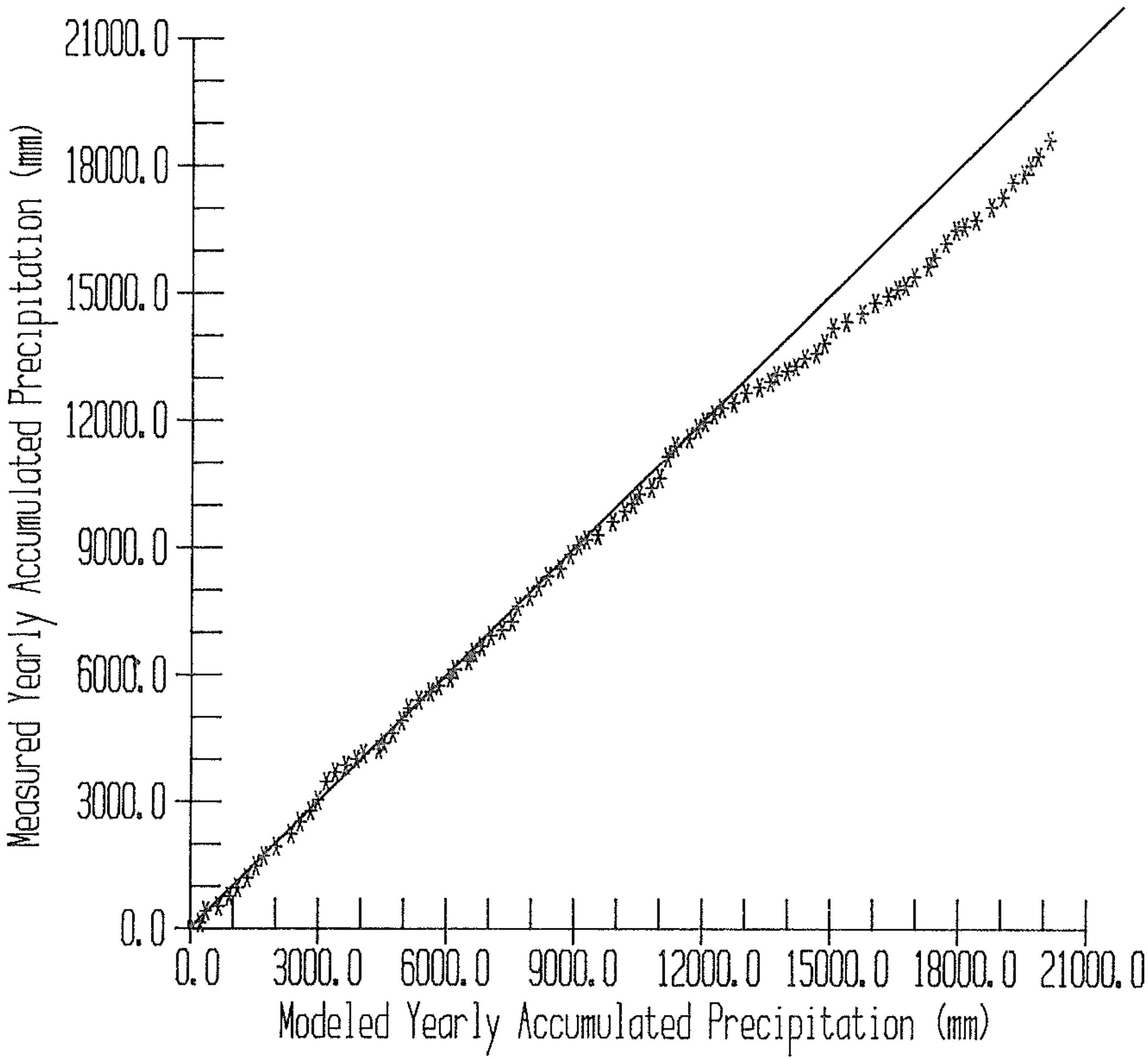


Figure 6. Measured and modeled long term precipitation record (1892-1981) at Las Cruces, New Mexico.

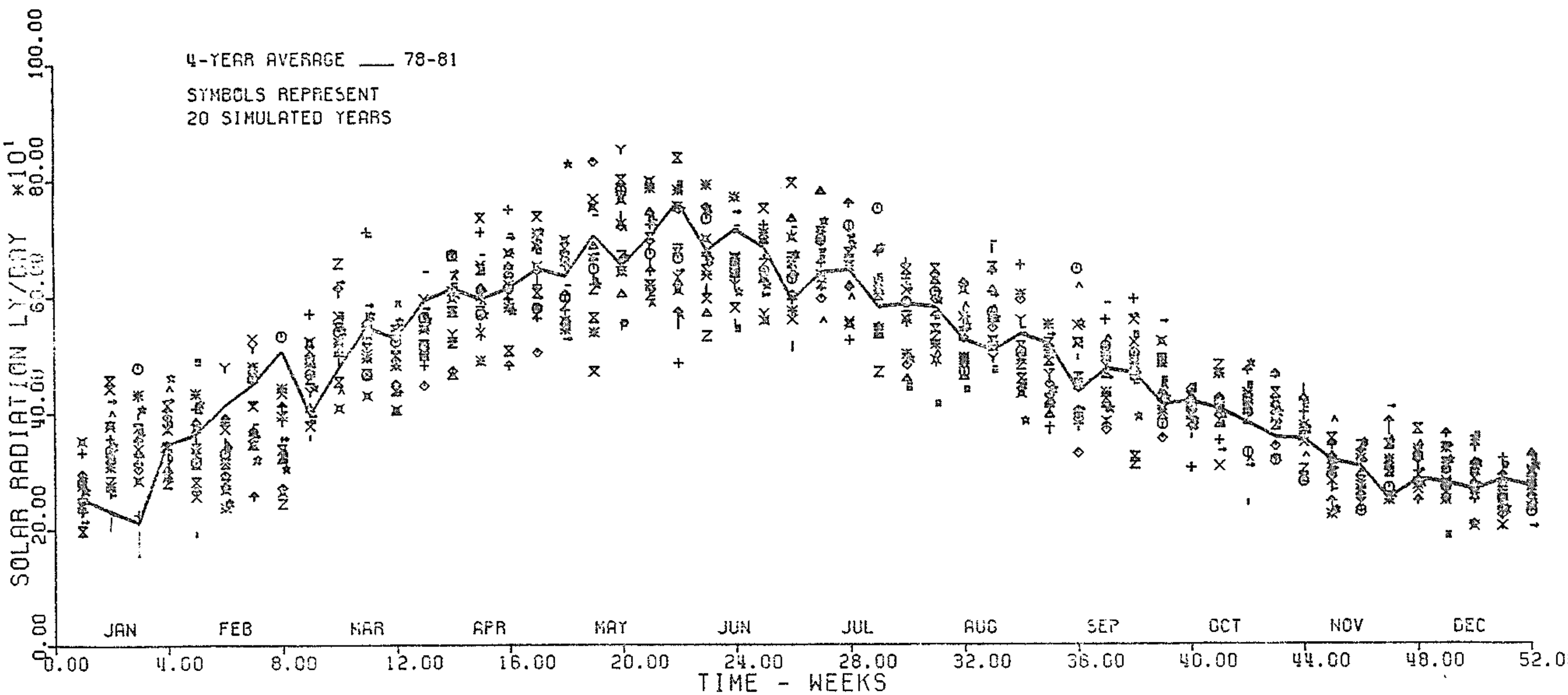


Figure 7. Measured and modeled solar radiation at Las Cruces, New Mexico.

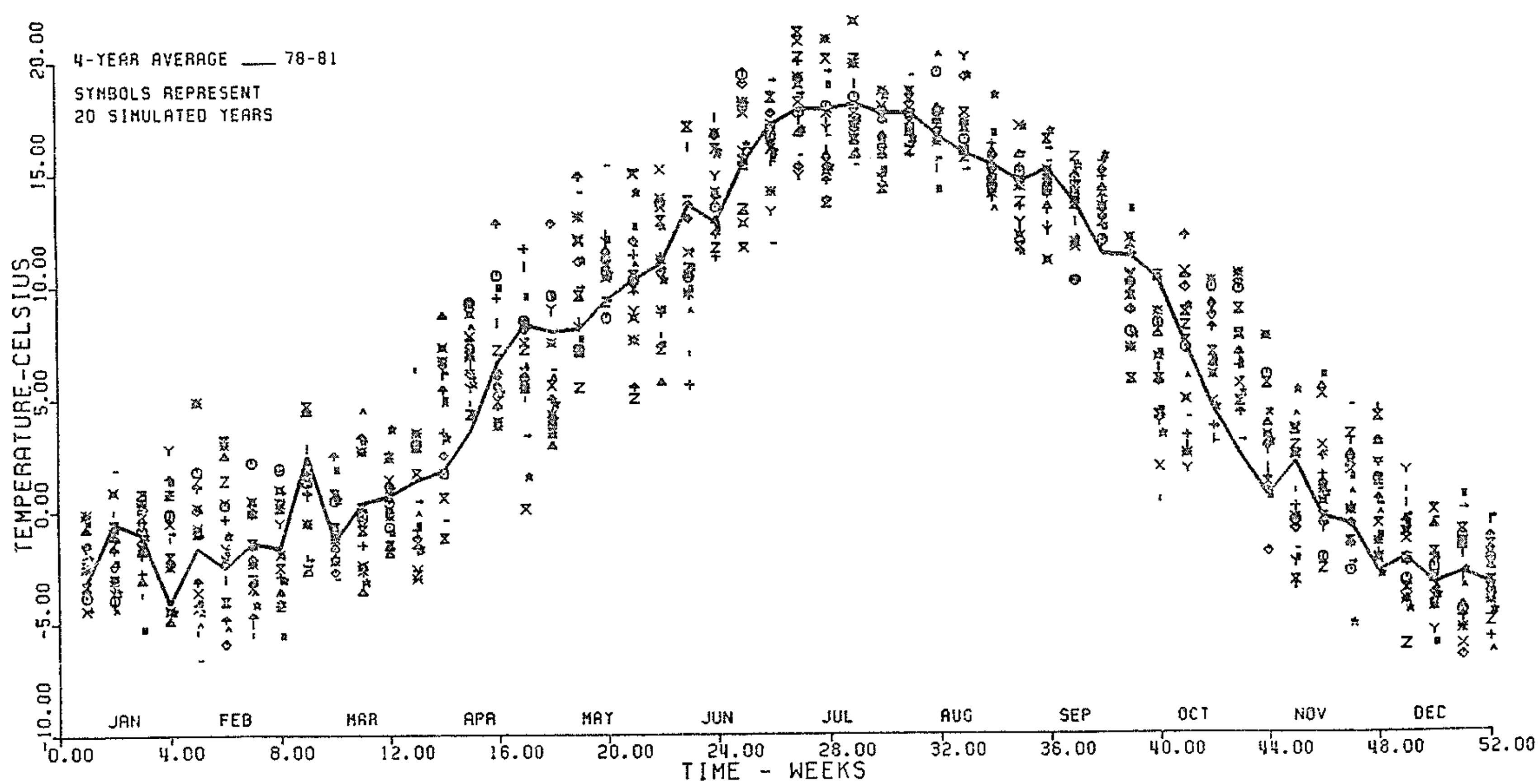


Figure 8. Measured and modeled minimum air temperature at Las Cruces, New Mexico.

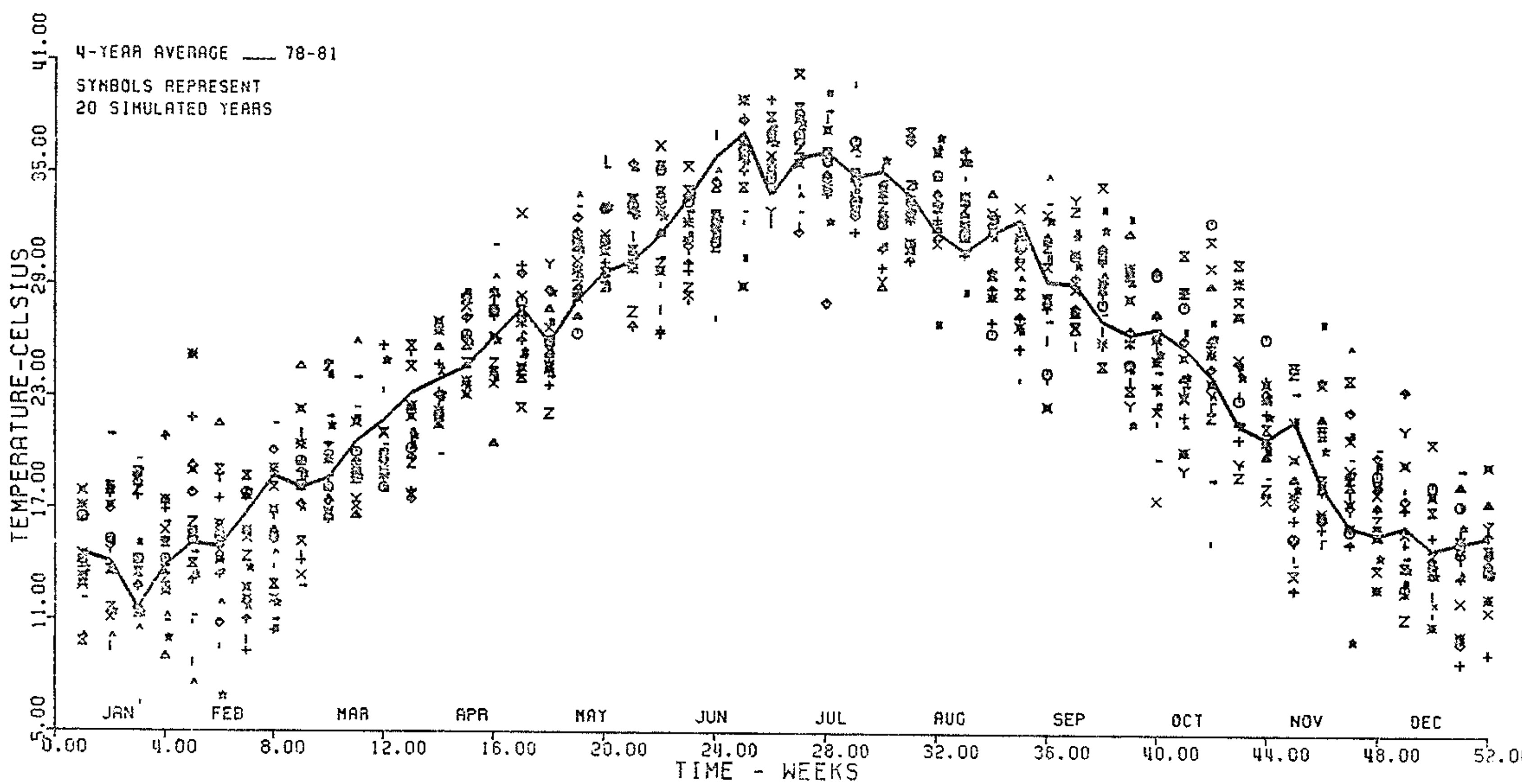


Figure 9. Measured and modeled maximum air temperature at Las Cruces, New Mexico.

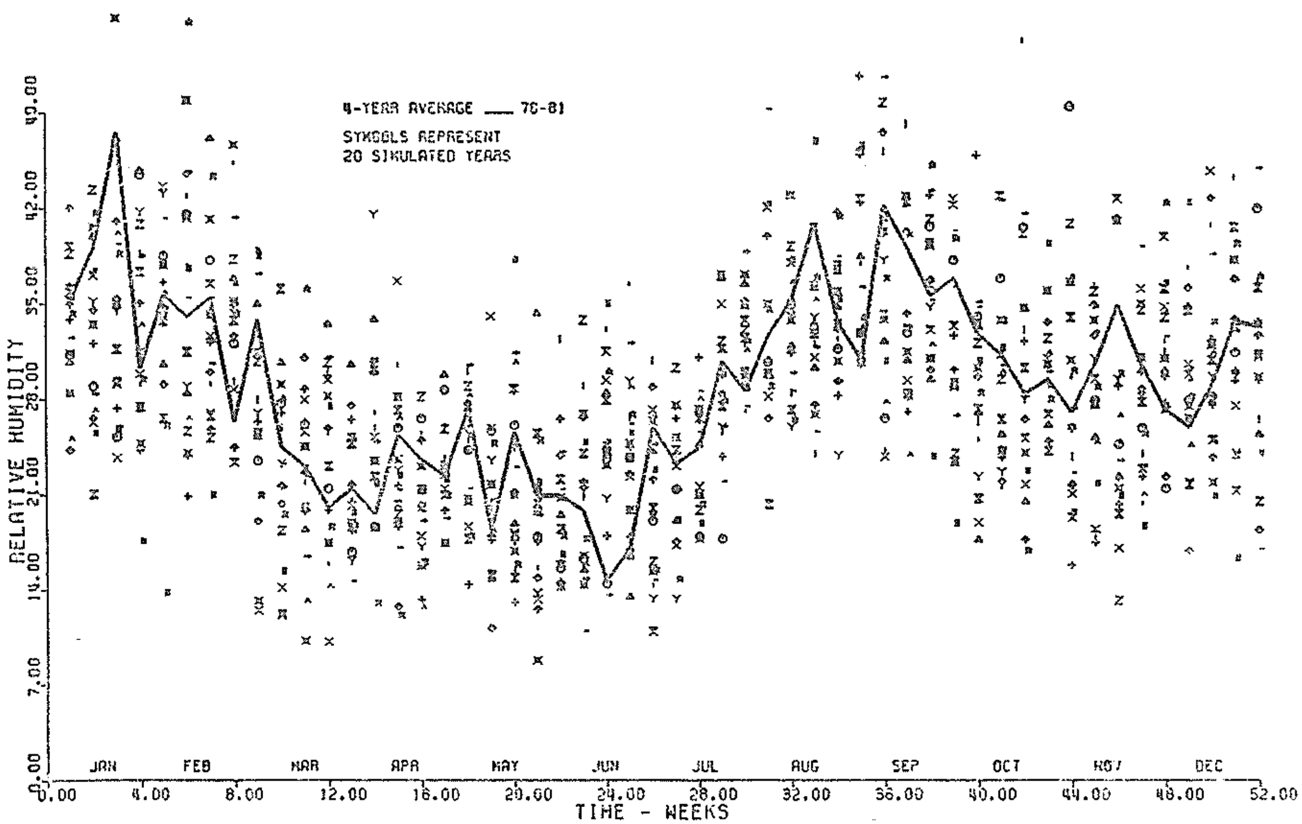


Figure 10. Measured and modeled minimum relative humidity at Las Cruces, New Mexico.

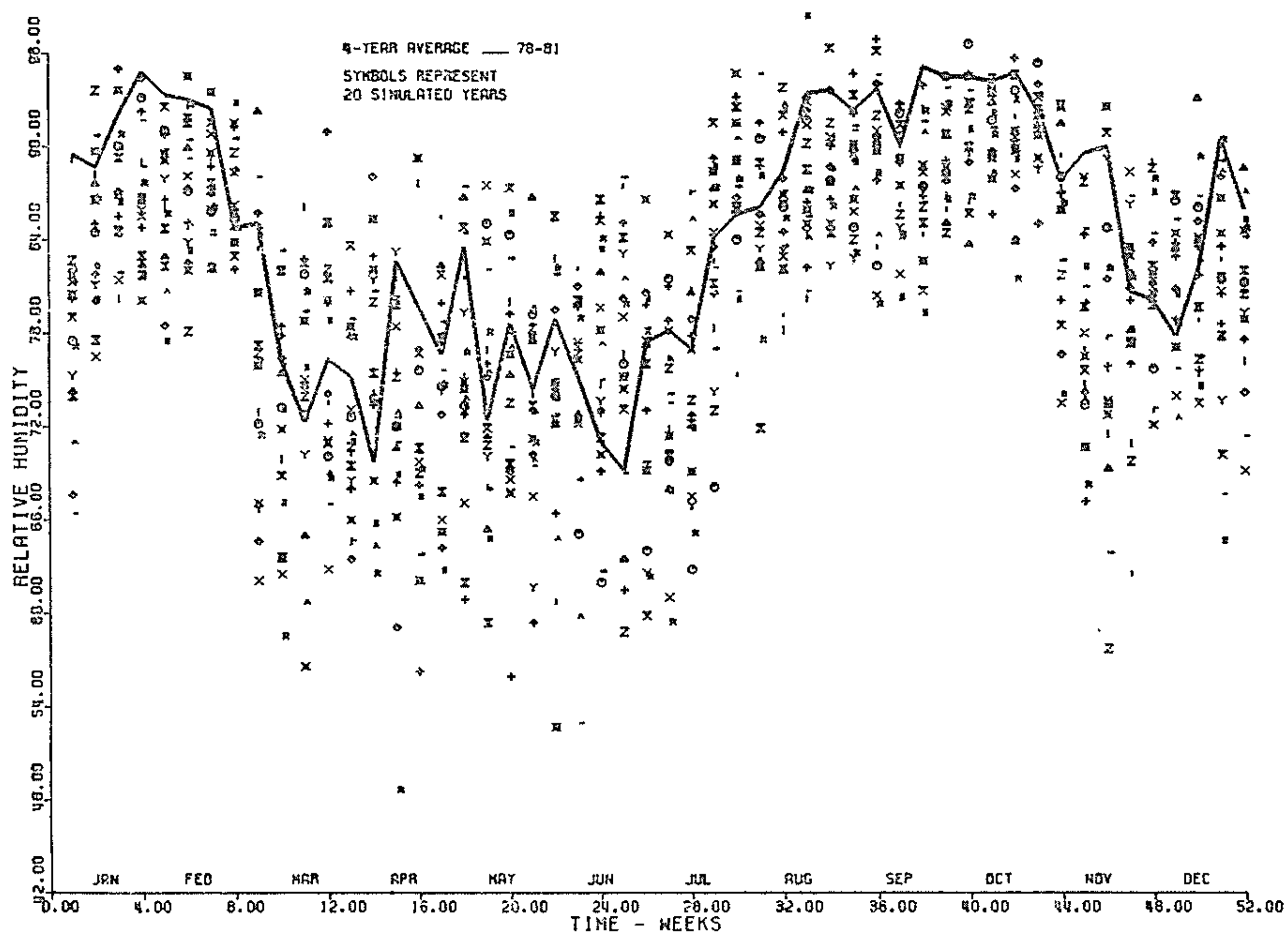


Figure 11. Measured and modeled maximum relative humidity at Las Cruces, New Mexico.

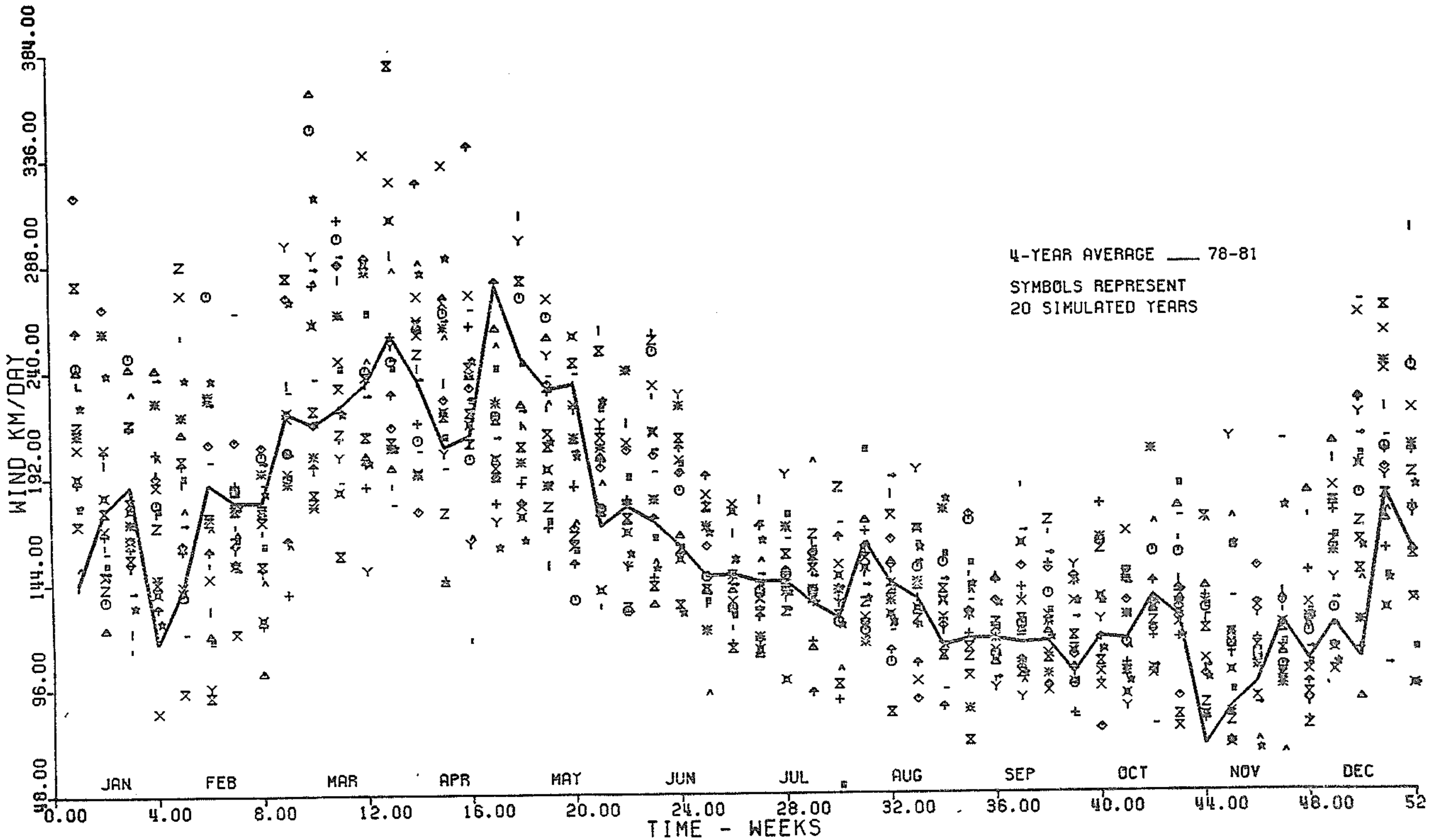


Figure 12. Measured and modeled daily wind run at Las Cruces, New Mexico.

Table 2. Pecan tree trunk diameter measured and modeled for selected age trees

Age of trees years	Tree trunk diameter 1/ Measured Mean	Sd2/	Predicted by model
	cm	cm	cm
1	1.6	0.27	0.6
8	13.0		14.6
13	24.0	2.79	22.6
28	41.7	4.13	43.5
30.8	41.1		46.9
35.1	53.2		51.0

1/ 9.14 x 9.14m spacing of trees

2/ Standard deviation not reported by Miyomoto (1983).

measured and modeled tree trunk diameter for selected age trees. The model tree trunk (T_{rm}) size is related to the measured tree trunk size (T_r) by equation 17:

$$T_{rm} \text{ (cm)} = 0.56 + 0.96\, T_r \text{ (cm)} \quad r^2 = 0.98 \qquad (17)$$

The data for an eight-year-old, 30.8-year-old and 35.11-year-old tree was reported by Miyamoto (1983) and that data had no standard deviations associated with it. The coefficient of variation of the measured diameter of pecan trees averaged 12 percent indicating a large variability in growth potential due to difference in genetic material. Information on the input data required to run the model is presented in Appendix A along with a flow chart of the model and a brief description of each subroutine in the model (Appendix B).

Water Production Function

When pecans are not managed properly for water, fertilizer and pruning operations, they have a tendency to bear in alternate years. When fertilizer, pruning and water application are controlled, the alternate yield fluctuation can be smoothed out and a water production function can be used to estimate yearly yield from seasonal transpiration. Table 3 presents data from the literature (Malstrom et al. 1983a, 1983b, Gorman et al. 1979) relating tree age, yield, and modeled transpiration under assumed non-moisture soil stress conditions. The water production function (figure 13) is non-linear because transpiration is related to photosynthesis and, as a tree becomes larger, a greater percentage of photosynthesis is used by the tree as respiration. A third order polynomial fits the data with a coefficient of determination (r^2) of 0.94. Malstrom's data shows the alternate bearing characteristics of the pecan tree under management not conductive to smoothing out the peaks and valleys of yearly production. The data by Gorman was based on growers'

Table 3. Tree age and non-moisture stress yield and transpiration for pecans.

Age of trees years	Yield for 48 tree acre	Modeled transpiration	Reference 1/
	kg/ha	cm	
1	0	15.7	1
2	0	21.1	1
3	11	23.1	1
4	34	29.7	1
5	56	34.3	1
6	280	41.4	1
7	448	42.4	1
8	1008	55.9	1
9	1344	60.2	1
10	1680	68.8	1
11	2016	77.5	1
14	2920	99.6	2
15	1229	100.8	2
16	3491	100.8	2
17	1766	102.6	2
25	2240	123.1	1
50	2316	126.0	3
	Two year average for years 14-17 Data which was not adjusted for alternate heavy crop years		
14.5	2074	100.2	2
16.5	2628	101.7	2

1/ - W. D. Gorman, D. F. Landrum, S. D. Hicks. Pecan Orchard Cost and Returns for 40 and 320 Acre Southern Rio Grande Valley. New Mexico, 1979. Agriculture Experiment Station Research 413.

2/ - H. L. Malstrom, L. B. Fenn, T. D. Riley. 1983. Nitrogen Fertilization of Pecan in Far West Texas. The Pecan Quarterly, Vol. 17, No. 2.

3/ - H. L. Malstrom, W. White, T. D. Riley. Effect of Irrigation on Nut Quality and Nut Drop. Western Pecan Conference Proc., Jan 1983 #7, Las Cruces, New Mexico.

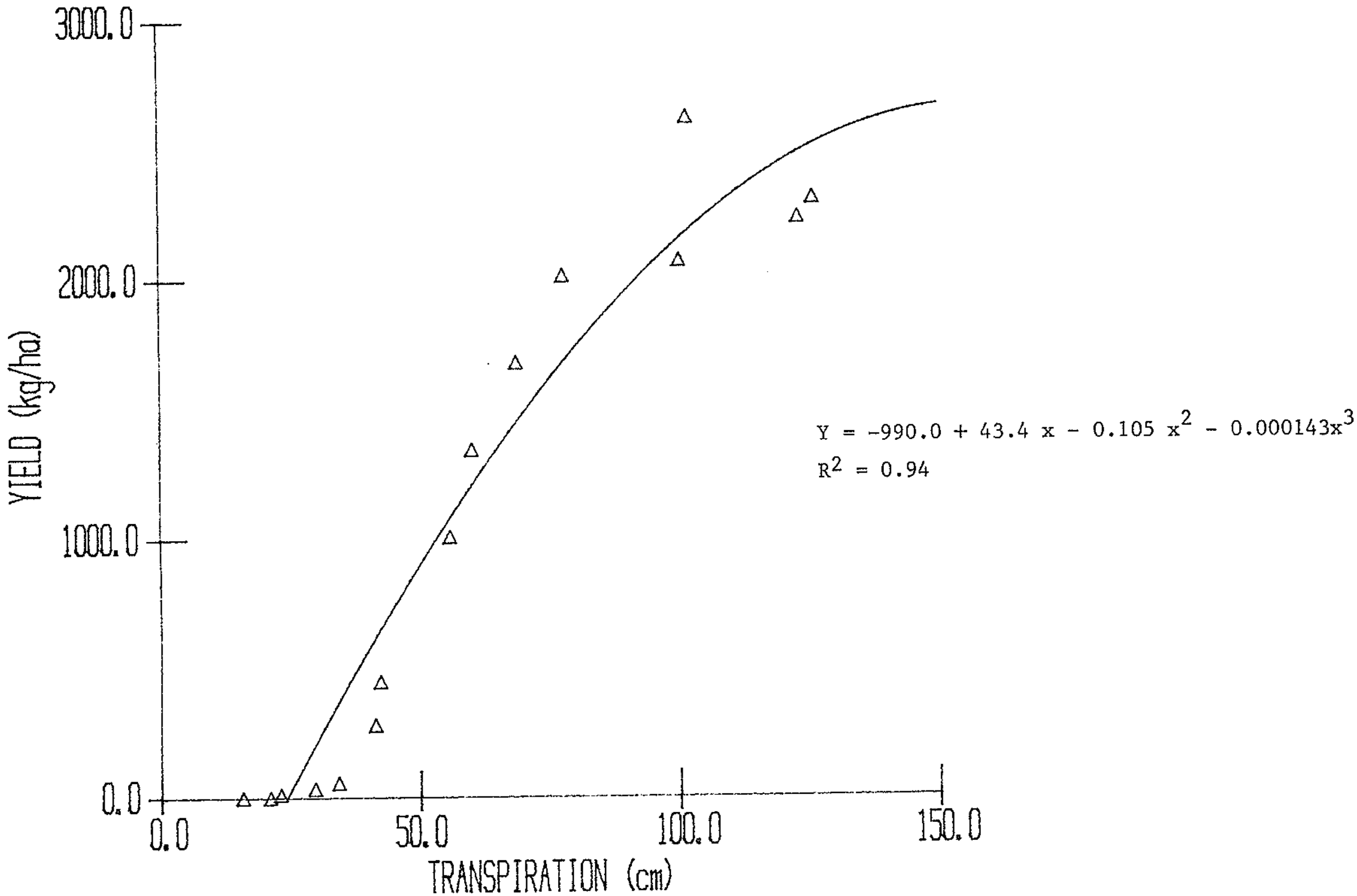


Figure 13. Pecan yield as related to yearly transpiration.

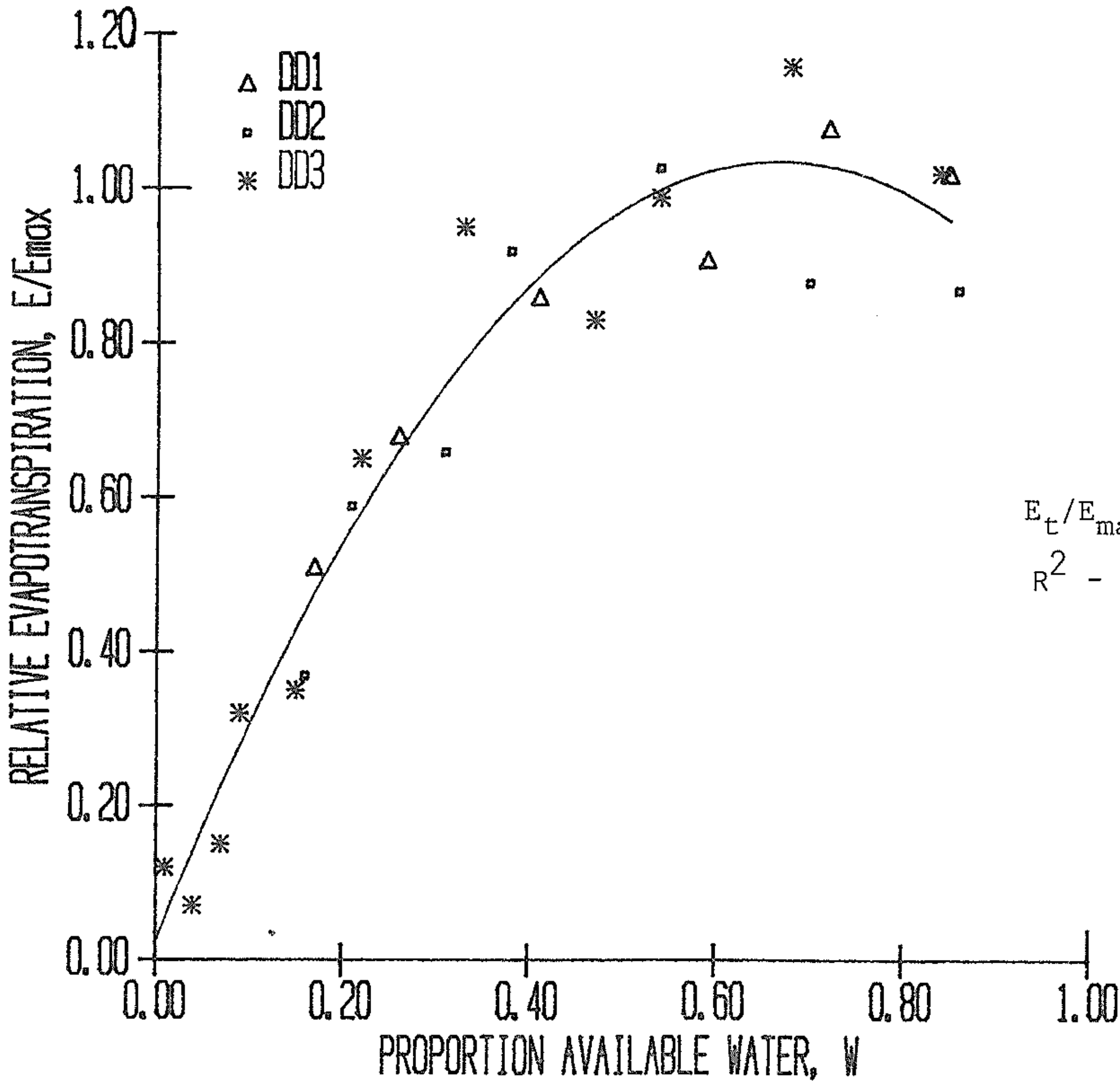
records and is already smoothed for the alternate bearing characteristics of a pecan orchard.

Relative Evapotranspiration Under Moisture Stress in the Pecan Dry Down Experiment

Relative evapotranspiration remains equal to one until 40 percent of the proportional available water in the soil profile has been depleted. After that point, relative evapotranspiration decreases according to a polynomial function (figure 14). The dry down data was collected during August and one week in September, 1984, when potential evapotranspiration was 6.9 mm per day. The results are very similar to those reported by Abdul-Jabbar et al. (1983) for alfalfa grown on a sandy loam soil. In the alfalfa experiment, the functional relationship became linear and the slope decreased when the experiment was conducted on clay soils. The vermiculite mixture has 69 percent moisture by volume at field capacity and 38 percent moisture by volume at permanent wilting points and represents a clay soil. A similar experiment needs to be conducted with pecans growing in a sandy loam soil to determine if the relationship changes between relative E_t and proportional available water.

Model Simulation

Table 4 presents the total water balance from the irrigation model for a pecan field irrigated when soil moisture depletion reaches 50 percent, and represents non-moisture stress conditions; for a pecan field irrigated when soil moisture depletion reaches 75 percent, the figure represents a moisture stress condition. The irrigation scheduling model under non-moisture stress conditions predicts water use efficiencies, E_a, (E_t/water applied) ranging from 89 to 100 percent based on a 100 percent application uniformity. When the trees are put under moisture stress condition the water use efficiency increases and ranges from 91 percent to 100 percent. The loss in nut



$$E_t/E_{max} = 0.0219 + 3.046W - 2.285W^2$$

R^2 - 0.94

Figure 14. Relative evapotranspiration E_t/E_{max} as a function of the porportion of available water (W) for pecans in a vermiculite soil for 3 dry down cycles (DDI-3).

Table 4. Modeled response of pecan trees to moisture stress under 100 percent application uniformity and a random mean application depth of 10.1 cm and standard deviation of 3.30 cm.

Irrigation at 50% Available Soil Moisture Depletion

Year	Rainfall 3/ (cm)	Number of Irrigations	Irrigation 1/ Amount (cm)	E_s (cm)	T (cm)	E_t (cm)	Effic. E_a %2/	Yield hg/ha
1	10.7	4	31.7	30.7	15.7	46.4	100	0
3	12.7	3	36.1	23.0	23.1	46.9	96	0
5	6.9	6	60.7	28.9	34.3	63.2	93	368
7	11.9	7	67.1	28.7	42.5	71.1	90	651
10	10.4	10	88.8	31.4	68.8	100.3	100	1453
15	8.9	12	129.6	26.2	100.8	127.0	92	2172
20	15.2	13	128.8	23.1	104.6	127.6	89	2237
25	10.4	13	128.8	18.5	123.2	141.7	100	2495
30	8.1	14	134.3	16.7	123.6	140.4	99	2498

Irrigation at 75% Available Soil Moisture Depletion

Year	Number of Irrigations	Irrigation Amount (cm)	E (cm)	T (cm)	E_t (cm)	Ea %	Yield kg/ha
1	0	0.0	11.4	13.9	25.3	100	0
3	3	31.8	23.8	16.8	40.6	91	0
5	3	36.0	20.5	22.9	43.4	100	0
7	4	40.3	25.5	25.9	51.4	98	61
10	5	49.2	21.3	40.8	62.1	100	596
15	8	77.0	31.4	60.2	91.6	100	1210
20	8	87.9	20.5	78.3	98.6	96	1695
25	9	102.3	24.3	93.7	118.0	100	2037
30	10	112.3	18.0	97.2	115.2	95	2105

1/ Depth of irrigation determined randomly from a normal population with a mean of 10.16 cm and standard deviation of 3.30 cm. Application uniformity 100%.

2/ Ea = water use efficiency as E_t/water applied (irrigation plus rainfall).

3/ Rainfall same amount for both simulation runs production over the 30-year-period under moisture stress condition predicted by the model was 4,170 kg/ha with a water savings of only 269 centimeters, making the value of additional water needed to supply full irrigation equal to $15.5 per centimeter of water. Consequently, the cost of water has to be excessively large before it would pay to conduct deficit irrigation on pecan trees.

Under non-moisture stress conditions in the first three years of tree growth, soil evaporation exceeds transpiration by 38 percent. In the last five years when the trees are 25 to 30 years old, soil evaporation is only 14 percent of transpiration. Consequently, this irrigation scheduling model has determined that a large amount of water savings can occur if pecan trees are trickle irrigated rather than flood irrigated. The model will be converted in future research to simulate trickle irrigation and a comparison of the water savings under trickle and flood can then be calculated.

Table 5 presents the average moisture content throughout the growing season in 1983 and 1984 at the Salopek farm that was flood irrigated. The dates and amounts of irrigation and rainfall are presented in table 6. The farmer irrigated to maintain his field under non-moisture stress conditions and the average soil water content in the profile remained near field capacity. Irrigation dates and amounts were put into the irrigation scheduling model and the comparison between the measured and modeled soil moisture profile is presented in figures 15 and 16. Average diameter of the trees at Salopek's farm was 22.49 cm. Model E_T (139 cm in 1983 and 146 cm in 1984) was 52.8 cm in 1983 and 22.3 cm in 1984 less than the water application rate (irrigation plus rainfall) indicating that the water use efficiency for Salopek's irrigation system was 0.71 and 0.87 in 1983 and 1984, respectively. Yield predicted by the model was 2508 kg/ha and 2589 kg/ha in 1983 and 1984,

Table 5. Average percent water in the soil profile (W) to a depth of 213 cm cm at Salopek's Pecan Orchard in the Mesilla Valley of New Mexico.

1983			1984		
Date	W 1/ %	Std. Dev. %	Date	W 1/ %	Std. Dev. %
03/17	0.25	0.0086	05/20	0.26	0.0081
04/20	0.29	0.0076	06/06	0.25	0.0091
05/10	0.28	0.0077	06/15	0.26	0.0108
05/19	0.29	0.0101	06/29	0.28	0.0121
07/28	0.25	0.0175	08/01	0.28	0.0090
09/22	0.22	0.0166	09/11	0.29	0.0069
			10/06	0.31	0.0058
			11/09	0.28	0.0084

1/ Mean of six measurements

Table 6. Irrigation and rainfall date and depth of water applied to Salopek's Farm in 1983 and 1984.

Date 1983	Depth 1/cm	Date 1984	Depth cm
	Irrigation		
04/08	13.7	04/10	9.5
04/11	11.7	05/25	10.9
05/15	12.6	06/11	10.0
06/01	13.2	06/28	10.8
06/15	13.0	07/09	9.7
06/29	13.1	07/25	15.4
07/15	11.2	08/08	11.4
07/26	10.0	08/22	8.5
08/10	14.3	08/30	11.2
08/20	9.7	09/12	8.2
08/30	10.1	09/20	8.7
09/13	9.2	09/26	6.4
10/01	9.7	10/03	7.5
10/04	22.5	11/06	6.0
TOTAL	174.0		134.1
	Rainfall 2/		
07/25	0.53	05/15	1.07
07/31	0.10	05/16	.58
08/01	0.25	05/18	.13
08/02	0.03	06/14	.84
08/04	0.13	06/15	1.02
08/07	0.18	06/19	.71
08/10	0.10	06/24	.20
08/11	1.04	06/28	2.80
08/22	2.16	07/12	.13
08/23	0.03	07/23	.13
08/24	0.56	08/01	.10
09/13	1.24	08/02	1.27
		08/04	1.70
		08/05	.51
		08/06	.76
		08/10	.71
		08/11	1.00
		08/20	.51
		08/24	1.52
		08/27	1.70
		09/25	.76
		09/28	.25
		10/03	.20
		10/04	1.47
		10/11	.46
		10/25	3.28
		10/27	2.29
TOTAL	6.35		26.10

1/ Area of Plot = 2.068 Ac Diameter of tree X = 22.49 cm
Standard Deviation = 3.35 Sample Size = 26

2/ Rainfall measured only during growing season outside growing season assumed equal to rainfall at Plant Science Center

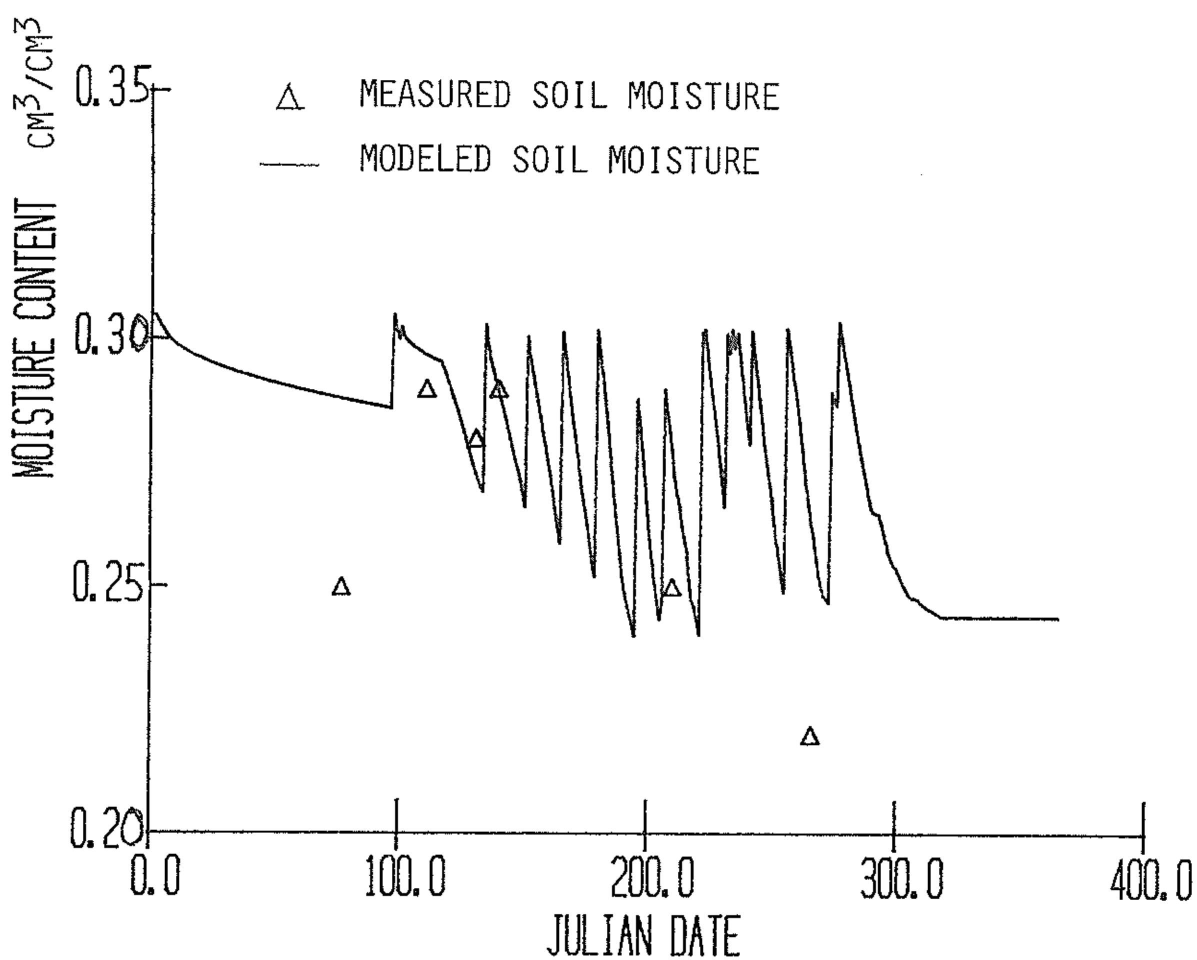


Figure 15. Change in pecan soil moisture to a depth of 213 cm during the growing season in 1983 at Salopek's Farm.

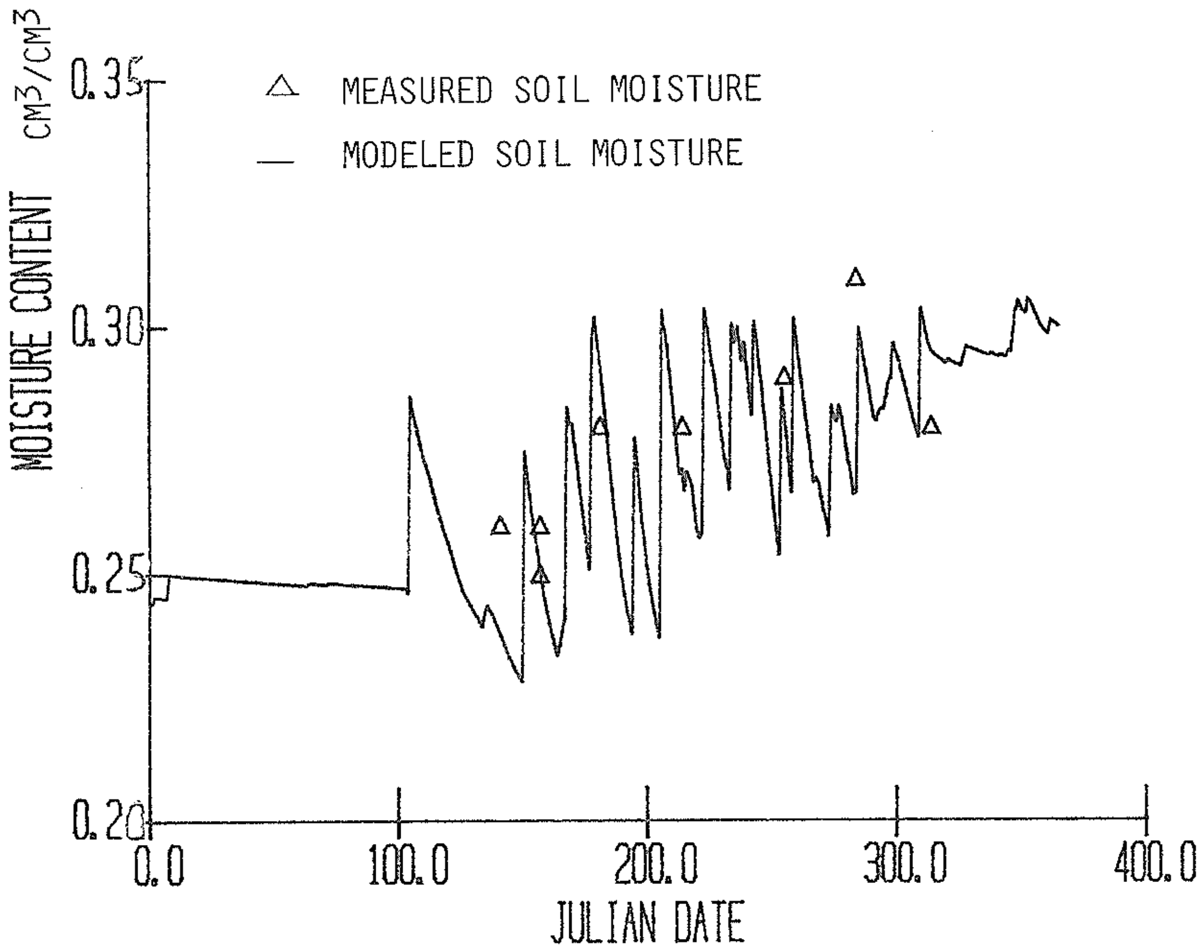


Figure 16. Change in pecan soil moisture to a depth of 213 cm during the growing season in 1984 at Salopek's Farm.

respectively. Yield at the plot was 4704 kg/ha in 1983 and 896 kg/ha in 1984. The average for the two years agrees within nine percent. The model does not account for the fluctuation in yield from year to year that can be smoothed out by proper water, nutrient and pruning practices.

Leaflet Diffusion Resistance

Leaflet diffusion resistance measurements made throughout the growth season were taken only on the abaxial side (bottom side) of the leaflets. The majority of the stomates on a pecan leaflet are on the abaxial side of the leaflet. However, a limited number of stomates are on the adaxial leaflet surface. The error associated with computing leaflet diffusion resistance based on measurements only on the abaxial surface is less than three percent (table 7).

An average leaflet diffusion resistance for the canopy of a pecan tree must be determined by measuring both sunlit and shaded leaflets. On an open canopy, the diffusion resistance ratio of sunlit to shaded leaflets is 0.81 (table 8). As the tree canopy closes, the light intensity reaching the shaded leaflets decreases below the threshold to maintain open stomates. Also the ratio of the leaflet diffusion resistance of sunlit to shaded leaflets decreases (table 8) requiring measurements of leaflet diffusion resistance to be taken from the outside to the inside of the canopy. When the trees were irrigated based upon tensiometer readings, the mid-day leaflet diffusion resistance on sunlit leaflets, even in the non-stress irrigation treatment, showed a fluctuation ranging from 2 to 6 sec/cm with an average of 4.2 sec/cm (table 9). In 1984 when the trees were irrigated three times a week, the average diffusion resistance was 1.7 sec/cm and the range was from 1.3 to 2.1 sec/cm. The coefficient of variation of the mid-day leaflet diffusion resistance averaged 66 percent for irrigation treatment 1 in 1983 and only 24

Table 7. Comparison of diffusion resistance on the top and bottom of pecan leaflets that were under non-moisture stress located in irrigation treatment 1 at the Plant Science Center.

Date	Tree Number	Abaxial Surface of Leaflet1/			Adaxial Surface of Leaflet1/			Error2/
			sec/cm			sec/cm		
		Mean	sd	cv	Mean	sd	cv	
9/21/84								
	1	2.8	0.59	0.21	73.4	57	0.78	2.7
	2	3.2	1.12	0.35	79.3	46	0.58	3.1
	3	2.2	0.45	0.21	90.8	61	0.67	2.1
	4	2.5	1.16	0.47	99.4	58	0.58	2.4
	5	4.0	1.6	0.41	47.6	19	0.10	3.7
10/6/84								
	6	1.8	0.34	0.18	160.0	137	0.85	1.8
	7	3.5	0.68	0.20	112.0	142	1.27	3.4
	8	4.1	0.64	0.15	292.0	250	0.85	4.0
	9	2.7	0.37	0.14	37.4	6	0.15	2.5
	10	2.4	0.33	0.13	96.3	111	1.16	2.3
	11	2.9	0.94	0.32	139.8	169	1.20	2.8

1/ Sample Size 50

2/ % error between computing leaflet resistance using adaxial and adaxial surface of leaflet vs. using only adaxial surface of leaflet.

Table 8. Comparison of pecan leaflet diffusion resistance measured in 1984 on sunlit and shaded leaves at the Plant Science Center.

Date	Irrigation treatment	Tree trunk diameter	Sample size	Diffusion Resistance of Abaxial Leaflet Surface: Sunlit		Shaded		Ratio sunlite/shaded
		(cm)		Mean sec/cm	SD**	Mean sec/cm	SD	
				Small Trees Open Canopy				
7/11	1	7.3	30	2.06	0.49	2.36	0.58	0.87*
	4	5.2	30	1.70	0.44	1.96	0.27	0.86*
7/24	1	7.3	30	2.33	0.79	3.63	0.92	0.64*
	4	5.2	30	1.81	0.28	2.56	0.67	0.70*
8/17	1	7.3	30	1.25	0.21	1.45	0.47	0.86*
8/21	1	7.3	20	1.45	0.41	1.60	0.29	0.96
				Medium Trees Closed Canopy				
7/30	1	23.6	10	1.00	0.58	1.10	0.39	0.91
8/14	1	29.1	10	1.20	0.45	1.10	0.32	1.09
				Large Trees Closed Canopy				
8/02	Flood	21.6	20	1.88	0.52	4.81	0.06	0.39*
8/14	Flood	20.4	30	1.46	0.56	2.73	0.63	0.53*

* Means statistically different ($P \leq 0.05$)

** Standard deviation

Table 9. Mid-day diffusive resistance readings in 1983 and 1984 for pecan leaflets under 4 irrigation treatments

Date	Irrigation treatments 1983: 1		2		3		4		Net radiation
	sec/cm		sec/cm		sec/cm		sec/cm		w/m^2
	$\bar{x}$*	s^2**	$\bar{x}$	s^2	$\bar{x}$	s^2	$\bar{x}$	s^2	
2 June	4.4	1.1	5.4	1.4	5.1	0.6	5.7	2.1	676.1
6 June	4.5	9.2	3.9	0.9	4.8	0.8	4.7	1.7	662.2
9 June	1.8	0.2	2.3	0.4	2.3	0.1	2.3	0.4	648.2
14 June	4.0	2.3	5.2	2.4	4.9	2.9	5.6	2.8	606.4
20 June	6.2	4.5	6.9	3.1	7.8	2.1	5.7	1.9	627.3
23 June	4.1	1.5	6.3	2.7	4.5	1.1	6.7	2.3	655.2
14 July	6.0	4.2	7.2	3.2	7.0	3.7	7.7	3.8	---
18 July	5.8	3.1	7.4	3.5	5.6	5.7	7.2	2.0	641.2
25 July	2.5	0.9	2.7	0.8	2.7	0.7	3.0	0.4	271.8
28 July	2.2	1.2	2.7	0.6	2.7	1.3	2.6	0.6	278.8
MEAN	4.2	2.8	3.5	1.9	4.7	1.9	5.3	1.8	563.0
					1984				
3 June	1.7	0.3	1.4	0.9	1.5	0.8	1.8	0.4	620.3
5 June	1.6	0.3	1.7	0.4	1.8	0.2	2.0	0.3	676.1
9 June	2.1	0.4	2.0	0.1	3.1	0.2	1.9	0.1	564.6
16 June	1.9	0.4	1.7	0.2	1.8	0.2	2.5	0.5	662.2
23 June	1.7	0.2	2.4	0.5	2.7	0.6	2.7	1.0	620.3
27 June	1.7	0.9	1.7	0.5	2.7	0.6	2.7	1.0	467.0
30 June	1.5	0.6	1.3	0.5	1.8	0.4	2.1	0.3	578.5
13 Aug	1.3	0.3	1.1	0.7	1.1	0.7	1.2	0.1	620.3
17 Aug	1.6	0.2	1.4	0.1	1.8	0.2	1.8	0.2	585.5
21 Aug	1.6	0.1	1.6	0.1	2.0	0.6	2.6	0.5	585.5
MEAN	1.7	0.4	1.6	0.4	2.0	0.5	2.1	0.4	598.0

* Mean diffusive resistance of two trees (two trees and ten readings from each tree)

** s^2 = variance

percent in 1984 indicating that the sample size and error for the non-stress leaflet diffusion resistance measurement decreases if the plants are not put through a moisture stress cycle condition. Increase in leaflet diffusion resistance, as the plants were put under additional moisture stress, only increased 26 percent from irrigation treatments 1 to 4 in 1983 and 24 percent from the irrigation treatments 1 to 4 in 1984.

Daily Cycle of Leaflet Diffusion Resistance

Leaflet diffusion resistance is higher early in the morning when the sun first comes up because of low light intensity (table 10, figures 17 and 18). Diffusion resistance rapidly decreases and stays low throughout the day but rises again at the end of the day due to low light intensity. The mid-day leaflet diffusion resistance readings has to be increased by 150 percent to equal the daily integrated values (table 11).

Leaflet Area as Related to Pecan Basal Area

Table 12 and figure 19 presents the relationship between trunk cross-sectional area (basel area) and total leaf area. The coefficient of termination of the polynomial is 0.98. This data can be used to convert the transpiration from an individual leaflet to the transpiration from the canopy of a tree.

Water Application Under Trickle Irrigation

Water was applied to the trickle irrigated trees with an increasing number of irrigations each year as the trees grew larger. Table 13 presents a summary of the total water application, projected crown size, number of irrigations and yearly rainfall. From 1979 to 1983, the number of irrigations were determined by when the tensiometers reached the 40 to 60 mb range and increased in number from 4 to 12. In 1984, the trees were irrigated three times a week for a total of 22 irrigations. This increase resulted in a

Table 10. Hourly diffusive resistance (D), leaflet water potential (P) and net radiation (Rn) for pecan leaflets under non-stressed irrigation regime in 1984 and stress and non-stress conditions in 1981 at Las Cruces, New Mexico.

Irrigation Treatment 1

Time	0700	0900	1100	1300	1500	1700	1900
7/19/84							
D cm/sec	4.83 1/	1.85	1.37	1.90	1.83	1.78	4.85
S cm/sec	2.03	.95	.58	.61	.60	.43	2.35
Rn w/m2	38.99	350.88	565.30	662.77	565.30	331.38	38.99
8/2/84							
D cm/sec	4.63	1.50	1.47	1.13	1.70	1.75	7.43
S cm/sec	1.39	.32	.26	.30	.47	.49	1.75
Rn w/m2	38.99	155.95	350.88	448.34	233.92	233.92	19.49
8/2/84							
D cm/sec	7.30	2.03	1.60	1.06	2.13	2.58	8.70
S cm/sec	2.85	0.46	.38	.28	.65	.84	3.00
Rn w/m2	38.99	136.45	565.30	662.77	584.80	331.38	19.49

Time	0600	0800	1000	1200	1430	1600	1800	2000
8/21/81								
D cm/sec	4.19	1.37	1.28	1.08	1.47	2.54	2.19	6.79
S cm/sec	2.83	0.46	0.48	0.40	0.83	1.41	1.67	8.38
P M Pa	-0.22	-1.25	-1.82	-1.23	-1.68	-1.76	-1.02	-0.31
S M Pa	0.05	0.36	0.46	0.45	0.61	0.66	0.31	0.10

Time	0800	1000	1200	1500	1700	1900	2000
8/26/81							
X cm/sec	2.75	2.52	2.40	3.49	4.07	5.12	11.70
S cm/sec	0.96	0.74	0.92	1.00	1.18	2.98	7.29
P M Pa	-0.47	-1.51	-2.21	-1.50	-1.71	-1.21	-0.68
S M Pa	0.10	0.75	0.30	0.54	0.41	0.18	0.07

Irrigation Treatment 4

Time	0645	0830	1030	1230	1530	1715	1845
8/21/81							
X cm/sec	4.14	0.95	1.25	1.36	1.96	2.24	2.74
S cm/sec	3.07	0.21	0.19	0.39	1.25	1.86	1.17
P M Pa	-0.26	-1.15	-1.72	-1.59	-2.01	-1.52	-1.40
S M Pa	0.08	0.15	0.42	0.74	0.46	0.65	0.57

Time	0830	1030	1230	1530	1730	1900	2100
8/26/81							
X cm/sec	1.25	1.82	1.45	2.26	2.44	3.50	25.70
S cm/sec	0.48	0.87	0.19	0.63	0.46	1.39	19.75
P M Pa	-0.97	-1.76	-1.90	-2.02	-1.72	-2.02	-0.38
S M Pa	0.30	0.79	0.65	0.46	0.48	0.22	0.09

1/ Mean diffusive resistance of three trees (3 trees and 10 readings from each tree.

\- Means of four trees (4 trees and 10 readings from each tree).

2/ S is standard deviation.

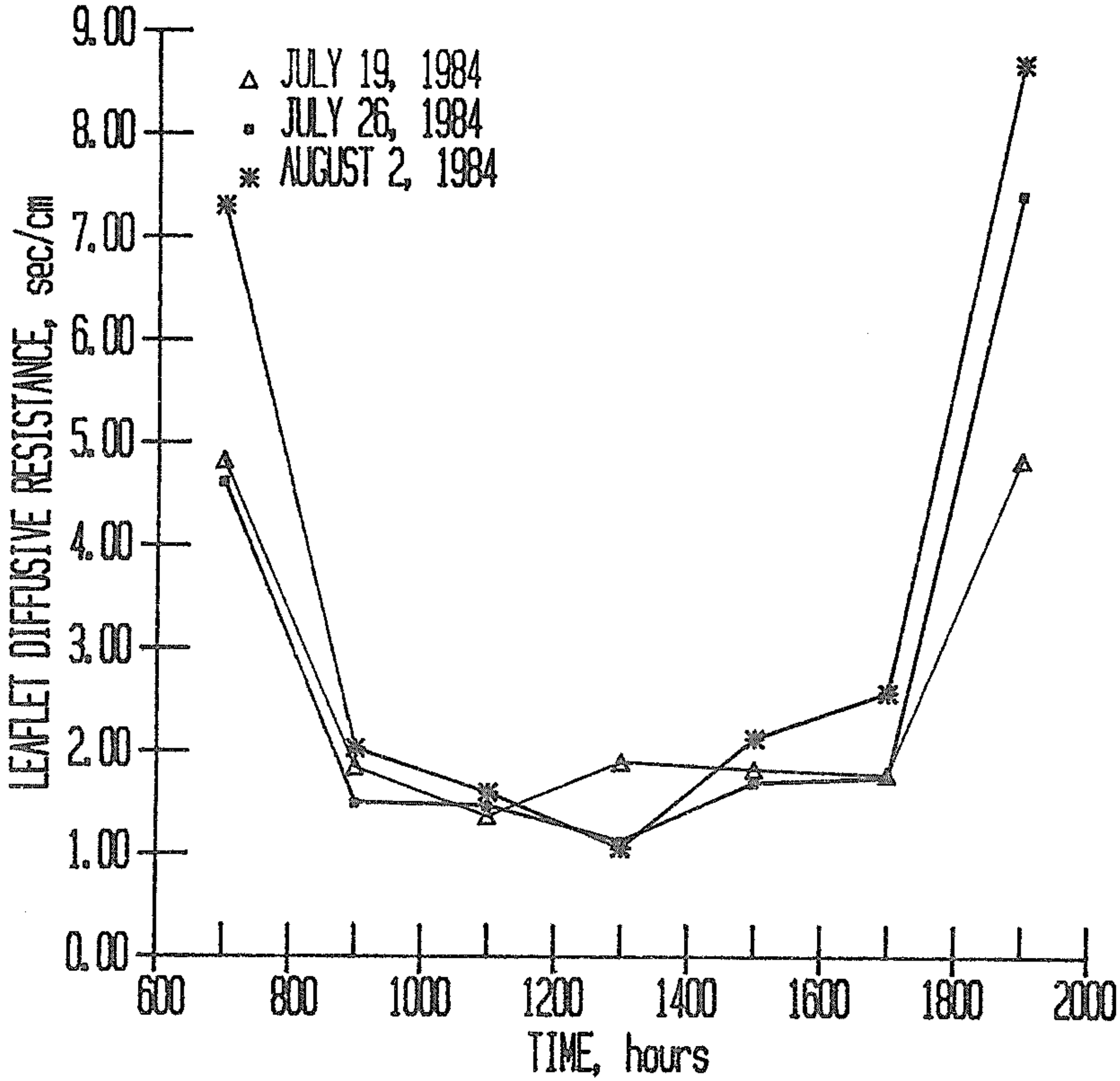


Fig. 17. Diurnal variation in leaflet resistance to water flow for pecan trees under nonstress conditions at Las Cruces, New Mexico, 1984.

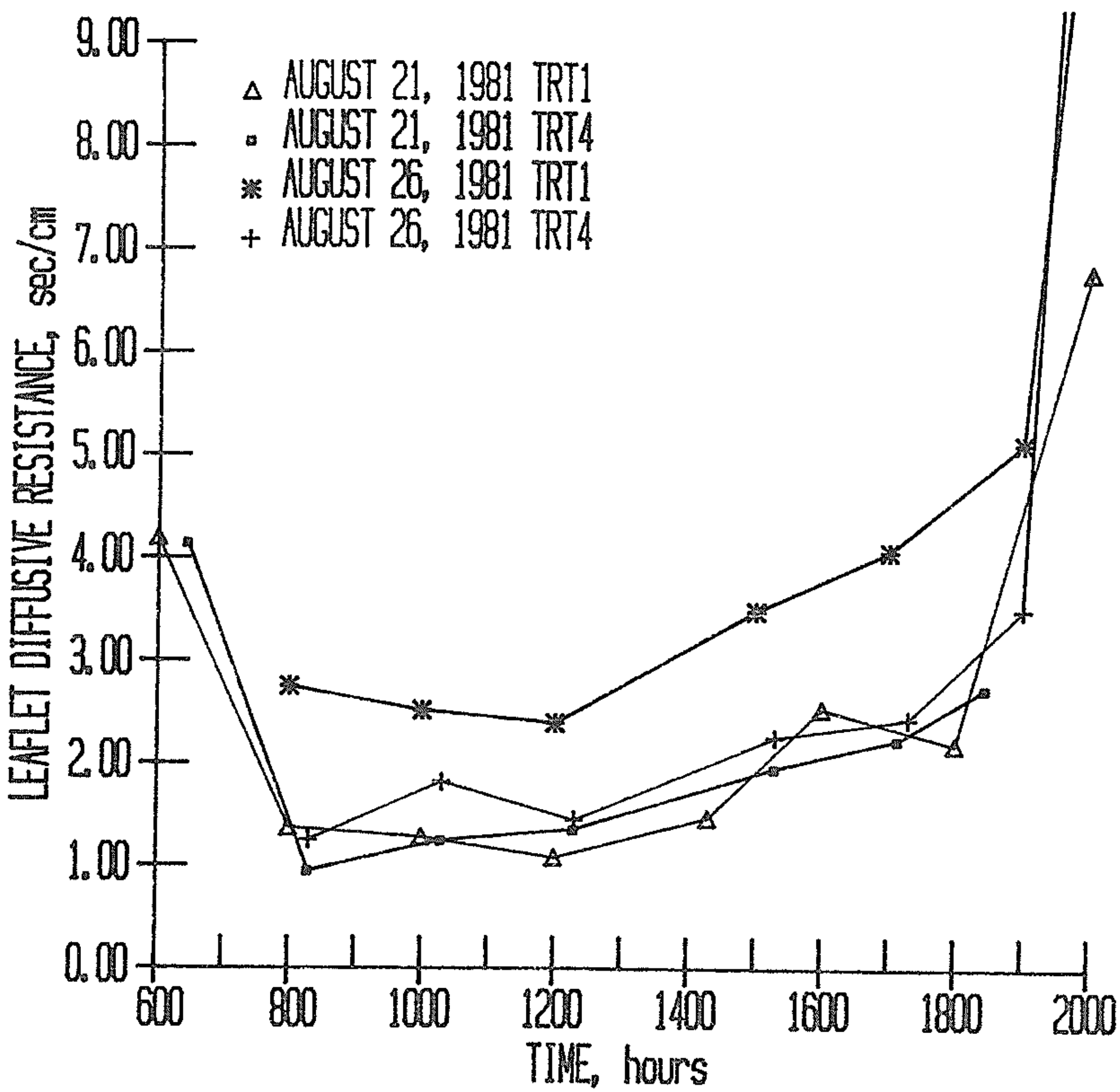


Fig. 18. Diurnal variation in leaflet resistance to water flow for pecan trees under stress and nonstress conditions at Las Cruces, New Mexico, 1981.

Table 11. Comparison of daily and mid-day pecan leaflet diffusion resistance.

Date	Irrigation level	Diffusion resistance intergrated over day sec/cm	Diffusion resistance mid day sec/cm	Ratio
Aug 21, 1981	1	2.19	1.23	1.78
Aug 21, 1981	4	1.80	1.50	1.20
Aug 26, 1981	4	2.02	1.77	1.14
July 19, 1984	1	2.26	1.75	1.29
July 26, 1984	1	2.26	1.36	1.66
Aug 02, 1984	1	2.90	1.46	1.98
			Ave.	1.50

Table 12. Leaf area (L_a) and tree trunk cross section area (T_a)

Leaf area one side m^2	Tree trunk basel area cm^2
155.9	167.5
181.0	139.7
451.8	439.3
516.9	665.4
93.1	123.4
16.3	32.8
13.0	34.9
11.5	43.9
10.0	33.7
111.9	33.7
12.6	32.7
7.3	17.0
9.7	18.5
12.8	25.1
2.6	8.7
1.7	7.2
1.8	8.7
3.0	7.2
4.7	10.4
2.7	10.4
5.2	9.3
4.1	11.0
7.6	
4.1	11.0
7.6	20.8
6.6	18.5
5.1	19.3
7.0	12.8
6.7	20.8
2.2	7.7
7.4	20.8
4.7	11.6
4.7	12.8
3.1	14.1

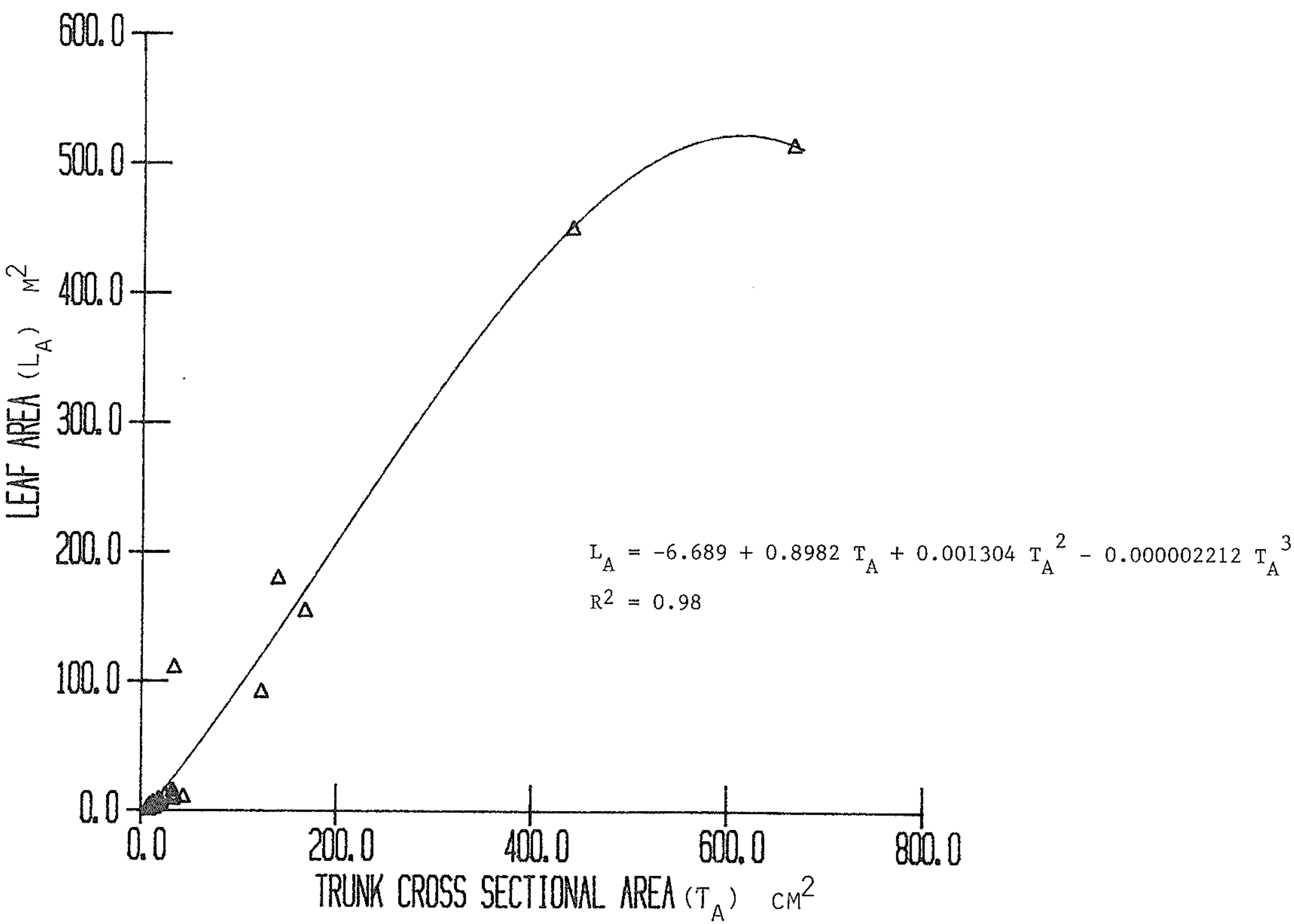


Figure 19. Leaf area of a pecan tree as related to trunk cross section or area.

Table 13. Water Applied on the Trickle Irrigated Pecan Treatments.

Year	Irrigation treatments 1	2	3	4
1979				
Applied Water L/Tree	492	440	319	215
Projected Crown Area m^2#	0.007	0.007	0.001	0.001
Number of Irrigations 4				
Yearly Rainfall (cm) 19.47				
1980				
Applied Water L/Tree	3172	2532	1797	1388
Projected Crown Area m^2 #	1.16	0.64	0.68	0.86
Number of Irrigations 7				
Yearly Rainfall (cm) 22.75				
1981				
Applied Water L/Tree	5337	4003	3092	2045
Projected Crown Area m^2	2.04	1.41	1.32	2.36
Number of Irrigations 8				
Yearly Rainfall (cm) 23.90				
1982				
Applied Water L/Tree	4591	3205	2414	2115
Projected Crown Area m^2	3.76	2.48	2.23	2.29
Number of Irrigations 13				
Yearly Rainfall (cm) 26.00				
1983				
Applied Water L/ Tree	6266	4406	3669	2510
Projected Crown Area m^2	4.28	3.18	2.84	2.51
Number of Irrigations 12				
Yearly Rainfall (cm) 21.70				
1984				
Applied Water L/Tree	7134	5178	3871	2787
Projected Crown Area m^2	4.71	3.27	3.19	2.93
Number of Irrigations 22				
Yeary Rainfall (cm) 33.50				

\# Based on measurement of trunk diameter and regressive equation.

Crown area (m^2) = 0.8449 trunk diameter (cm) - 1.461 r^2 = 0.78.

better irrigation schedule in terms of preventing the trees from becoming moisture stressed. The diffusion resistance data in 1983 on irrigation treatment 1 indicated that the trees had undergone some moisture stress even though they were irrigated when the tensiometers reached 40 to 60 mb. The dates and amount of irrigation applied for 1983 and 1984 are presented in tables 14 and 15, respectively. The soil moisture content did not vary substantially (tables 16 and 17) from the beginning to the end of the growing season and, in 1984 when irrigated three times a week, remained essentially constant throughout the year. Yield data for 1983 and 1984 is presented in table 18 showing the decrease in yield due to moisture stress.

Leaflet Temperature Data

Leaflet temperature, air temperature and vapor pressure deficit were measured on both large trees at Salopek's farm and on the trickle irrigated trees under the non-moisture stressed treatment in 1983 and 1984 (table 19). This baseline data, when plotted, is a linear function and the coefficient of determination is 0.75 (figure 20). The baseline represents the temperature of pecan leaflets under non-moisture stress conditions for different vapor pressure deficits. The upper baseline (7.1 C, (table 20) represents non-transpiring leaflets and was determined by cutting the branch off, letting it desiccate, and then measuring leaflets and air temperature, or by letting trees in barrels completely desiccate.

Leaflet temperature measurements also were made on irrigation treatments 2, 3 and 4 (table 21). The crop water stress index (CWSI) is determined by a graphical technique (Idso 1981) and is equal to the relative distance between the lower and upper baseline. The data presented in figure 21 was averaged for May, June and July (figure 22) and the average crop water stress index was 0.14, 0.13 and 0.20 for irrigation treatments 2, 3 and 4, respectively.

Table 14. Irrigation date and amount of water applied on the trickle irrigated pecan orchard in 1983.

Date	Treatment 1 l/tree	Treatment 2 l/tree	Treatment 3 l/tree	Treatment 4 l/tree
05/15	378.0	189.0	189.0	189.0
06/04	525.4	378.0	412.0	151.2
06/22-23	480.1	427.1	328.9	185.2
06/28	166.3	0	0	0
07/05-06	570.8	306.2	336.4	173.9
07/18-19	366.7	291.1	185.2	90.7
08/01-02	688.0	393.1	192.8	109.6
08/10-11	332.6	189.0	143.6	86.9
08/22	332.6	223.0	215.5	86.9
09/15	412.0	181.4	166.3	90.7
09/19	306.2	215.5	136.1	60.5
10/10	211.7	306.2	177.7	173.9
Sub Total	4770.3	3099.6	2483.5	1398.6
March				
Irrigation*	568.0	568.0	568.0	568.0
Rainfall**	928.0	739.0	618.0	544.0
Total	6266.3	4406.6	3669.5	2510.6
Relative Water Application	1.0	0.70	0.58	0.40

* Pre-irrigation to full root zone estimated based on time system was operated.

** Rainfall based on projected area of crown of the tree

Table 15. Irrigation date and amount of water applied on the trickle irrigation pecan orchard in 1984.

Date	Treatment 1 l/tree	Treatment 2 l/tree	Treatment 3 l/tree	Treatment 4 l/tree
05/14	344.0	238.1	158.8	136.1
06/01	476.3	68.0	45.4	30.2
06/05	49.1	26.5	26.5	15.1
06/08	34.0	22.7	15.1	7.6
06/12	37.8	26.5	22.7	11.3
06/15	45.4	30.2	22.7	11.3
06/19	257.0	113.4	117.2	121.0
06/22	347.8	177.7	181.4	90.7
07/02	491.4	317.5	234.4	102.1
07/10	75.6	400.7	196.6	75.6
07/16	453.6	400.7	0	0
07/20	313.7	207.9	139.9	83.2
07/23	332.6	139.9	166.3	30.2
07/25	306.2	264.6	158.8	71.8
07/30	464.9	211.7	192.8	41.6
08/04	128.5	264.6	90.7	86.9
08/08	226.8	121.0	113.4	11.3
08/11	113.4	0	0	0
08/22	102.1	75.6	52.9	49.1
08/30	158.8	260.8	136.1	208.0
09/07	64.3	37.8	52.9	0
09/12	166.3	109.6	109.6	55.6
Sub Total	4989.6	3515.4	2234.0	1238.7
March				
Irrigation*	568.0	568.0	568.0	568.0
Rainfall**	1577.0	1095.0	1069.0	981.0
Total	7134.6	5178.4	3871.0	2787.7
Relative Water Application	1.0	0.72	0.54	0.39

* Pre-irrigation to fill root zone estimated based on time system was operated.

** Rainfall based on projected area of the crown of the tree

Table 16. Average percent water in the soil profile (W) to a depth of 152 cm at the trickle irrigation pecan orchard in 1983.

IRRIGATION TREATMENT 1				
	In drip line		Out of drip line	
Date	W %	Std. Dv. %	W %	Std. Dv. %
07/28	0.23	0.010	0.22	.005
09/17	0.18	0.020	0.19	.003
11/31	0.21	0.010	0.21	.004
IRRIGATION TREATMENT 2				
07/28	0.18	0.006	0.19	.009
09/17	0.15	0.001	0.17	.006
11/31	0.20	0.010	0.21	.005
IRRIGATION TREATMENT 3				
07/28	0.20	0.005	0.22	0.010
09/17	0.20	0.060	0.16	0.010
11/31	0.23	0.040	0.23	0.040
IRRIGATION TREATMENT 4				
07/28	0.19	0.010	0.20	0.030
09/17	0.15	0.008	0.15	0.003
11/31	0.20	0.010	0.23	0.006

Table 17. Average percent water in the soil profile (W) to depth of 152 cm at the trickle irrigation pecan orchard in 1984.

	In drip line		Out of drip line	
Date	W %	Std. Dev. %	W %	Std. Dev. %
IRRIGATION TREATMENT 1				
06/05	.167	.014	.176	.02
07/19	.190	.026	.194	.020
09/17	.167	.015	.186	.013
11/10	.167	.015	.185	.010
Tube #1, 2, 3, 7, 8, 9			Tube #4, 5, 6	
IRRIGATION TREATMENT 2				
06/15	.159	.005	.173	.007
07/19	.212	.006	.200	.025
09/17	.193	.008	.191	.010
11/10	.176	.010	.185	.010
Tube #10, 11, 17, 18			Tube #12, 13, 14, 15, 16	
IRRIGATION TREATMENT 3				
06/15	.159	.005	.174	.003
07/19	.187	.022	.170	.003
09/17	.155	.014	.169	.006
11/10	.155	.013	.167	.005
Tube #19, 20, 25, 26			Tube #21, 22, 23, 24	
IRRIGATION TREATMENT 4				
06/15	.166	.014	.157	.009
07/19	.174	.014	.173	.010
09/17	.164	.014	.167	.006
11/10	.165	.020	.164	.009
Tube #28, 29, 35, 36			Tube #30, 31, 32, 33, 34	

Table 18. Nut Yield from Trickle Irrigated Pecan Plots

Irrigation treatment	Nut Yield 1983 kg/ha	Nut Yield 1984 kg/ha
1	41	231.6 a*
2	21	141.7 b
3	15	120.5 bc
4	26	101.4 c

*Yields followed by the same letter are not stastically different (P<0.5) sample size 15 trees, yield adjusted to 49 trees/Ac 30 ft x 30 ft spacing.

Table 19. Net radiation over canopy (R); air temperature (AIRT); leaflet temperature minus air temperature for pecans (DIFF); coefficient of variation of pecan leaflet temperature (CVT); vapor pressure deficit (VPD) and sample size of pecan leaflet temperature using an infrared thermometer taken in selected fields under non-stress conditions.

Time	Date	R w/m²	AIRT C	N 1/	DIFF C	Cut	VPD (KPa)
* Omitted from Regression							
SALOPEK Diurnal on Large Trees							
1000	10/06		19.7	15	-0.72	0.03	0.5*
1030	10/06		20.0	15	-0.23	0.05	0.84
1100	10/06		20.7	15	-0.44	0.04	1.11
1130	10/06		21.5	15	-0.37	0.04	1.39
1200	10/06		22.22	15	-0.58	0.03	1.56
1230	10/06		22.88	15	-0.55	0.06	1.73
1300	10/06		23.33	15	-0.70	0.05	1.88
1330	10/06		23.61	15	-0.98	0.04	2.04
1400	10/06		23.88	15	-0.36	0.03	2.19*
1430	10/06		23.94	15	-0.17	0.04	2.34*
1500	10/06		24.72	15	-1.31	0.03	2.35
1530	10/06		24.16	15	-0.08	0.03	2.37*
1600	10/06		23.88	15	-0.85	0.06	2.34
1983 - 7 Dates Averaged on Trickle Irrigated Trees-Irrigation Treatment 1							
1130-1230	05/26-06/13	676.7	29.8	560	-1.17	0.04	2.96
1130-1230	05/27-06/21	685.0	30.7	560	-1.30	0.04	3.32
1130-1230	05/31-06/22	657.2	31.2	560	-1.68	0.04	3.47
1130-1230	06/01-06/24	626.6	31.1	560	-1.76	0.04	3.45
1130-1230	06/03-06/28	612.6	31.5	560	-2.03	0.04	3.64
1130-1230	06/08-06/29	609.9	32.0	560	-2.20	0.04	3.89
1130-1230	06/13-07/08	598.7	32.0	560	-2.30	0.04	3.76
1130-1230	06/21-07/15	593.1	32.5	560	-2.30	0.05	3.86
1130-1230	06/22-07/19	587.6	32.4	560	-2.30	0.05	3.71
1130-1230	06/24-07/27	601.5	31.9	560	-1.81	0.05	3.52
1130-1230	06/28-07/29	629.4	33.1	560	-1.75	0.05	3.84
1984 - 4 Days Averaged on Trickle Irrigated Trees-Irrigation Treatment 1							
1100-1200	07/05-07/27	609.2	31.9	135	-1.9	0.05	3.25
1100-1200	07/16-08/01	584.8	31.9	135	-2.3	0.05	3.28
1100-1200	07/23-08/13	575.0	30.1	150	-1.96	0.06	2.65
1100-1200	07/27-08/17	565.3	29.2	165	-1.96	0.06	2.49
1100-1200	08/01-08/21	594.5	29.3	150	-1.47	0.07	2.35
1984 - Diurnals on trickle irrigated trees-irrigation treatment 1							
0700	07/19	39.0	20.00	45	-0.7	0.04	0.49
0900	07/19	350.9	26.55	45	-0.75	0.07	1.56
1100	07/19	565.3	30.55	60	-2.2	0.04	2.93
1300	07/19	662.8	33.05	60	-2.63	0.04	3.68
1500	07/19	565.3	34.44	45	-2.97	0.04	4.25
0700	07/26	39.0	18.05	60	-0.3	0.03	0.46
0900	07/26	155.9	23.05	60	-0.97	0.03	1.13
1100	07/26	350.9	25.00	60	-0.57	0.03	1.49
1700	07/26	233.9	28.61	30	-2.06	0.06	2.39
1900	07/26	19.5	26.11	45	-1.41	0.02	1.79
1100	08/02	565.3	29.16	60	-1.41	0.08	2.02
1300	08/02	662.8	31.11	60	-1.78	0.06	2.80
1500	08/02	584.8	32.77	45	-1.47	0.05	3.48

1/ Sample Size

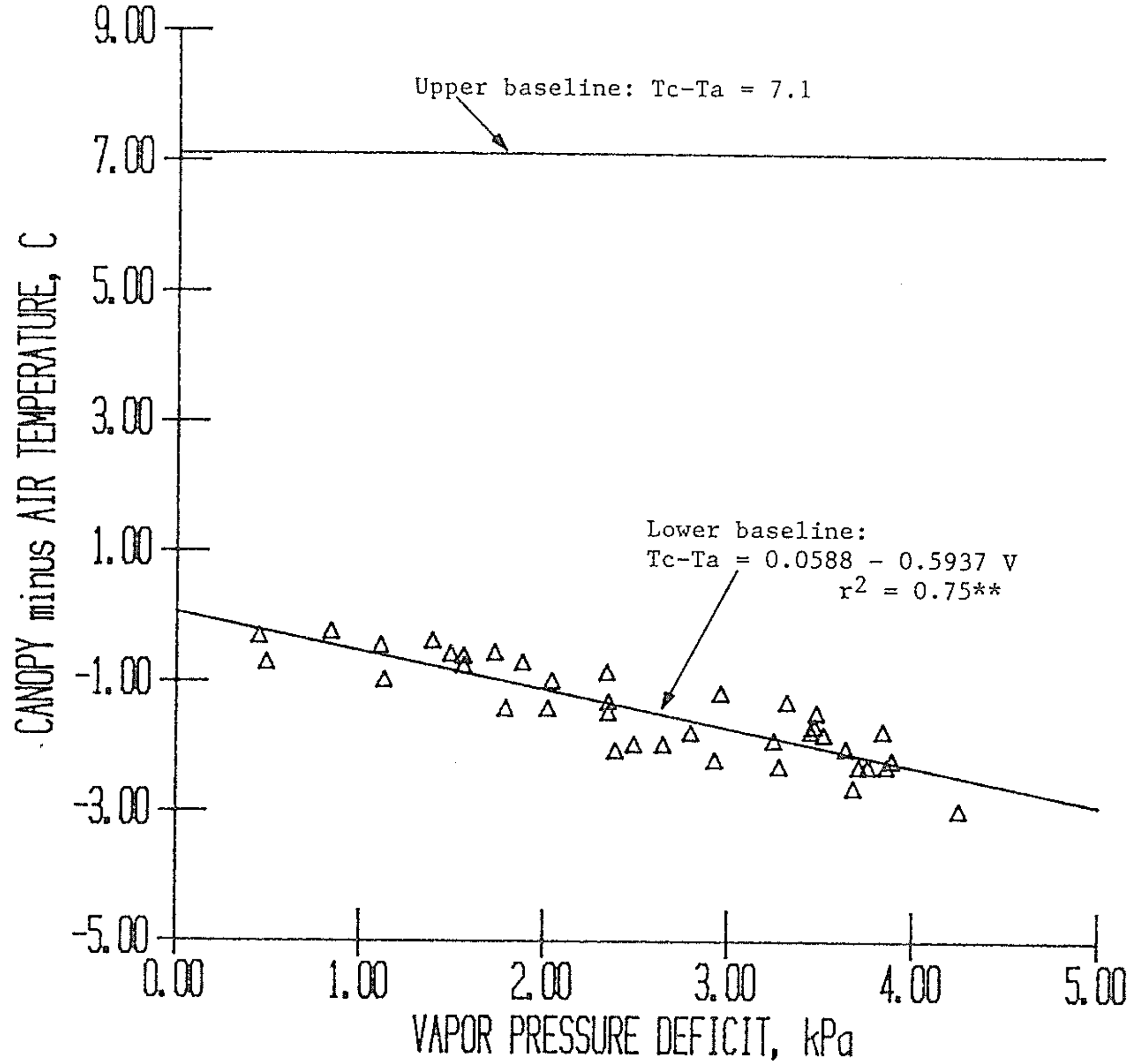


Fig 20. Relationship between vapor pressure deficit (V) and canopy minus air temperature (Tc-Ta) for non-transpiring (upper baseline) and fully transpiring (lower baseline) pecan trees growing at Las Cruces, New Mexico, 1983-84.

Table 20. Maximum pecan leaflet temperature under conditions of no transpiration.

Date	Sample size	Measurement on cut limb leaf temp C		Air temp C	Leaf-air temp C	Net radiation w/m2
		Mean	sd			
08/01	15	41.7	2.89	32.8	8.9	624
08/15	15	35.4	3.61	29.4	6.0	682
08/21	10	37.8	3.24	30.0	7.8	584
		Measurements on Dry Down Trees				
09/01	15	39.8	9.61	32.2	7.6	
09/02	15	38.1	7.29	32.8	5.3	
Ave.					7.1	

Table 21. Net radiation over canopy (R); air temperature (AIRT); leaflet temperature minus air temperature for pecan (DIFF); coefficient of variation of pecan leaflet temperature (CVT); vapor pressure deficit (VPD); and sample size of pecan leaflet temperature using an infrared thermomeber taken from selected trees under stress conditions, 1983.

Date	R w/m2	AIRT C	N1/	DIFF C	CVT	(KPa) VPD
		Trickle Irrigated Trees - Irrigation Treatment 2				
05/23	633.5	31.3	80	-0.65	0.04	3.42
05/26	594.8	29.9	80	-0.55	0.04	2.90
05/27	682.3	31.1	80	-0.60	0.04	3.47
05/31	642.3	29.2	80	-1.20	0.03	2.51
06/01	682.3	29.6	80	0.70	0.04	3.15
06/03	614.0	30.8	80	-1.39	0.05	3.80
06/08	594.5	32.7	80	2.00	0.03	4.27
06/13	672.5	32.0	80	-0.90	0.02	3.80
06/21	623.8	36.4	80	-0.70	0.03	5.56
06/22	565.3	34.8	80	-1.00	0.03	4.61
06/24	487.3	27.2	80	-1.20	0.04	1.98
06/28	584.8	32.3	80	-1.65	0.05	4.40
06/29	594.5	34.2	80	-2.90	0.04	4.70
07/08	623.8	33.6	80	-1.90	0.03	3.59
07/15	623.8	35.6	80	-1.60	0.03	4.74
07/19	662.8	33.2	80	-1.70	0.04	3.51
07/27	506.8	30.3	80	0.25	0.03	2.84
07/29	623.8	36.1	80	-1.70	0.04	4.75
		Trickle Irrigated Trees - Irrigation Treatment 3				
05/23	633.5	29.9	80	-0.70	0.04	3.19
05/26	623.8	29.3	80	0.25	0.04	2.74
05/27	682.3	30.2	80	-0.50	0.06	3.17
05/31	682.3	28.3	80	-1.75	0.04	2.44
06/01	662.8	29.3	80	-0.25	0.03	3.02
06/03	672.5	30.4	80	-1.70	0.04	3.69
06/08	604.3	31.9	80	1.10	0.04	4.00
06/13	653.0	32.0	80	-2.30	0.03	3.82
06/21	633.5	37.3	80	-3.00	0.04	5.63
06/22	545.8	33.4	80	-0.90	0.04	4.29
06/24	731.0	26.6	80	-0.20	0.04	1.57
06/28	584.9	31.7	80	-1.00	0.04	4.04
06/29	604.3	33.5	80	-1.20	0.05	4.57
07/08	584.9	33.2	80	-0.40	0.04	3.51
07/15	623.8	36.9	80	-3.10	0.04	5.06
07/19	604.3	33.1	80	-0.80	0.04	3.56
07/27	487.3	30.7	80	-1.00	0.04	2.94
07/29	614.0	33.4	80	0.90	0.05	3.72
		Trickle Irrigated Trees - Irrigation Treatment 4				
05/23	653.0	31.4	60	0.50	0.03	3.62
05/26	594.8	29.8	80	1.05	0.05	2.87
05/27	682.3	31.4	80	0.65	0.04	3.52
05/31	662.8	29.4	80	0.10	0.02	2.33
06/01	682.3	28.8	80	2.00	0.02	2.93
06/03	653.0	31.8	50	-1.20	0.04	4.21
06/08	594.5	33.8	80	-0.10	0.03	4.59
06/13	672.5	32.5	80	-1.20	0.03	4.31
06/21	594.5	37.4	80	-1.60	0.03	5.84
06/22	506.8	34.5	80	-0.30	0.03	4.58
06/24	487.3	26.8	80	-0.70	0.03	1.89
06/28	584.8	32.5	80	-1.05	0.04	4.30
06/29	614.0	34.7	80	-1.90	0.03	4.84
07/08	604.3	33.7	80	-0.10	0.03	3.62
07/15	594.5	37.1	80	-2.70	0.03	5.27
07/19	672.5	33.3	80	-0.20	0.03	3.63
07/27	575.0	30.0	80	0.20	0.02	2.80
07/29	614.0	35.7	80	-0.10	0.04	4.53

1/ Sample Size

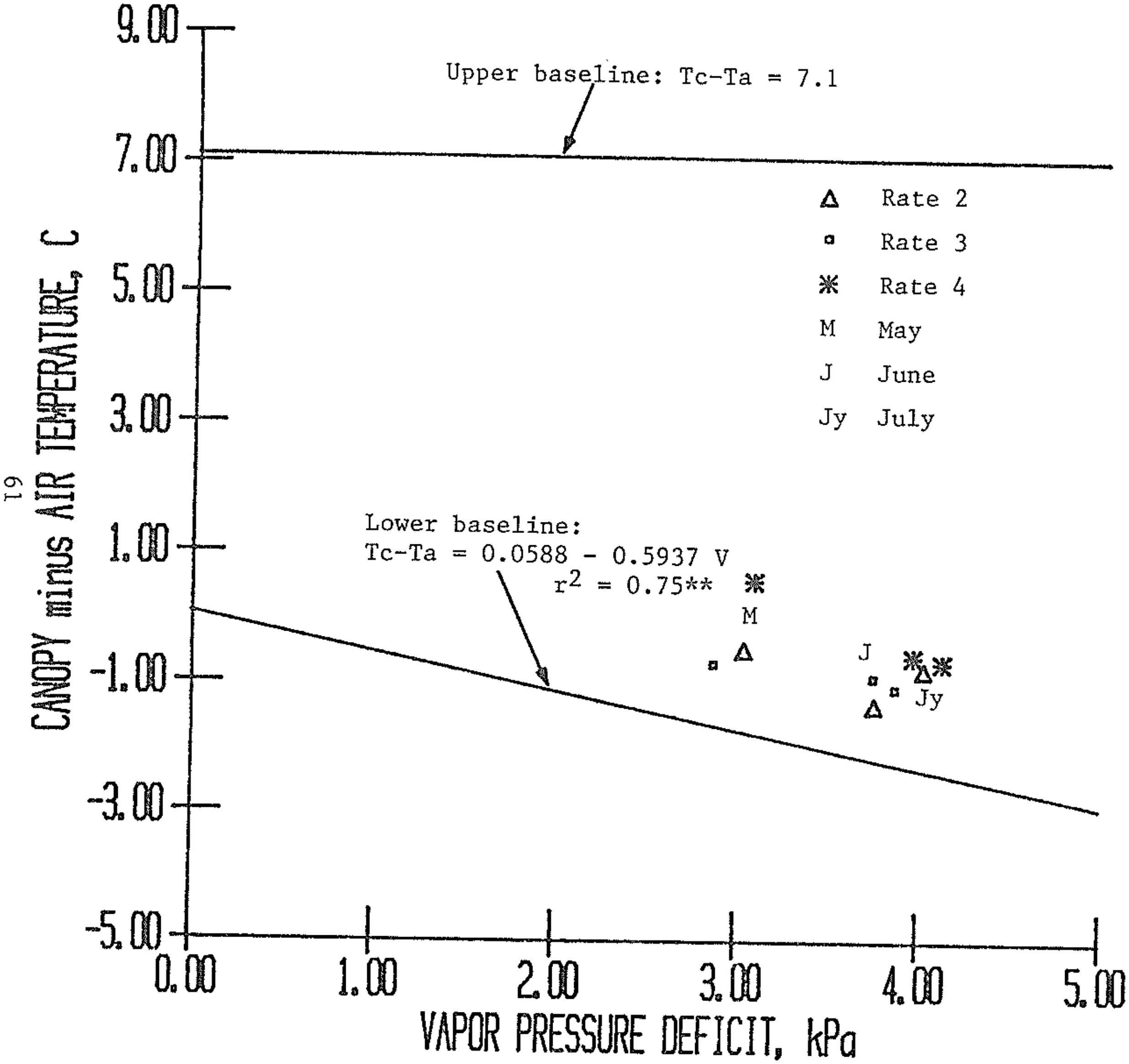


Fig 21. Relationship of vapor pressure deficit (V) and canopy minus air temperature (Tc-Ta) during May, June and July for pecan trees irrigated under less than optimum rates, Las Cruces, New Mexico, 1983.

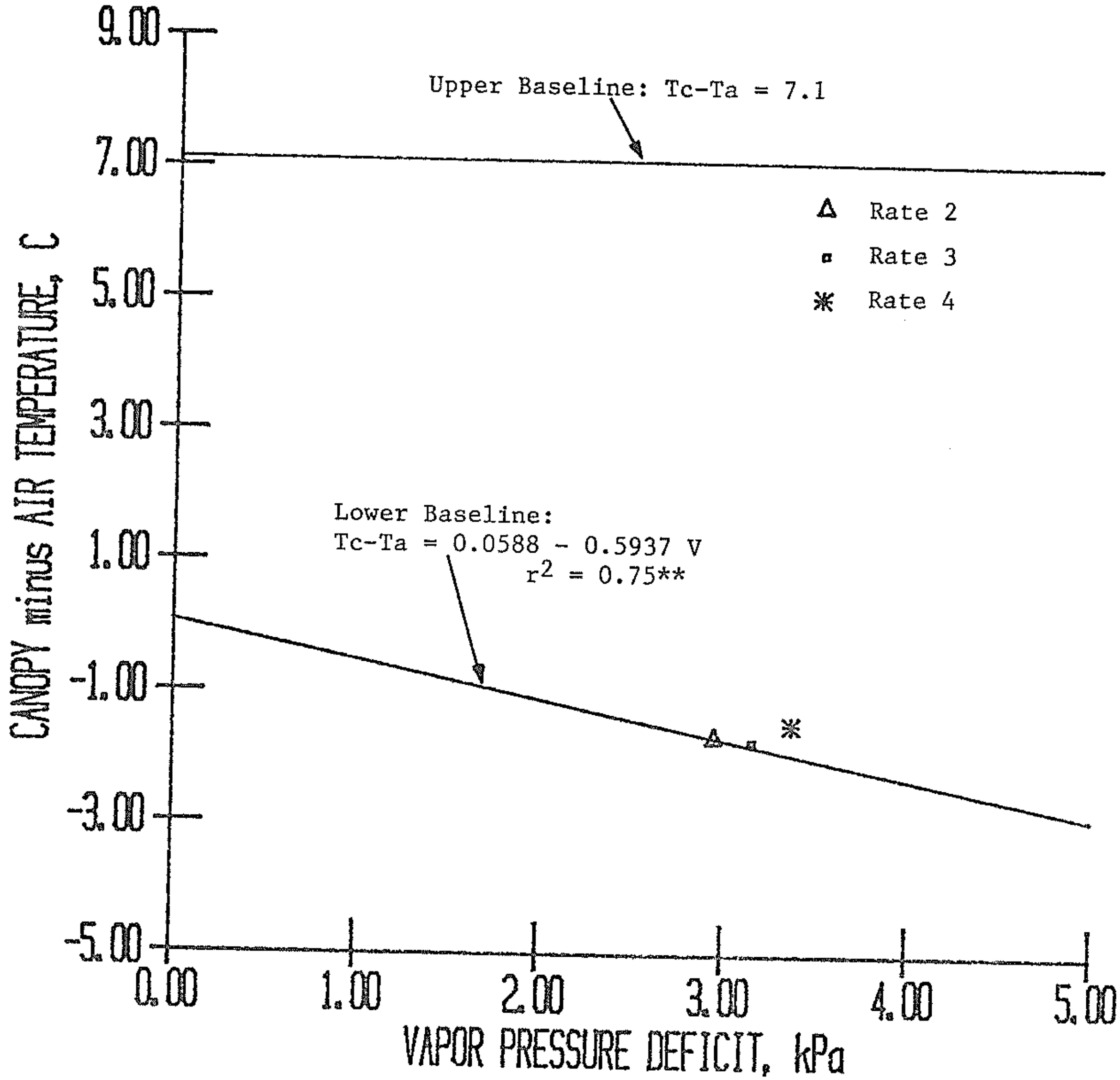


Fig 22. Relationship of vapor pressure deficit (V) and canopy minus air temperature (Tc-Ta) averaged over July and August for pecan trees irrigated under less than optimum rates, Las Cruces, New Mexico, 1984.

Identical data was taken in 1984 (table 22, figures 23 and 24). Rainfall that occurred during the summer months caused the crop water stress index to be near zero and was .006, 0.01 and 0.05 for irrigation rates 2, 3 and 4, respectively.

One, minus the crop water stress index (1-CWSI), is equal to the relative E_t. Evapotranspiration can be computed based on the amount of applied water per unit leaflet area, assuming deep drainage and change in soil moisture is negligible. Relative E_{tr}, equal to the E_t of the irrigation treatment divided by the E_t of irrigation treatment 1, was lower than that computed using infrared measurements (table 23).

Measurements of the CWSI were made on the pecan trees in the barrels during the dry down cycles to determine where the discrepancy was between (1-CWSI) and computed E_t based on the water balance (table 24). The crop water stress index resulted in a relative E_t calculation slightly larger than the measured value and the linear correlation between the measured and computed relative E_t has a coefficient determination of 0.78 (figure 25). Also the upper temperature of the sunlit leaflets on the dry down experiment was 7.3 degrees above air temperature, very close to the maximum temperature measured for the leaflet temperature minus air temperature at the Plant Science Center. Consequently, it appears that the infrared gun does a satisfactory job of computing relative E_t and that the water balance method can not be used to compute E_t on the trickle irrigated trees using the assumption that rainfall was equal to the amount of rain that fell within the drip line of the canopy. Apparently the root system of the drip irrigated trees must extend beyond the drip line. In addition, they are able to extract water from a larger area and are under less moisture stress than calculated by the simple water balance technique. Future research needs to be conducted to delineate the root zone

Table 22. Net radiation over canopy (R); air temperature (AIRT); leaflet temperature minus air temperature for pecan (DIFF); coefficient of variation of pecan leaflet temperature (CVT); vapor pressure deficit (VPD); and sample size of pecan leaflet temperature using an infrared thermometer taken from selected trees under stress conditions, 1984.

Date	R w/m2	AIRT C	N 1/	DIFF C	CVT	(KPa) VPD
		Trickle Irrigated Trees - Irrigation Treatment 2				
07/05	682.3	32.12	30	-1.32	0.04	3.35
07/16	662.8	34.55	30	-2.25	0.04	4.06
07/23	682.3	32.50	30	-3.45	0.04	2.93
07/27	506.8	30.14	30	-0.94	0.05	2.99
07/30	623.8	30.83	30	-1.08	0.06	3.07
08/01	604.3	31.55	30	-1.85	0.06	3.34
08/13	584.8	28.33	45	-0.93	0.04	1.70
08/17	604.3	28.89	30	-1.79	0.06	2.43
08/21	584.8	31.29	30	-1.19	0.04	2.70
		Trickle Irrigated Trees - Irrigation Treatment 3				
07/05	701.8	32.87	30	-0.87	0.04	3.50
07/16	662.8	34.77	30	-1.52	0.04	4.16
07/23	721.2	32.75	30	-2.65	0.03	3.08
07/27	506.8	31.11	30	-2.31	0.04	3.16
07/30	643.3	32.22	45	-1.82	0.05	3.47
08/01	604.3	32.15	30	-1.60	0.07	3.50
08/13	584.8	29.16	30	-0.86	0.08	1.94
08/17	604.3	29.45	45	-2.25	0.05	2.63
08/21	604.3	32.58	30	-1.68	0.06	3.00
		Trickle Irrigated Trees - Irrigation Treatment 4				
07/05	701.8	33.60	30	-1.30	0.05	3.64
07/16	682.3	35.00	30	-1.85	0.05	4.27
07/23	779.7	33.05	45	-2.45	0.08	3.23
07/27	545.8	31.66	45	-2.03	0.03	3.17
07/30	662.8	33.05	30	-0.55	0.04	3.83
08/01	623.8	32.77	30	-0.07	0.06	3.63
08/13	389.9	30.00	30	-2.35	0.04	2.25
08/17	623.8	30.00	30	-1.55	0.05	2.89
08/21	623.8	33.88	45	-1.18	0.05	3.38

1/ Sample Size

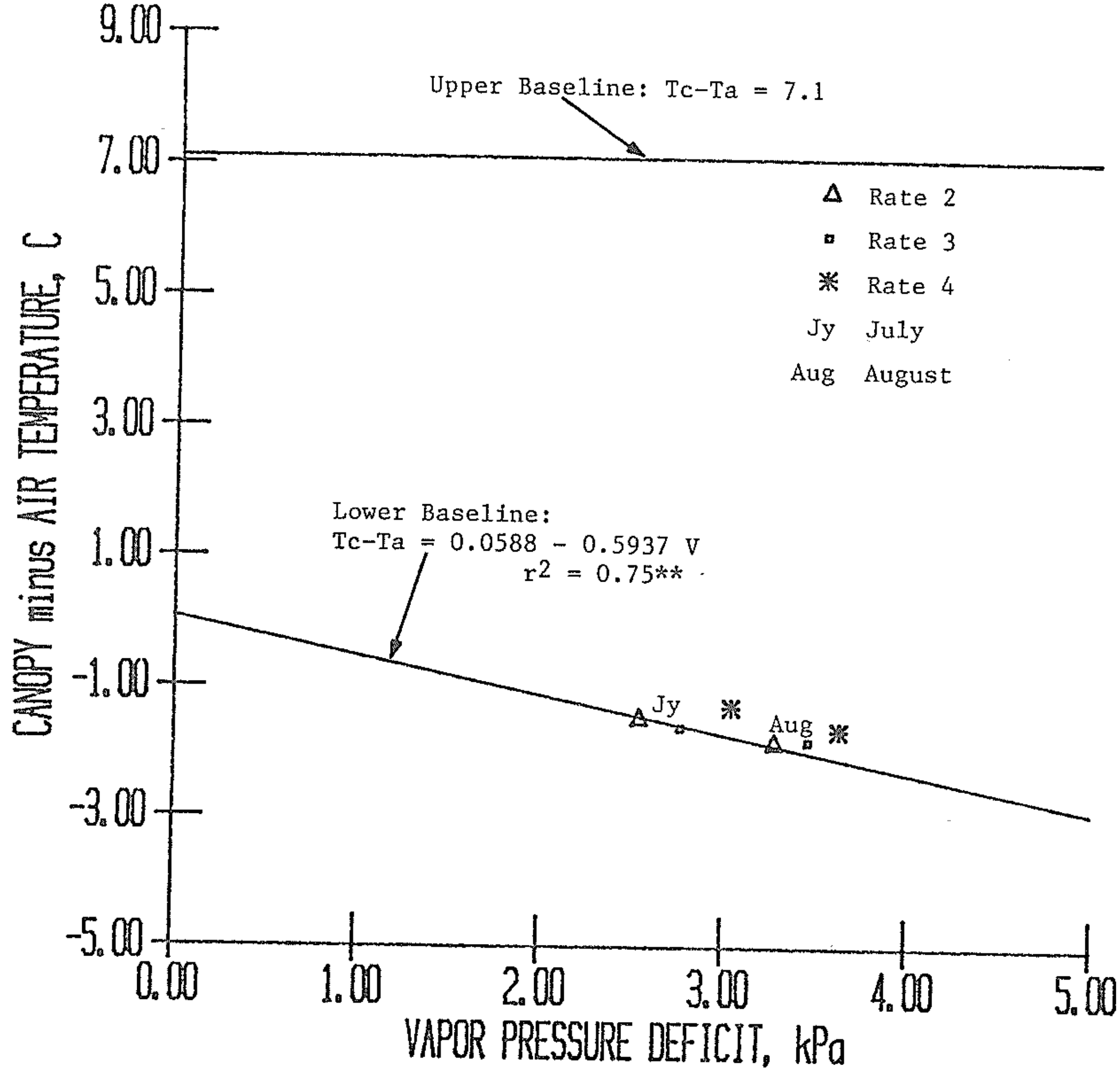


Fig 23. Relationship of vapor pressure deficit (V) and canopy minus air temperature (Tc-Ta) during July and August for pecan trees irrigated under less than optimum rates, Las Cruces, New Mexico, 1984.

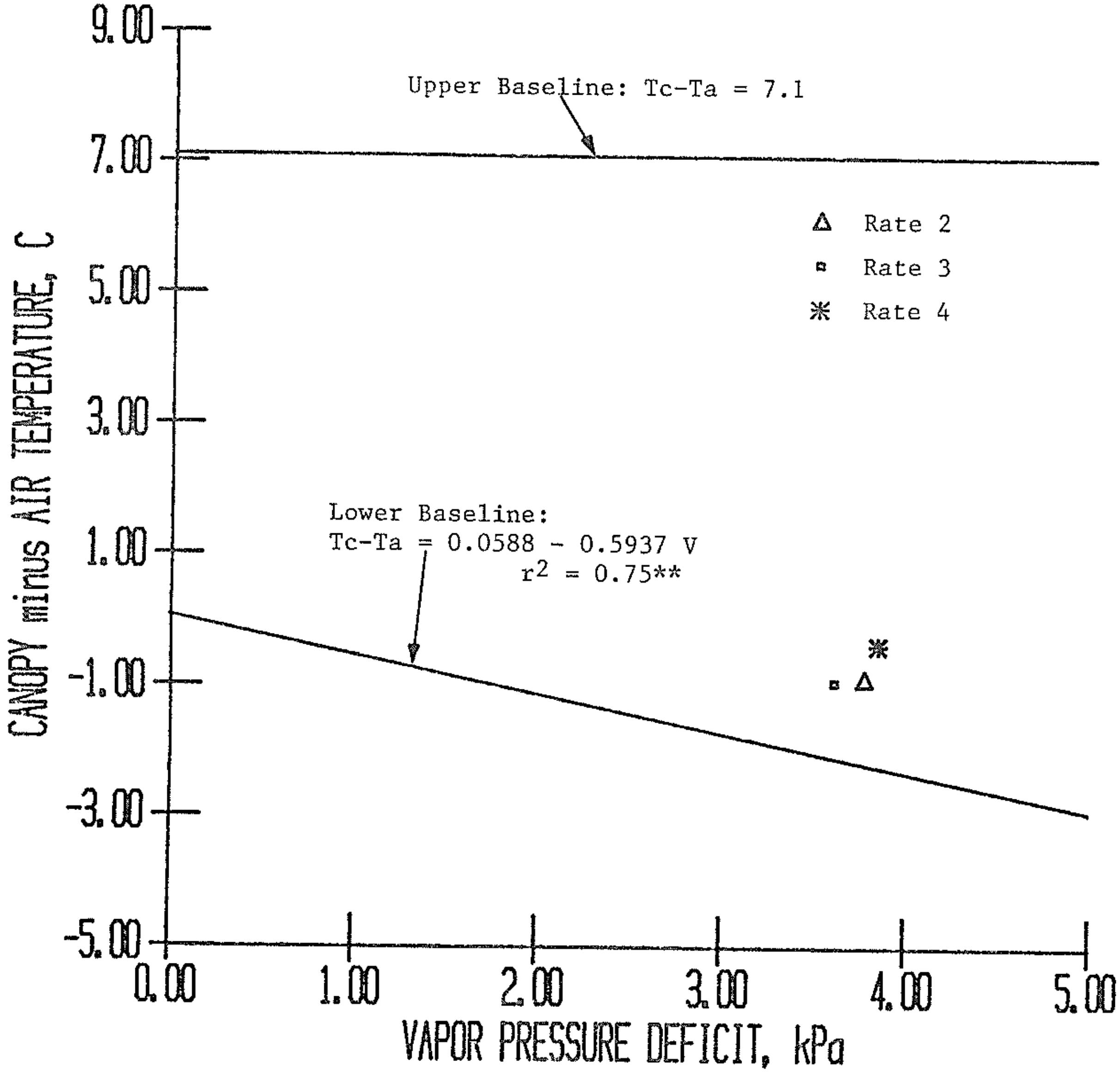


Fig 24. Relationship of vapor pressure deficit (V) and canopy minus air temperature (Tc-Ta) averaged over May, June and July for pecan trees irrigated under less than optimum rates, Las Cruces, New Mexico, 1983.,

Table 23. Comparison of relative evapotranspiration calculated from the water valance (E_{tr}) and the crop water stress index (CWSI) for trickle irrigated pecans at Las Cruces, New Mexico.

Date	Irrigation Level 1		2		3		4	
5/23–7/29	E_{tr}	1-CWSI	E_{tr}	1-CWSI	E_{tr}	1-CWSI	E_{tr}	1-CWSI
1983	1.0	1.0	0.66	0.86	0.62	0.87	0.39	0.80
7/05–8/21								
1984	1.0	1.0	0.89	1.0	0.50	0.99	0.34	0.95

Table 24. Leaf temperature minus air temperature (Diff), vapor pressure deficit (VPD), crop water stress index (CWSI), calculated (1-CWSI) and measured (ET/ET_{max}) ratio of actual to potential evapotranspiration for pecan trees growing in a vermiculite medium during three dry-down cycles.

Date	Diff	VPD	CWSI	I-CWSI	ET/ET_{max}
			Dry Down 1		
08/21	-1.27	3.27	0.07	0.93	1.02
08/22	-1.47	3.50	0.06	0.94	1.09
08/23	-1.83	1.52	-0.12	1.12	0.91
08/25	0.75	1.74	0.21	0.79	0.86
08/27	-0.7	3.18	0.13	0.87	0.68
08/28	2.05	3.46	0.45	0.55	0.51
			Dry Down 2		
08/30	-2.15	3.57	-0.01	1.01	0.87
08/31	-1.63	3.68	0.05	0.95	0.88
09/01	-1.53	3.63	0.06	0.94	1.03
09/02	-0.7	3.581	0.15	0.85	0.92
09/03	3.33	1.98	0.54	0.46	0.66
09/04	4.7	2.75	0.72	0.28	0.59
09/05	2.2	3.4	0.46	0.54	0.37
			Dry Down 3		
08/21	-1.95	3.19	-0.61	1.01	1.03
08/22	-3.45	3.5	-0.16	1.61	1.16
08/23	-0.05	1.47	0.1	0.9	0.99
08/25	0.8	1.78	0.22	0.78	0.83
08/27	1.85	1.78	0.35	0.65	0.95
08/28	0.7	3.08	0.28	0.72	0.65
08/29	2.7	3.4	0.51	0.49	0.36
08/30	2.4	3.55	0.49	0.51	0.32
08/31	3.25	3.76	0.58	0.42	0.15
09/01	7.3	3.52	1.02	-0.02	0.07
09/02	5.3	3.58	0.8	0.2	0.12

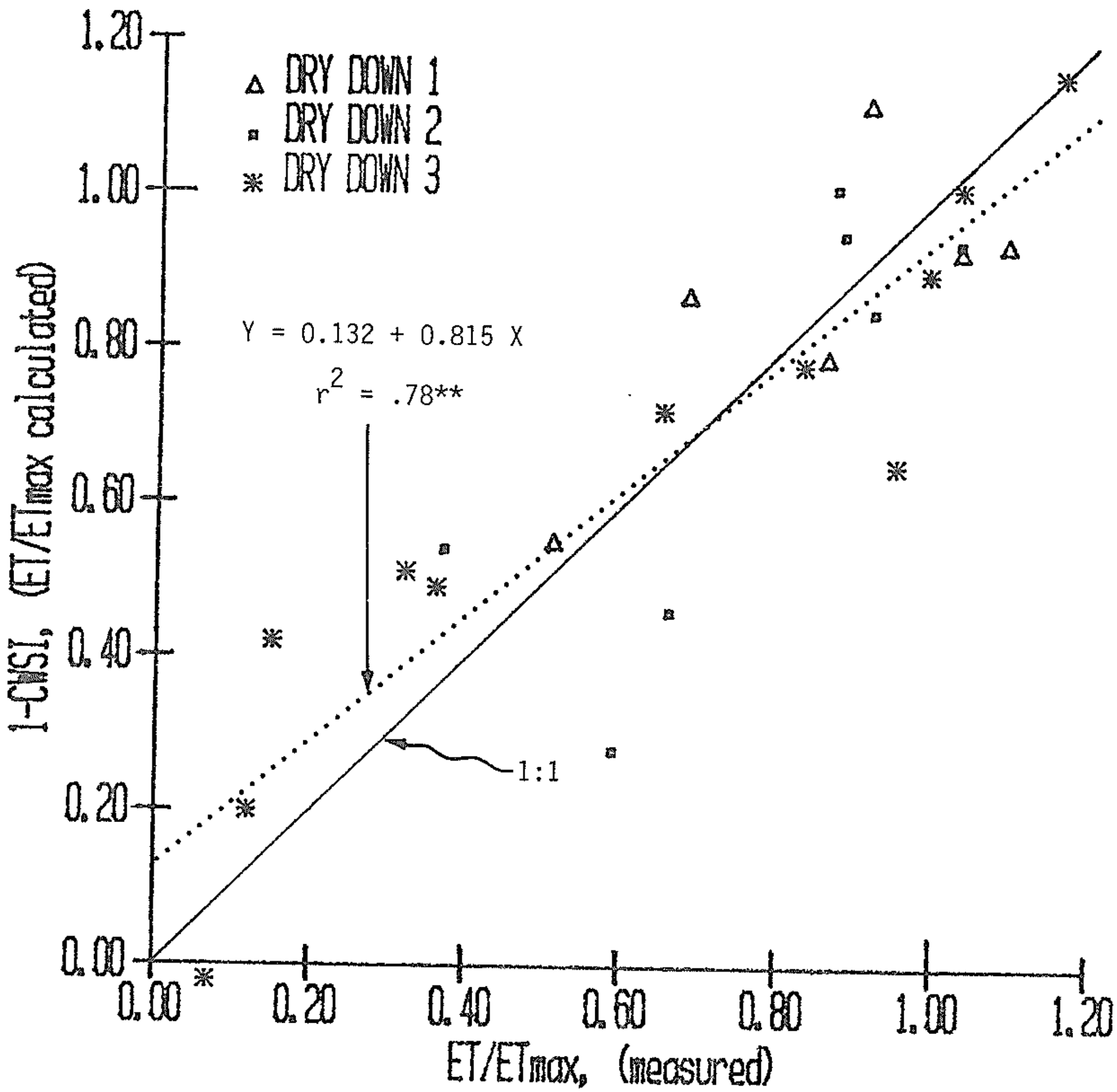


Fig. 25. The relationship between the calculated and measured ratio of actual (ET) to potential (ET_{max}) evapotranspiration for pecan trees in a vermiculite medium for 3 dry down cycles, Las Cruces, New Mexico, 1984.

of the pecan trees under drip irrigation with part of the area being supplied water by rainfall.

Canopy minus air temperature measurements were also made from early morning to late afternoon (table 25, figure 26) on irrigation treatment 1. Canopy minus air temperature measured early in the morning is below the baseline temperature. By 11:00 a.m. the data falls very close to the baseline data and remains there until after 1500 hours at which time the canopy minus air temperature again falls below the baseline. Consequently, baseline data can only be collected from 1000 until 1500 and measurements for determining the crop water stress index should be taken during mid-day from noon until 1400 hours.

Table 25. Net radiation over canopy (R); air temperature (AIRT); leaflet temperature minus air temperature for pecan (DIFF); coefficient of variation of pecan leaflet temperature (CVT); vapor pressure deficit (VPD) and sample size of pecan leaflet temperatures using an infrared thermometer (N) taken from sunrise to sunset on selected trees under non-stress conditions, 1984.

Time	Date	R w/m2	AIRT C	N	DIFF C	CVT	(KPa) VPD
0700	07/19	38.99	20.00	45	-0.07	0.04	0.49
0900		350.88	26.55	45	-0.75	0.07	1.56
1100		565.30	30.55	60	-2.20	0.04	3.68
1300		662.77	33.05	60	-2.63	0.04	3.68
1500		565.30	34.44	45	-2.97	0.04	4.25
1700		331.38	35.00	60	-4.27	0.04	4.44
1900		38.99	32.77	60	-4.64	0.03	4.02
0700	07/26	38.99	18.05	60	-0.75	0.03	0.46
0900		155.95	23.05	60	-0.97	0.03	1.13
1100		350.88	25.00	60	-0.57	0.03	1.49
1300		448.34	27.22	60	-1.76	0.03	1.69
1500		233.92	27.22	60	-2.17	0.02	2.13
1700		233.92	28.61	30	-2.06	0.06	2.39
1900		19.49	26.11	45	-1.41	0.02	1.79
0700	08/02	38.99	20.55	45	-2.68	0.03	0.51
0900		136.45	23.33	60	-1.43	0.08	0.72
1100		565.30	29.16	60	-1.41	0.08	2.02
1300		662.77	31.11	60	-1.78	0.06	2.80
1500		584.80	32.77	45	-1.47	0.05	3.48
1700		331.38	32.77	45	-3.77	0.03	2.80
1900		19.49	30.83	60	-3.25	0.03	2.80

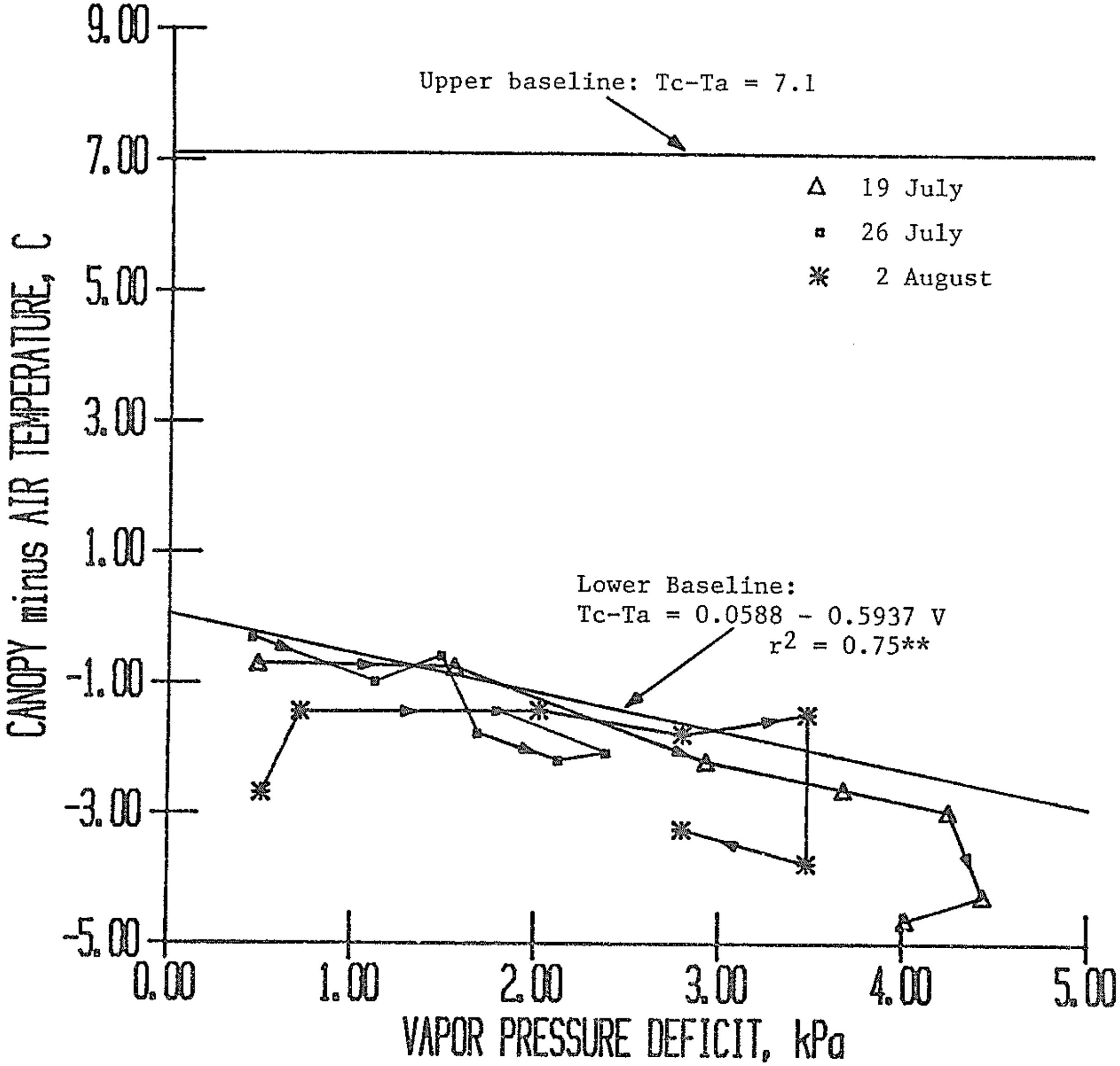


Fig. 26. Relationship between vapor pressure deficit (V) and canopy minus air temperature (Tc-Ta) from sunrise until sunset on three days for pecan trees irrigated under optimum rates at Las Cruces, New Mexico, 1984. (Arrows indicate direction of time change.)

SUMMARY

This report presents data on irrigation scheduling through the use of a computer model and verification of the irrigation scheduling procedure through the use of infrared temperature measurements of pecan leaflet temperatures. The report also presents data on leaflet diffusion resistance measurements, total leaf area measurements, and the relationship between relative evapotranspiration and available water. The irrigation scheduling model does a satisfactory job of predicting when to irrigate pecan trees; and given an irrigation scheduling practice, the model will satisfactorily predict the resulting yield. Future work will include measurement of leaf diffusion resistance and evapotranspiration simultaneously using Bowen ratio equipment. These measurements will allow the calculation of the aerodynamic resistance needed in Montieth's equation which can be used to directly compute transpiration instead of computing transpiration based on a crop curve, E_o and a moisture stress function, which is the method currently used in the model.

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APPENDIX A

Table A-1. WORK-UP SHEET FOR THE INPUT FILE

(FOR VERSION IRR104) DATE - 12/4/84

1) TITLE <A80> ____

2) NUMBER OF YEARS FOR MODEL TO RUN <I3> ________

2b) IRRIGATION UNIT 0 INCHES 1 CM <I1> ________

2c) NUMBER OF IRRIGATION ITERATIONS <I2> ________

2d) CONTROLLED BY ECONOMIC MODEL (0 NO) OR (1 YES) ________

3a) ELEVATION OF THE SITE (METERS) <F10.2> ________

3b) CROP PERINEAL (0 NO) OR (1 YES) <I1> ________

3c) PRINT OUT DAILY OUTPUT (0 NO) OR (1 YES) <I1> ________

3d) PRINT PUT DAILY WEATHER (0 NO) OR (1 YES) ________

4a) BASE TEMPERATURE IN CELCLUIS <F10.2> ______________

4b) MAXIMUM CUTOFF TEMPERATURE <F10.2> ______________

4c) MINIMUM CUTOFF TEMPERATURE <F10.2> ______________

5a) FIELD NUMBER -----------------<I4> ______________

5b) NAME OF CROP ----------------- <A8> ______________

5c) CROP ID -------------------- <I2> ______________

5d) ROOT COEFFICIENT ------------ <F6.2> ______________

5e) MAXIMUM ROOT DEPTH ---(INCHES) <F6.0> ______________

5f) LENGTH OF EACH DEPTH (INCHES) <I2> ______________

5g) MIN ROOT DEPTH INCHES ________<F6.0> ______________

5h) NUMBFR OF TRESS PER AC ________<F6.0> ______________

6) SOIL TYPE FOR EACH DEPTH

SANDY SOIL ---- <1>
SANDY LOAM SOIL <2>
LOAM SOIL ----- <3>
CLAY SOIL ----- <4>
SILTY CLAY SOIL <5>
CLAY SOIL ----- <6>

SOIL TYPE FOR EACH DEPTH <I2> 1) ____________
SOIL TYPE FOR EACH DEPTH <I2> 2) ____________
SOIL TYPE FOR EACH DEPTH <I2> 3) ____________
SOIL TYPE FOR EACH DEPTH <I2> 4) ____________
SOIL TYPE FOR EACH DEPTH <I2> 5) ____________
SOIL TYPE FOR EACH DEPTH <I2> 6) ____________
SOIL TYPE FOR EACH DEPTH <I2> 7) ____________
SOIL TYPE FOR EACH DEPTH <I2> 8) ____________
SOIL TYPE FOR EACH DEPTH <I2> 9) ____________
SOIL TYPE FOR EACH DEPTH <I2> 10) ____________
SOIL TYPE FOR EACH DEPTH <I2> 11) ____________
SOIL TYPE FOR EACH DEPTH <I2> 12) ____________
SOIL TYPE FOR EACH DEPTH <I2> 13) ____________
SOIL TYPE FOR EACH DEPTH <I2> 14) ____________
SOIL TYPE FOR EACH DEPTH <I2> 15) ____________

7a) MAXIMUM LEAF AREA ------------ <F10.2> ____________

7b) FINAL STRESS TRANSPIRATION --- <F10.2> ____________

7c) TRANSPIRATION AT MAXIMUM AKC <F10.2> ____________

8a) COEFF. A (INTERCEPT) REDUCE TRANSPIRATION <F10.8>

____

8b) COEFF. B (SLOPE) REDUCE TRANSPIRATION <F10.8>

____

8c) COEFF. A (SLOPE) CONVERT CHRISTRIAN TO STASTICAL <F10.8>

____

8d) COEFF. B (INTERCEPT) CONVERT CHRISTRIAN TO STASTICAL <F10.8>

____

8e) SALT COEFF. A (INTERCEPT) REDUCE TRANSPIRATION <F10.8>

____

8f) SALT COEFF. B (SLOPE) REDUCE TRANSPIRATION <F10.8>

____

9a) PLANTING DATE (MMDDYY) <I6> ____________

9b) EMERG DATE (MMDDYY) <I6> ____________

9c) HARVEST DATE (MMDDYY) <I6> ____________

10a) PROJECT YIELD <F10.2> ____________

10b) MAXIMUM YIELD <F10.2> ____________

10c) COEF A (SLOPE) WATER PRODUCTION <F10.2> ____________

10d COEF B (INTERCEPT) WATER PRODUCTION <F10.2>
____

11A) GROWING DEGREE TEST <F10.2> ____________

11b) COEF CROP POLONOMIAL 1 ____________
COEF CROP POLONOMIAL 1 ____________
3 ____________
4 ____________
SECOND POLONOMIAL 5 ____________
6 ____________
7 ____________
8 ____________

12) APPLICATION DISTRIBUTION 7(1X, F6.2) ____________
$\pm$ x *STANDARD DEVIATION FOR
DIFFERENT LOCATIONS IN FIELD

13. WEIGHING COEFFICIENT FOR DISTRIBUTION 7(1x, F6.2) ____________
LINEAR = FLOOD
NORMAL = SPRINKLER DRIP

14) INITIAL SOIL MOISTURE CONTENT <F4.2>

DEPTH 1) ______
2) ______
3) ______
4) ______
5) ______
6) ______
7) ______
8) ______
9) ______
10) ______
11) ______
12) ______
13) ______
14) ______
15) ______
16) ______
17) ______
18) ______
19) ______
20) ______
21) ______

15a) RATION AT WHICH IRRIGATION WILL BE FORCED (%) <F3.0>
______

15b) MEAN AMOUNT OF IRRIGATION (INCHES) <F4.2> ______

15c) ION TURN ON DUTTUS MODEL (0 NO) OR (1 YES) <I1> ______

15d) CHRISTRIANS UNIFORMITY (%) <10.2> ______

15e) STANDARD DEVIATION <F10.2> ______

15f) RANDOM NUMBER GENERATOR (GT.10000) <I6> ______

15G) STRTIO RELATIVE ET % LEVEL TO IRRIGATION <F3.0> ______

16) INITIAL SOIL EXTRACT FOR EVERY DEPTH <F6.2>

COLUMN	DESCRIPTION
1	ELECTRICAL CONDUCTIVITY OF SOIL
2	CALCIUM CONC (PPM) ON INPUT MEQ/LITER
3	MAGNESIUM
4	SODIUM
5	SULFATE
6	CHLORIDE
7	BICARBONATE
8	CARBONATE
9	CALCAREOUS SOIL (1.0 YES) OR (0.0 NO)
10	CATION EXCHANGE CAPACITY (MEQ/100 GRAM)
11	GYPSUM (MEQ/100 GRAM)
12	EXTRACT SATURATION MOISTURE

1	2	3	4	5	6	7	8	9	10	11	12	13
1.												
2.												
3.												
4.												
5.												
6.												
7.												
8.												
9.												
10.												
11.												
12.												
13.												
14.												
15.												
16.												
17.												
18.												
19.												
20.												
21.												

17) SINITY OF THE WATER (WELL #1) <F10.2> ____________
SINITY OF THE WATER (WELL #2) <F10.2> ____________
SINITY OF THE WATER (WELL #3) <F10.2> ____________
SINITY OF THE WATER (WELL #4) <F10.2> ____________
SINITY OF THE WATER (WELL #5) <F10.2> ____________
SINITY OF THE WATER (WELL #6) <F10.2> ____________
SINITY OF THE WATER (WELL #7) <F10.2> ____________
SINITY OF THE RAINFALL <F10.2> ____________

18) DIAMETER OF THE TREE (INCHES) <F5.2> ____________

19) IRRIGATION FILE INPUT

WELL NO. REPETITION WELL NO. REPETITION <F4.0 I4 F4.0 I4>

20) NUMBER OF IRRIGATIONS --- <I3> ____________

1- IRRIGATION DATE <I6> ____________
AMOUNT OF IRRIGATION <F4.2> ____________
WHICH WELL WILL IRRIGATE <I2> ____________

2-IRRIGATION DATE <I6> ____________
AMOUNT OF IRRIGATION <F4.2> ____________
WHICH WELL WILL IRRIGATE <I2> ____________

3-IRRIGATION DATE <I6> ____________
AMOUNT OF IRRIGATION <F4.2> ____________
WHICH WELL WILL IRRIGATE <I2> ____________

4-IRRIGATION DATE ____________
AMOUNT OF IRRIGATION ____________
WHICH WELL WILL IRRIGATE ____________

5-IRRIGATION DATE ____________
AMOUNT OF IRRIGATION ____________
WHICH WELL WILL IRRIGATE ____________

6- IRRIGATION DATE <I6> ____________
AMOUNT OF IRRIGATION <F4.2> ____________
WHICH WELL WILL IRRIGATE <I2> ____________

7-IRRIGATION DATE <I6> ____________
AMOUNT OF IRRIGATION <F4.2> ____________
WHICH WELL WILL IRRIGATE <I2> ____________

8-IRRIGATION DATE <I6> ______
AMOUNT OF IRRIGATION <F4.2> ______
WHICH WELL WILL IRRIGATE <I2> ______

9-IRRIGATION DATE ______
AMOUNT OF IRRIGATION ______
WHICH WELL WILL IRRIGATE ______

10-IRRIGATION DATE ______
AMOUNT OF IRRIGATION ______
WHICH WELL WILL IRRIGATE ______

11- IRRIGATION DATE <I6> ______
AMOUNT OF IRRIGATION <F4.2> ______
WHICH WELL WILL IRRIGATE <I2> ______

12-IRRIGATION DATE <I6> ______
AMOUNT OF IRRIGATION <F4.2> ______
WHICH WELL WILL IRRIGATE <I2> ______

13-IRRIGATION DATE <I6> ______
AMOUNT OF IRRIGATION <F4.2> ______
WHICH WELL WILL IRRIGATE <I2> ______

14-IRRIGATION DATE ______
AMOUNT OF IRRIGATION ______
WHICH WELL WILL IRRIGATE ______

15-IRRIGATION DATE ______
AMOUNT OF IRRIGATION ______
WHICH WELL WILL IRRIGATE ______

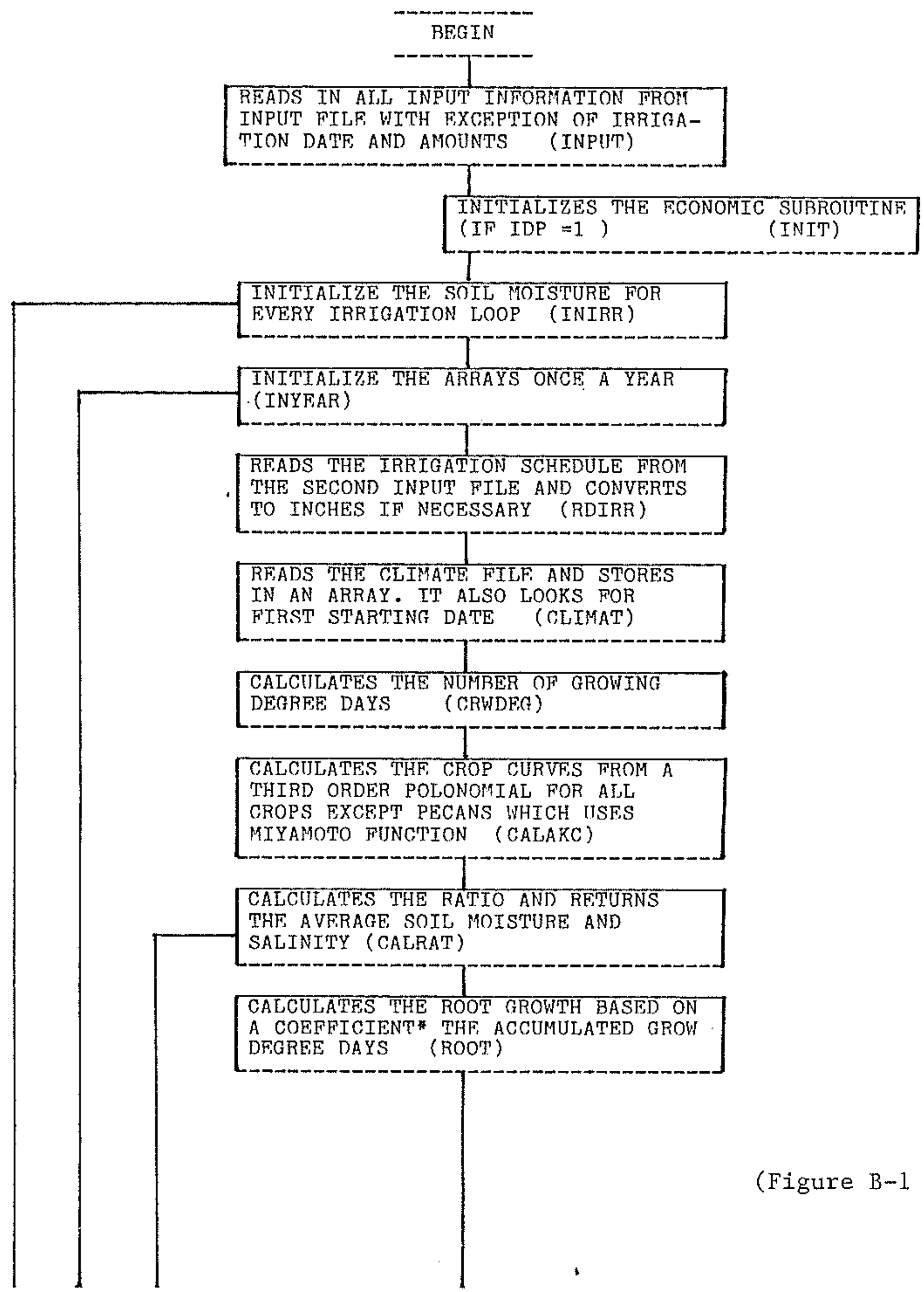
16- IRRIGATION DATE <I6> ______
AMOUNT OF IRRIGATION <F4.2> ______
WHICH WELL WILL IRRIGATE <I2> ______

17-IRRIGATION DATE <I6> ______
AMOUNT OF IRRIGATION <F4.2> ______
WHICH WELL WILL IRRIGATE <I2> ______

18-IRRIGATION DATE <I6> ______
AMOUNT OF IRRIGATION <F4.2> ______
WHICH WELL WILL IRRIGATE <I2> ______

19-IRRIGATION DATE ______
AMOUNT OF IRRIGATION ______
WHICH WELL WILL IRRIGATE ______

APPENDIX B



(Figure B-1 continued on next page.

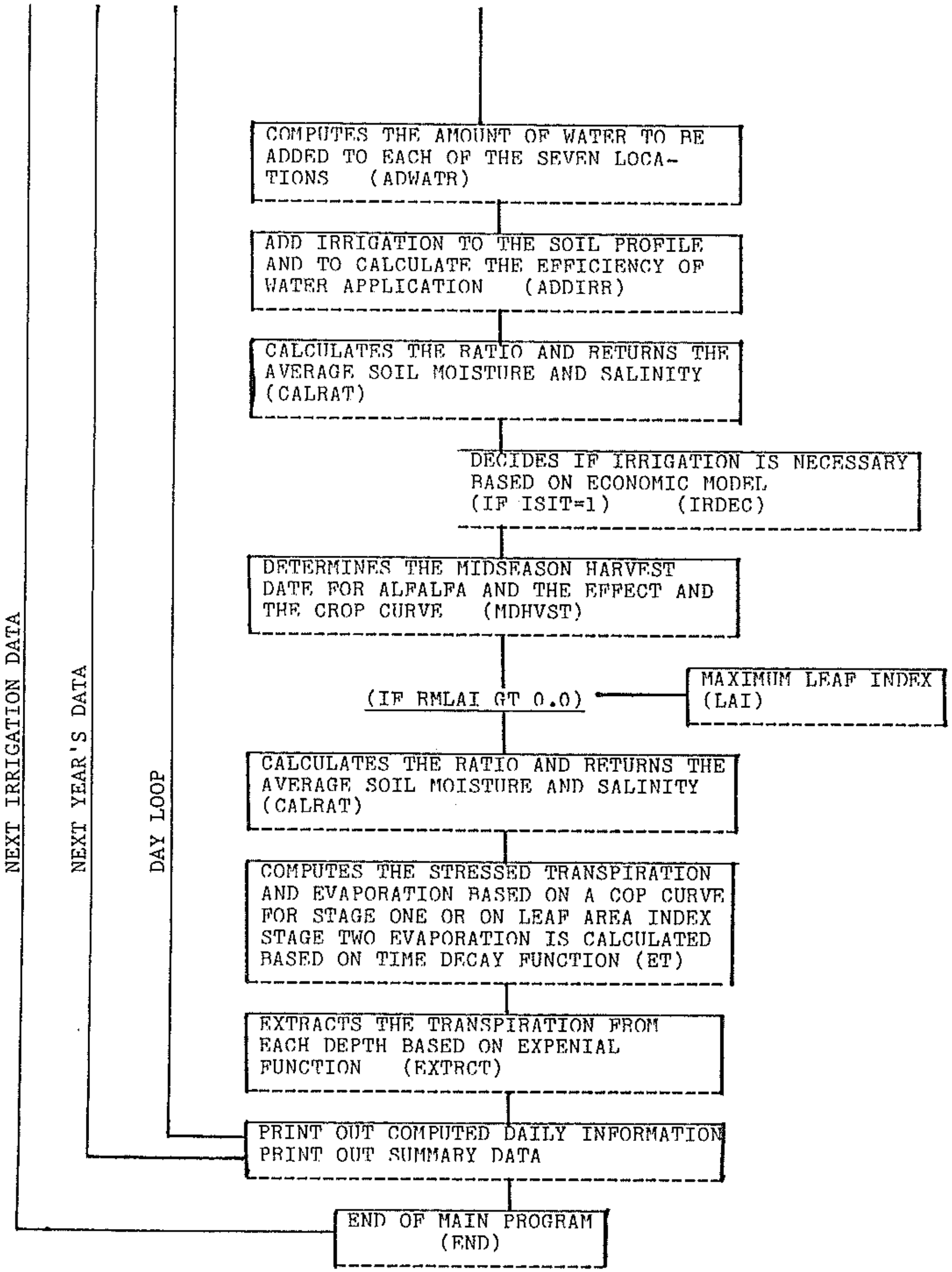


Figure B-1. Flow Chart of Irrigation Scheduling Model

LIST OF SUBROUTINE

FIGURE B-2

INPUT - This subroutine enters the data for the program. This data includes soil crop and irrigation parameters

OPENN - This subroutine opens and closes the files for the IBM-PC.

CALRAT - This subroutine calculates ratio and returns the average soil moisture and salinity.

INIRR - This subroutine initializes the soil moisture array every irrigation loop.

INYEAR - This subroutine initializes the arrays once a year.

RDIRR - This subroutine reads the irrigation schedule, converts the irrigation to inches if necessary.

SOIL - This subroutine determines the field capacity and permanent wilting point for the soil type.

1. sandy loam soil
2. loam soil
3. clay loam soil
4. silty clay soil
5. clay soil

JULIAN - This subroutine converts month, day, year to a Julian date.

FUNCTION POTEN - This function computes potential evaporation based on Penman's equation.

CLIMATE - This subroutine reads the climate file and stores it in a climate array. It also looks for the starting date which becomes the first position in the array.

GRWDEG - This subroutine is to calculate the growing-degree-days based on the following function:

GDD = (max temp - min temp)/2 - base temp

CALAKC - This subroutine calculates the crop curve based on growing-degree-days and a third order polonomial for all crops except pecans which use functions developed by Miyamoto (1983).

ROOT - This subroutine calculates the root growth based on a coefficient times the accumulated growing-degree-days.

SALBAL - This subroutine calculates the salt inflow and outflow and change in salt in each salt to make sure the salt balance is zero.

STOREW - This subroutine stores the salt in each soil layer.

ADWATR - This subroutine adds irrigation to the soil profile and calculates the efficiency of water application.

URAND FUNCTION - This function computes and random variant that is used in zedv.

ZDEV - This subroutine produces a standard normal deviate.

ADDWATER - This subroutine computes the amount of irrigation water added to each of seven locations on the field.

EXTRCT - This subroutine extracts the transpiration from each depth based on an expenial function. Evaporation is subtracted from the first 12 inches of the soil profile. If the top 12 inches is at permanent wilting point then evaporation is decreased to zero. The effect of extraction of salt concentration is calculated in this subroutine.

IRDEC - This subroutine decides if an irrigation is necessary based on an economic model.

MDHVST - This subroutine determines the midseason harvest dates for alfalfa and the effect and the crop curve.

ET - This subroutine computes the stressed transpiration and the evaporation based on a crop curve for stage one or on leaf area index model by Sammis (1984). Stage two evaporation is calculated based on a time decay function since switching to stage two. This switch occurs when the plant available water in the top foot falls below 0.80.

LAI - maximum leaf area index.

IRR1 - This subroutine is the apl matrix used by the economic irrigation decision model.

INIT - This subroutine initialized the economic subroutine.

COVERT - This subroutine converts salts from ppm to meq/liter.

EQEX - This subroutine computes the amount of ion in the exchange complex based on initial soil analysis and initial soil moisture for each soil depth.

IONEX - This subroutine calculates the chemical equalibrium of the salt according to Dutts model.

COMMNT - This subroutine contains the parameters needed in the input file to run the model for each crop.