DISPOSITION OF WATER FROM FRUIT CROPS AND APPROACHES TO INCREASE WATER USE EFFICIENCY

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SUMMARY

There were two major objectives for this three-year study. The first dealt with an evaluation of water loss and needs for fruit crops. The second objective of equal importance was the effort to find and evaluate ways of improving water use efficiency. Because a number of individuals were working on this project over the three-year period, each section of the research was written as it was accomplished. Thus, this report includes a number of detailed studies which taken together document the work toward the two major objectives.

A major field study on the water balance in a peach orchard was conducted for an entire year. These results are discussed in Chapter 2. Much detail is given on the methods used and data from this study.

A theoretical water balance study is discussed in Chapter 3. Here two approaches for obtaining water balance and water needs for Florida citrus are discussed. The first (3.1) is the result of a combined effort of inputs by a number of staff members within the Institute of Food and Agricultural Sciences and includes the analysis of water needs of citrus throughout the State (the version of the report published here is not necessarily agreed upon by all of the staff having an input). The second analysis (3.2) uses daily climatic records for rainfall and average air temperature for calculating a water balance assuming different soil water-holding capacities. From this data one can simulate the number of irrigations which would have to occur with recommended practices. Both 3.1 and 3.2 give those managing water, concepts and numbers to work with relative to irrigation needs.

Chapter 4 reports on studies of methods for improving water use efficiency. Section 4.1 attempts to quantitize the possible advantage of using different rootstocks that have varying abilities for taking up water from the soil. If rootstocks could be found that were better able to extract water from the soil and maintain the scion (top of the tree) in a better water status, then less frequent irrigations might be required for the same yield. In 4.2 the thesis of Paul Ryan is given in detail. The supposition here was that under high atmospheric demand in Florida and with the poor water-holding capacities of Florida soil, we should look at different ways of using irrigation water available. In this study rather than put the water on the soil, the same amount was used to intermittently sprinkle trees during the peak stress periods of the day. This fairly new and innovative approach toward improving water use efficiency was studied in great detail. Another approach is given in 4.3 where drip irrigation was used to just replace the water required by the tree on a daily basis. Results from this three-year study are presented which include growth, water use and yield.

1. INTRODUCTION

Management of our water resources is of vital importance. However, this can only be accomplished when models for the complete water cycle of large areas are obtained. A key factor in this model is the interception and disposition of water at the earth's surface. In Florida, as in many areas, a large share of the surface is occupied by crops; thus, the disposition of water from crop surfaces must be well understood to utilize efficiently the limited water resources available.

According to Baragona, in the past five years irrigated acreage in Florida has increased 2 1/2 times (2). He predicts that if there is to be sufficient water for agriculture by the year 2000, methods of conservation must be illuminated since its use is expected to quadruple by that time. In a recent study by the Institute of Food and Agricultural Sciences entitled "Agricultural Growth in an Urban Age" (AGUA), an attempt was made to evaluate the direction of agricultural growth during the next decade. In summary, relative to land and water use, it was projected that land use for agriculture would not expand during the next decade. However, increased agricultural productivity would be the result of a more technologically intensive agriculture. This increasingly intense type of agriculture for higher productivity requires additional water inputs. The following is a quote from the AGUA report. "Part of the trend toward more intensive agriculture will be a sharp increase in irrigation. With increasing costs, farmers cannot afford to let periods of drought inhibit production. Currently, we are irrigating about 1,900,000 acres; by 1985, we will be irrigating close to 2,500,000 acres." This increase in demand for irrigation water by nearly a fourth during one decade could place tremendous strains on the water supply available. This will particularly be true in certain areas of the state where there is already a high demand for the available water (3).

Water use is frequently divided into three categories by users, users being industry, agriculture and urban. In Florida, industry and agriculture are the largest users of water (4). Water use by industry is relatively simple to measure because of the concentrated use. Water use in agriculture is much more complex since it is spread over a large geographic area and is used intermittently on many crops. A recent inventory (1), lists a total of approximately 640,000 irrigated acres of orchards, vineyards and brush fruit. This one category represents 1/2 of the total irrigated acreage reported.

A major citrus area in Florida is located on the Ridge area which is also the main recharge area for the Floridan Aquifer. Most of the artesian water in central and southern Florida is derived from this area centered around Polk County (4). Polk County alone has 190,000 acres of crop land of which 155,000 acres is in fruit crops (1). Of this fruit acreage, 140,000 is irrigated. Thus, fruit crops (mainly citrus) play a key role in both water use and recharge of the Floridan Aquifer which is of major importance to 75 percent of Florida.

Citrus irrigation research, conducted in Florida largely by Koo, has shown that irrigation in citrus increased yield and profits (8). However, little work has been done which dealt with the final disposition of the water added by supplemental irrigation to orchards (7). It could be anticipated with the low water holding capacity (2.3 inches in the top 5 feet for Lakewood fine sand, and 2.1 inches in the top 5 feet of Lakeland fine sand) and fast infiltration that much of the supplemental water added to Florida citrus might end up as deep percolation rather than contributing significantly to increase evapotranspiration. Unfortunately, this premise has not been evaluated. The premise cannot be evaluated using potential ET equations or evaporation pan data since citrus transpires below potential as shown by van Bavel in California (9). Gerber (5) has shown the ratio of actual ET to potential ET for citrus grown in Florida to be 0.72. However, considerable variability in the ratio of actual to potential ET occurred; therefore, further study is required before the ratio is widely used.

It becomes obvious that for water management models of large areas to be valid, information relative to ET, infiltration and water storage below fruit crops must be known. In addition, the disposition of water added by supplemental irrigation must be evaluated.

An additional area of importance is knowing when and how to irrigate. Irrigation timing can probably be scheduled best by relating irrigation requirements to plant water stress rather than soil moisture conditions. Thus, the interaction of plant water stress on fruit growth and yield should be investigated so better timing of supplemental irrigation can be achieved. In addition, irrigation methods other than those presently used are needed. One is drip irrigation which is a water conserving method of irrigation in various areas of the world (6). However, little research has been done on fruit crops in Florida with drip irrigation or other new methods.

Unfortunately, few new methods are acceptable without evaluation and modification needed for different climatic and soil conditions. Work with new irrigation techniques should be evaluated, since less water may be required for the same production.

1.1 Nature and Scope of This Report

This research project evaluated the disposition of water added to fruit crops through rainfall or supplemental irrigation. This water was partitioned into percolation, horizontal loss, storage and evapotranspiration. The components were evaluated by the water-budget technique. This study incorporated as part of its second and third objectives the evaluation of how water can be utilized more efficiently by the state's million acre fruit crop industry. Because of the scope of this project, three years were required for its completion.

With Florida's ever-increasing water use in urban, recreational, industrial and agricultural areas, it is imperative to understand the complete water cycle. The water cycle must be completely understood so that a model can be developed to account for all water movement. The results of this research can be readily incorporated into a complete model for the water cycle of large areas.

Because of the basic nature of this project, some of the mathematical models and instrumentation for measuring evapotranspiration could be used to determine ET from other crops, forests and the Everglades.

1.2 Objectives

Because of the magnitude and breadth of this project, this report will be divided into three major sections. First is a study of actual evaporation from a nine-acre peach orchard and some of the associated specialized studies that were required to better understand water movement in that system. The second area involves water needs in the citrus industry. This is largely an undertaking that makes use of existing knowledge and climatic data and applying it directly to acquiring information on the water that would be required for citrus irrigation and the disposition of water from citrus groves. The third area involves water use efficiency studies. This involves three studies: (A) was to assess root stalks with the same scion for their ability to take up soil water and minimize plant water stress in the top of the tree; (B) was to consider in detail how the plants respond to modified moistures regimes in the soil and by intermittently sprinkling water on the plant; (C) was an experiment with drip irrigation in an attempt to just apply the water needed daily by the plant.

Due to the number of individuals involved in this study, appropriate authorship is given for each section.

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2. WATER BALANCE IN A PEACH ORCHARD

2.1 Measurements of Evapotranspiration in a Mature Orchard

Tan Phung and J. Bartholic

Evapotranspiration (ET) is defined as the sum of water lost by the combined processes of evaporation and transpiration from a particular area in a specified time (4). It cannot be measured directly in large areas, and must be estimated as a residual in the water-balance equations, or through evaporation equations that are derived from basic energy balance and turbulent transfer principles (2).

Values of ET vary with local climate, soil conditions and vegetation. Evapotranspiration varies seasonally depending on changes in radiation, soil and air temperatures, humidity, vegetative cover, precipitation and other antecedent conditions that affect soil moisture.

An estimation or prediction of the quantity and rate of ET from vegetated land surfaces is important in designing irrigation projects and systems, and in determining when to irrigate and the proper quantity of water to apply. Other practical applications include prediction of water supply, estimation of drought incidence, forecasting of crop yields, and estimation of soil moisture conditions connected with military operations (3).

The purposes of this study were to measure actual ET by the water-balance method, and to compare results with those obtained from pan evaporation. With sufficient data, it is hoped to increase water-use efficiency of the peaches and other fruit crops.

2.1.1 Materials and Methods

The experimental site was a nine-acre orchard of peaches and nectarines at the Horticultural Unit, north of Gainesville. The soil was predominantly Arredondo loamy fine sand, a member of the loamy, siliceous, hyperthermic family of Grossarenic Paleudalf (see Identification of the Soil in Peach Orchard, sec. 2.2). Six drain lines, 830 feet long and 80 feet spaced, were installed five years ago from north to south at an average depth of four feet. Charts from recorders indicated depths of water table were usually below the drain lines except after heavy rainfall.

Soil moisture in the orchard was determined twice weekly at six-inch intervals to a depth of 36 inches from 12 locations with a neutron probe (see Measurement of Soil Moisture with a Neutron Probe). Rainfall was recorded by the Weather Station and outflow readings from 6 drain lines were measured manually every six hours when the flow velocities were high, and daily when there was only slow flow.[1]

Pan evaporation was measured daily from a standard-size pan at the Weather Station. Instrumentation and techniques for measuring parameters in the energy-balance methods are given elsewhere (1).

2.1.2 Calculations for ET by the Water-Balance Method

The water-balance method estimates the quantities of water involved in each component of inflow and outflow parameters for a given period. Each component taken into consideration in the water balance is given in the equation below:

$$P + I - D - R - ET = \Delta S \qquad [1]$$

where
P = precipitation, cm
I = irrigation, cm
D = deep percolation, cm
R = runoff, cm
ET = evapotranspiration, cm
ΔS = change in soil moisture, cm.

Rearranging Equation [1], we have

$$ET = P + I - D - R - \Delta S. \qquad [2]$$

Since the orchard has a slope of 1% (north) to 1.7% (south), R is assumed to be negligible, and Equation [2] is further simplified to:

$$ET = P + I - D - \Delta S. \qquad [3]$$

Due to the presence of a highly impermeable layer at five feet and below, the system is assumed to be a closed one with

[1]Automatic recording of outflow velocities with computer print-outs had been installed and preliminary data suggest that some modifications of instrumentation are necessary for precise measurements.

insignificant quantity of water lost into the groundwater. Thus, D is presumably equal to the sum of outflow from the six underground tiles.

In calculating soil moisture at a given time, readings for the top six inches were discarded owing to the escape of neutrons from the soil surface. More specifically, total soil water to a depth of 40 inches was calculated from the following expression:

$$S = .15(\theta_{12''}) + .06(\theta_{18''} + \theta_{24''} + \theta_{30''} + \theta_{36''})$$

where θ is the % water on volume basis.

Total outflow from six tiles for the whole orchard is derived as follows:

Total area = 9 acres = 9 * 4051.1m^2 = 36460m^2

Flow velocity (liters/day) = 1440 * flow velocity (liters/min.)

Cm of water = cm^3/cm^2

Total outflow (liters/area) = 1000cm^3/m^2 = 10^{-1}cm

Total outflow (cm/day/area) thus is:

$$\frac{1440}{364600} (F_1 + F_2 + F_3 + F_4 + F_5 + F_6)$$

$$= 0.004 \ (F_1 + F_2 + F_3 + F_4 + F_5 + F_6)$$

where F_1, F_2, F_3, F_4, F_5 and F_6 are flow velocities (liters/min.) for drain Nos. 1, 2, 3, 4, 5 and 6, respectively.

2.1.3 Results and Discussion

Results from laboratory determinations of water-retention characteristics indicated no significant differences among the water content at field capacity for 0-1, 1-2, and 2-3 foot depths. They averaged 10.5% (volume basis) or 1.3 inches (3.3 cm) of water per foot depth. Changes of soil moisture in the peach orchard during 1973 are presented in figs. 2.1 and 2.2. Most of the water was removed from surface two feet. As a result of precipitation and irrigation practice, there were more fluctuations in the 0-1 and 1-2 foot depth, particularly during the summer months, than in the 2-3 foot depth. The soil moisture at three feet below surface was always above field capacity; it responded only after heavy rainfall. There

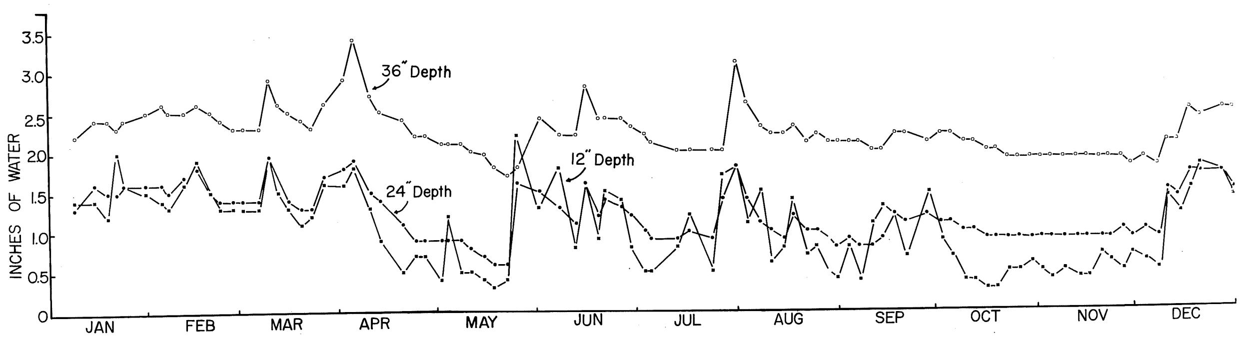

Fig. 2.1. Inches of soil water at three depths in the peach orchard during 1973.

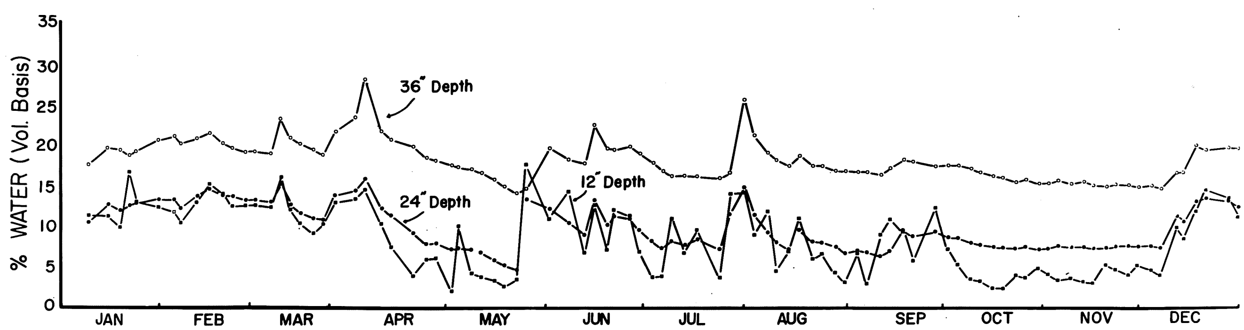

Fig. 2.2. Percent water on a volume basis at three depths in the peach orchard during 1973.

was adequate water in the soil for plant use except during April, May, October and November, and its distribution was quite uniform. This was in contrast with the soil moisture during most of the summer. The October and November low moisture content may not be significant to plant growth since the peach trees were pruned and entered dormancy during the fall.

Water supply from overhead sprinklers amounted to 1 inch each for April and June, and to 3.5 inches for May. During spring and summer months the water table fluctuated, with highest water table recorded at 35 inches below the surface. Its drawdown varied from 2 to 7 inches per day, depending upon location and height of water table. In general, the six drain lines provided adequate drainage for the orchard.

Detailed calculations of ET based on water balance are tabulated in Table 2.1. Values of ET were lower in the fall and winter when the trees entered dormant stage than those in the spring and summer. Total rainfall for the year exceeded ET (Table 2.1 and fig. 2.3). However, because of uneven distribution of precipitation, irrigation was practiced to lower plant water stress imposed on the trees.

Monthly inflow from precipitation and irrigation and total drain outflow are shown in fig. 2.4. Maximum outflow appeared after heavy rains with record high occurring in April and June. This was attributed to heavy precipitation in late March and early April and late May and early June, respectively.

May was the drought month with maximum ET of 15.40 cm (6.06 in.) and pan evaporation of 24.46 cm (9.63 in.) recorded (fig. 2.5). The substantial increase in ET for December was probably due to availability of water for evaporation. In January, however, interference of work in widening the ditch on the south side with outflow measurements could attribute some error to the observed ET.

On a monthly basis, actual ET and pan evaporation were highly correlated (fig. 2.6), as expressed by the following equation:

$$y = -0.17 + 0.54x \qquad (r = 0.73)$$

where y is ET and x is pan evaporation.

Earlier reports showed that water use in this orchard varied from 0.08 inch (0.21 cm) per day during bloom to as high as 0.20 inch (0.51 cm) per day during fruit ration. However, with moderate irrigation practices, the water use

Table 2.1. Evapotranspiration in the Peach Orchard, 1973

Period	Components*, cm					
	Inflow	Outflow	ΔS	ET	Pan Ep	ET/Pan Ep
January						
1-9	.67	.46	-.30	.51	1.48	.34
10-15	2.95	.81	1.30	.84	.86	.98
16-19	0	.48	-.76	.28	1.88	.15
20-22	1.98	.20	1.52	1.52	1.06	1.43
23-24	.03	.29	-1.52			
25-31	3.46	2.43	.25	.78	1.12	.70
	9.09	4.67	+.49	3.93	6.40	Avg .61
February						
1-5	3.07	1.19	1.25	1.50	1.75	.86
6-7	0	.15	-1.02			
8-12	3.12	1.10	1.52	.50	.84	.60
13-16	1.98	.54	0.52	1.19	2.00	.60
17-20	.06	.12	-.33			
21-23	0	.28	-.51	.23	1.52	.15
24-28	0	.23	-.51	.28	1.83	.13
	8.23	3.61	0.92	3.70	7.94	Avg .47
March						
1-7	1.32	.33	0	.99	3.50	.66
8-13	5.77	3.23	1.05	1.49	1.80	.83
14-20	1.22	.71	-2.04	2.55	5.35	.48
21-23	0	.12	-1.28	1.16	1.50	.77
24-31	8.38	2.68	4.83	.87	3.02	.29
	16.69	7.07	2.06	7.06	15.17	Avg .47
April						
1-10	13.97	11.65	-.56	2.88	6.63	.43
11-13	0	.86	-1.91	1.05	1.68	.63
14-20	0	.50	-3.28	2.78	5.26	.53
21-27	2.84	.02	.94	1.88	4.50	.42
28-30	0	0	-.85	.85	2.90	.29
	16.81	13.03	-5.66	9.44	20.97	Avg .45
May						
1-4	2.54	0	1.39	1.15	3.45	.33
5-8	.25	0	-2.59	2.84	3.58	.79
9-11	.56	.05	-.46	.97	1.50	.65
12-15	1.27	.04	-.66	1.89	3.40	.56
16-18	0	0	-.76	.76	2.16	.35
19-22	2.54	0	-.08	2.62	3.58	.73
23-25	7.26	.22	6.35	.69	2.18	.32
26-31	2.95	.55	-2.08	4.48	3.61	1.24
	17.37	.86	1.11	15.40	23.46	Avg .66

*Inflow includes rainfall and irrigation. Positive ΔS indicates a moisture gain. Negative ΔS indicates a loss in soil moisture. $S = \theta' - \theta^{o}$ where θ' and θ^{o} are final and initial soil moisture content in cm.

Table 2.1, cont.

Period	Inflow	Outflow	ΔS	ET	Pan Ep		ET/Pan Ep
	Components, cm						
June							
1-7	4.06	1.19	.41	2.46	4.62		.53
8-15	8.10	5.14	1.42	1.53	6.23		.23
16-21	3.05	2.01	-1.65	2.69	3.63		.74
22-26	3.71	1.66	-.53	2.58	2.34		1.10
27-30	0	.40	-2.51	2.11	2.19		.96
	18.92	10.40	-2.86	11.37	19.01	Avg	.60
July							
1-3	.48	.12	-2.06	2.42	1.12		2.16
4-6	0	.10	-.48	.38	2.13		.18
7-13	3.28	.12	1.11	2.05	4.68		.44
14-17	3.63	.08	1.60	1.95	1.85		1.05
18-24	1.02	.09	-3.00	3.93	3.56		1.10
25-31	14.81	7.01	6.73	1.07	3.99		.27
	23.22	7.52	3.90	11.80	17.33	Avg	.68
August							
1-3	.20	2.09	-2.57	.68	.81		.84
4-7	2.13	.77	-.25	1.61	1.51		1.07
8-14	.16	.61	-3.25	2.80	5.26		.53
15-17	2.18	.28	.89	1.01	1.35		.75
18-24	1.24	.27	-2.69	3.66	3.99		.92
25-28	.08	.18	-1.60	1.50	2.03		.74
29-31	.20	.09	-.66	.77	1.42		.54
	6.19	4.29	-10.12	12.03	16.37	Avg	.73
September							
1-7	1.27	.28	.05	.94	3.74		.25
8-14	3.93	.14	3.22	.57	3.02		.19
15-21	2.93	.68	-.99	3.24	4.19		.77
22-30	2.34	.34	1.70	.30	3.30		.09
	10.47	1.44	3.98	5.06	14.25	Avg	.36
October							
1-5	0	.15	-1.91	1.76	2.26		.78
6-9	0	.11	-1.32	1.21	2.19		.55
10-12	0	.06	-.08	.02	1.89		.01
13-16	0	.05	-.89	.84	1.73		.49
17-19	0	0	-.03	.03	1.68		.27
20-26	.69	0	.58	.11	3.07		.04
27-31	.84	0	.16	.68	1.55		.44
	1.53	.37	-3.49	4.65	14.07	Avg	.33

Table 2.1, cont.

Period	Inflow	Outflow	ΔS	ET	Pan Ep		ET/Pan Ep
	Components, cm						
November							
1-5	.03	0	-.29	.32	1.50		.21
6-13	0	0	-.20	.20	2.82		.07
14-20	.76	0	.28	.48	2.39		.20
21-23	0	0	-.13	.13	.94		.14
24-27	0	0	-.20	.20	1.35		.15
28-30	.53	0	.38	.15	1.12		.13
	1.32		-.16	1.48	10.12	Avg	.15
December							
1-4	0	0	-.20	.20	1.14		.18
5-7	.13	0	-.38	.51	.66		.77
8-11	3.05	0	2.72	.33	.89		.37
12-14	0	0	-.86	.86	.74		1.16
15-21	7.39	1.01	5.98	.40	1.70		.24
22-28	1.60	.64	-.38	1.34	1.45		.92
29-31	0	.31	-1.47	1.16	1.46		.79
	12.17	1.96	5.41	4.80	8.04	Avg	.60
Total for 1973:	142.01 cm (55.91 in)	55.22 cm (21.74 in)		91.22 cm (35.91 in)	172.62 cm (67.96 in)	Avg	.53

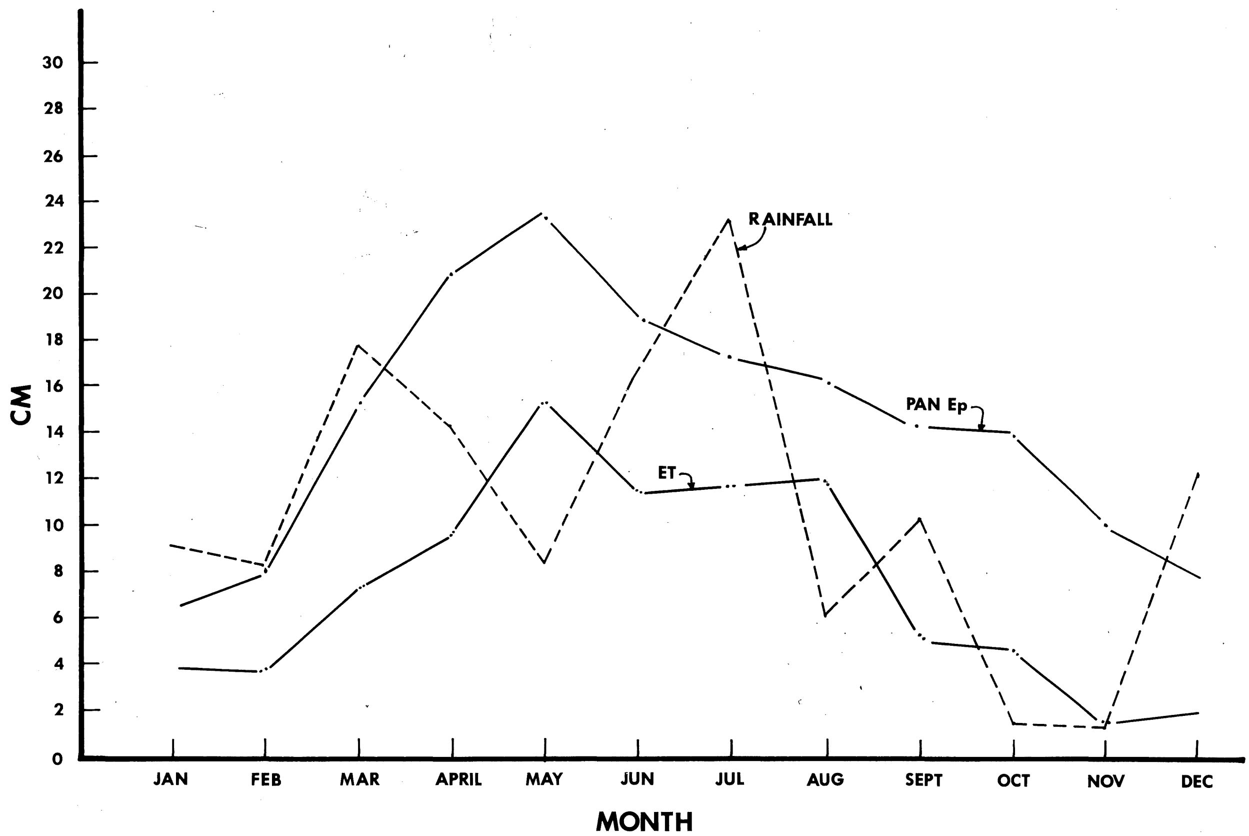

Fig. 2.3. Monthly distributions of rainfall, actual ET and pan evaporation in the peach orchard, 1973.

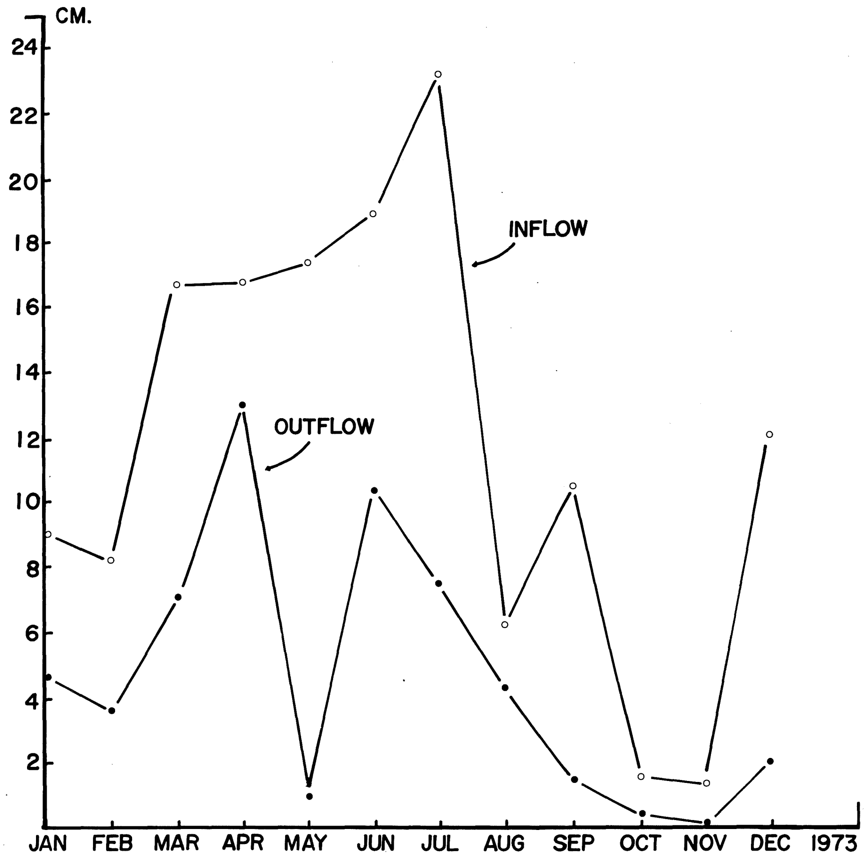

Fig. 2.4. Total monthly inflow (irrigation and precipitation) and outflow (from 6 drains) in the peach orchard during 1973.

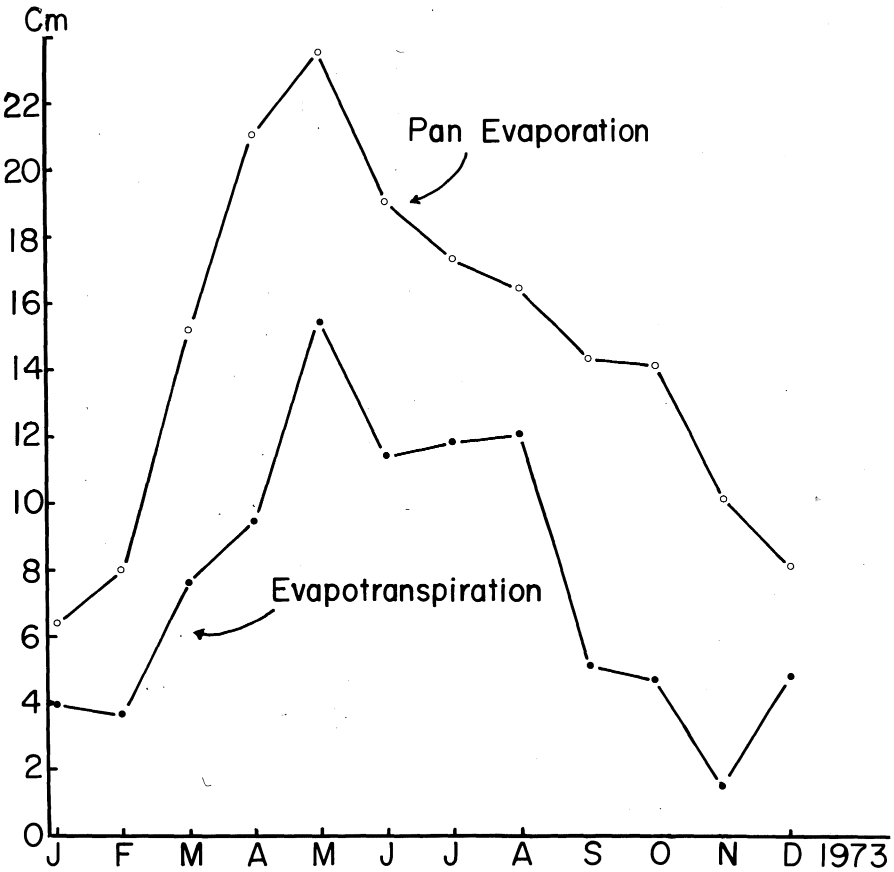

Fig. 2.5. Changes in pan evaporation and actual evapotranspiration in the peach orchard during 1973.

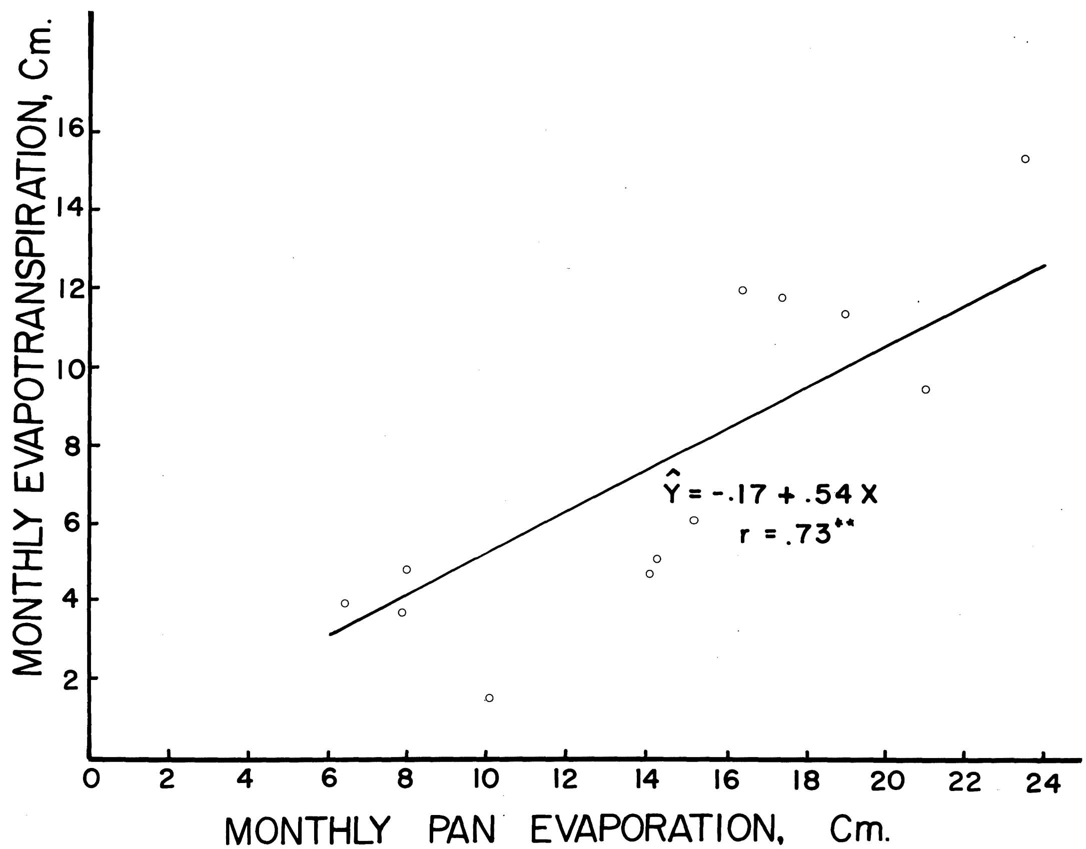

Fig. 2.6. Correlation between monthly evapotranspiration and pan evaporation.

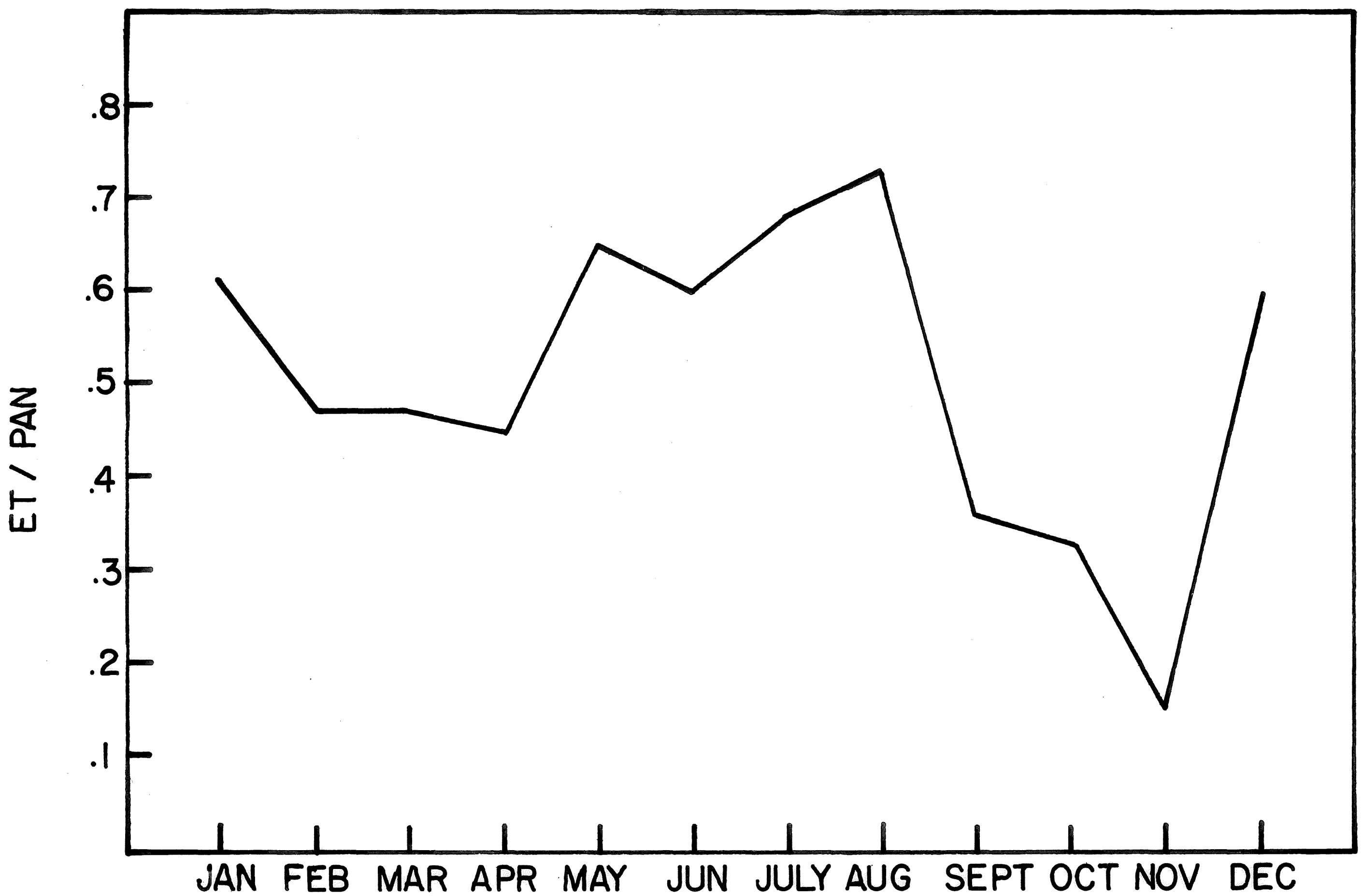

Fig. 2.7. Ratios of actual ET/PAN evaporation in the peach orchard for 1973

could be reduced to 0.16 inch (0.41 cm) per day without reducing yields (3). No attempt was made to compare water use in this study with their data, since the trees were at different ages and techniques used in measuring water use or ET were also different.

The ratio of actual ET: pan evaporation fluctuated; it varied with air and soil temperature, radiation, wind speed, tree growth, rainfall, and available soil moisture (fig. 2.7 and Table 2.1). Generally, the ratios were in the order: summer (0.7) > winter (0.6) = spring (0.6) > fall (0.3). Yearly average of actual ET/pan evaporation was 0.53. Total ET and total pan evaporation for 1973 were 91.22 cm (35.91 in.) and 172.62 cm (67.96 in.), respectively.

2.1.4 Literature Cited

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4. Robin, J. S. 1965. Evapotranspiration. In C. A. Black et al. (ed.) Methods of Soil Analysis, Part I. Agronomy No. 9: 286-298.

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2.2 Identification of the Soil in the Peach Orchard

The nine-acre orchard is located south of the climatology building in the Horticulture Unit, north of Gainesville. Five acres were planted to peaches and the remaining to nectarines. Grasses were growing between rows to reduce soil erosion. Six drains, 80 feet apart and 830 feet long, were installed from north to south.

The soil in the area was first classified as Arredondo fine sand and then Kanapaha fine sand by Leighty of the Soil Science Department.[1] A detailed description was made specifically

[1]Personal communication from Leighty, Soil Sci. Dept., University of Florida, Gainesville, Florida.

for the soil in the orchard on April 2, 1973 by Ah Chu and Phung. General morphology and description of the soil profile are presented in fig. 2.8 & Table 2.2, respectively. Based on field observations and laboratory analyses, the soil should be classified as Arredondo loamy fine sand, a member of the loamy, siliceous, hyperthermic family of Grossarenic Paleudalf. It is an Alfisol.

2.2.1 Determination of Water-retention Characteristics of an Arredondo Loamy Fine Sand

Two pits were dug in the peach orchard and one in the nectarine area in late May, 1973 for observation and sampling purposes. Location of Pit Number 1 was about 100 feet south and slightly to the left of the climatology building. Location of Pit Number 2 was about 100 feet east of Pit Number 1. Location of Pit Number 3 was in the nectarines, approximately 90 feet south of the site of the water table recorder.

Undisturbed soil cores (136.9 cm^2) were taken at different depths from surface 4 inches (10.2 cm) to approximately 58 inches (147.3 cm). Water table was present at approximately 60 inches (152.4 cm) deep at the time of sampling. The cores were then wrapped in plastic bags and brought back to the Soil Physics Laboratory for water-retention determinations.

The samples were mounted in Tempe pressure cells, saturated, and extracted sequentially at pressures of 30, 60, 100, 150, 200 and 345 millibars of water. Water content was determined from the weight of the cell at each equilibrium pressure and the oven-dry weight of the soil core. Determination of saturated hydraulic conductivity was made before oven drying the soil cores by resaturating the samples and using the constant-head method.[1] After oven drying the samples were ground to pass a 2 mm. sieve and the 15 bar water retention was determined. Unsaturated conductivities were calculated from the soil moisture characteristics by the method of Green and Corey.[2]

2.2.2 Results

(See fig. 2.9 & Table 2.3.) The bulk densities increased with soil depths and are characteristic of the texture of a sandy soil. Saturated conductivities varied with sites and soil depths. Soil cores sampled at three feet and deeper showed a significant increase in bulk density, indicative of a poorer drainage of the subsoil than the surface soil. The

[1] Klute, A. 1965. In C. A. Black et al. (ed) Method of Soil Analysis, part 1, pp. 210-221.

[2] Soil Sci. Soc. Amer. Proc. 35: 3-8. 1971.

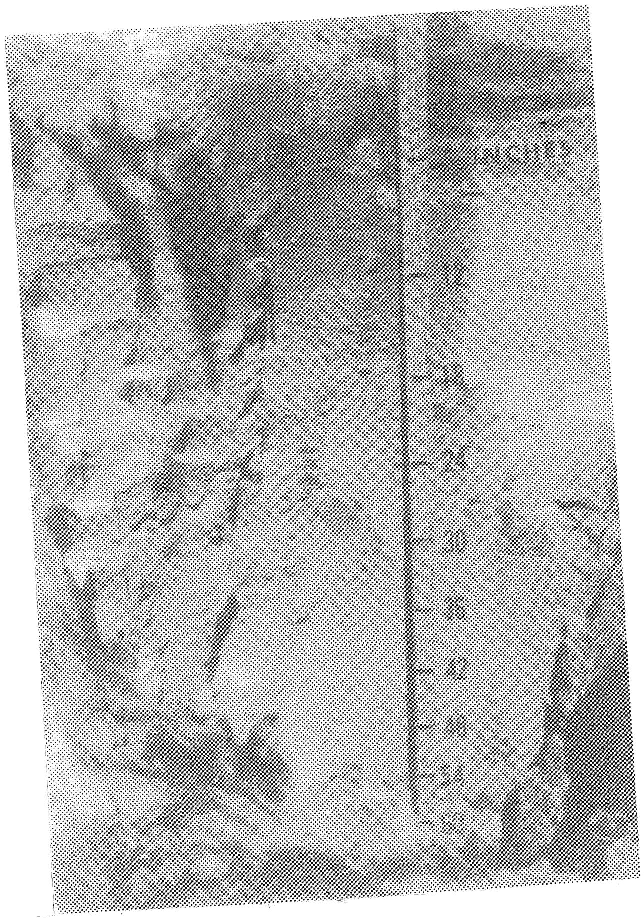

Fig. 2.8. Photo showing soil profile for the Arredondo Sandy Loam in the peach orchard

Table 2.2 Profile description of the soil in the peach orchard.

Horizon description	Depth (in.)	Morphology
A1	0-6	Very dark brown (10YR 2.5/2) loamy fine sand; weak medium crumb; subangular blocky; nonsticky and nonplastic; many to abundant medium and fine roots; strongly acid; abrupt clear boundary.
A21	6-10	Dark grayish-brown (10YR 4/2) loamy fine sand; very weak fine granular; very slightly friable; nonsticky and nonplastic; many medium and fine roots; strongly acid; smooth diffuse boundary.
A22	10-16	Brown (10YR 5/3) loamy fine sand; very fine distinct mottles; very weak fine subangular blocky; friable; nonsticky and nonplastic; very few roots; strongly acid; clear to gradual irregular boundary.
A3	16-25	Brown (10YR 5/6) loamy fine sand with many medium to fine yellowish-brown (10YR 5/4) mottles; very weak fine subangular blocky; very friable; slightly sticky and slightly plastic; strongly acid, gradual wavy boundary.
B2	25-33	Brown (10YR 5/3) light sandy loam with many coarse prominent strong brown (7.5 YR 5/6) mottles; moderate medium subangular blocky; friable to firm; slightly sticky and slightly plastic; strongly acid; gradual wavy boundary.
C1	33-40	Light brownish-gray (10YR 6/2) light sandy loam with some sandy loam concretions; massive; slightly sticky and slightly nonplastic; strongly acid; gradual wavy boundary.
C2	41-60	Gray (10YR 5/1) fine sandy clay loam with rock and shells; massive, slightly hard, firm; slightly sticky and slightly plastic; strongly acid.

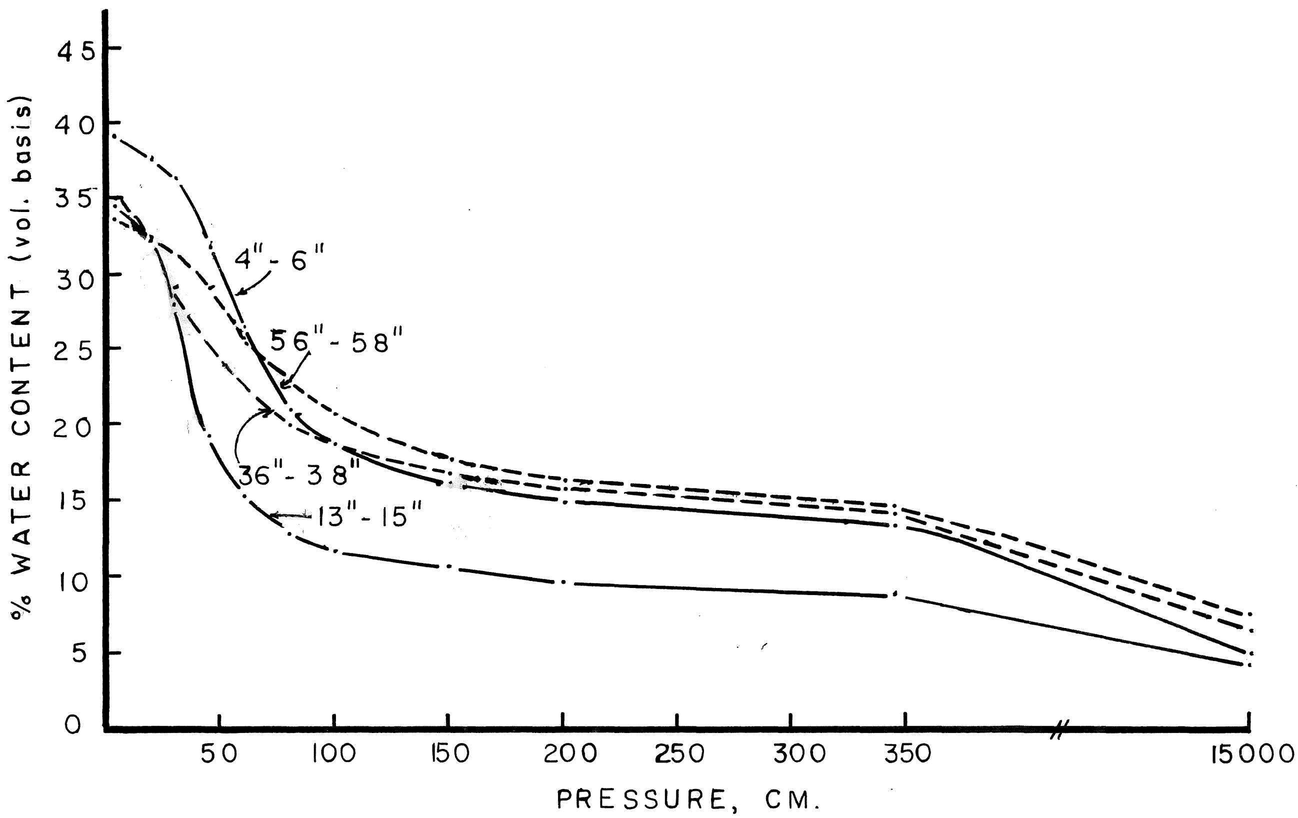

Figure 2.9 Soil tension curves of soil cores taken at different depths.

Table 2.3 Bulk densities, saturated conductivities and field capacities of Arrendondo loamy fine sand at different depths in three locations in the peach orchard.

Sample	Depth	Bulk Den.	Sat. Cond.		Field Cap*
	in.	g/cc	cm/hr	in/hr	Θ at 345 cm
A	4-6	1.46	20.4	8.02	11.47
B	13-15	1.51	25.6	10.1	9.86
C	30-32	1.62	23.0	9.06	9.91
D	36-38	1.61	13.8	5.43	9.67
E	48-50	1.74	11.4	4.49	10.08
F	56-58	1.69	15.3	6.04	10.04
H	4-6	1.59	13.07	5.23	14.74
G	14-16	1.59	16.2	6.38	8.85
I	29-31	1.67	15.3	6.04	9.91
J	38-40	1.75	2.63	1.04	16.30
K	48-50	1.61	3.17	1.25	13.12
L	57-59	1.76	3.51	1.38	14.71
M	4-6	1.40	15.3	6.04	14.20
N	15-17	1.54	28.9	11.40	7.71
O	32-34	1.60	11.0	4.31	11.56
P	38-40	1.51	7.45	2.93	16.80
Q	50-52	1.68	2.76	1.09	18.60

*Field capacity is the % water on volume basis (Θ) at a pressure of 345 cm of water.

pit at location 3 in particular contained rock of various sizes at depths below three feet. Field capacities, as indicated by the moisture content on volume basis (θ) at a suction of 345 cm of water, were higher at the surface six inches and again at three feet or deeper. It was observed that the water contents at three feet and deeper were always above this definition of field capacity and changed very little during the year.

Average values of θ for the surface 0-40 inches were 10.23, 12.45, and 12.57 for the three locations. It has been a common practice in the orchard that if the moisture is below 50% of field capacity, irrigation is necessary to avoid water stress. Based on these field capacity values, it is possible to predict the irrigation timing using readings from the neutron moisture probe for the surface three feet. The calibration equation is y = 43.981x - 9.80 where y is the soil moisture content θ, x is the ratio of actual counts: background count. Assuming the average background counts are 57,000 cpm (using our probe model RSN 104A and serial H-1715) and knowing that the average of 50% field capacity is 11.75 * .50 = 5.88, then, the actual counts can be estimated as follows:

$$5.88 = 43.981\left(\frac{\text{actual counts}}{57{,}000}\right) - 9.80$$

$$\text{actual counts} = \frac{15.68}{7.71} * 10^{-4} = 2.03 * 10^{-4}$$
$$= 20{,}000 \text{ cpm.}$$

Therefore, if the average reading of the 1-, 2-, and 3-foot depths should fall below 20,000 irrigation is necessary.

2.3 Measurement of Soil Moisture with a Neutron Probe: Introduction

Tan Phung and J. Bartholic

The development of the neutron scattering technique provides a rapid and accurate method for determining soil moisture. Since its introduction in the 50's, instruments based on this technique have found wide application, particularly in agricultural and hydrological research. This method has some obvious advantages over the other methods of measuring soil moisture. It measures moisture regardless of its physical state and enables observations to be made at any depth limited only to the length of the access tube. In addition, it allows automatic recording and continuing observations of the same soil throughout cyclic seasonal changes.

2.3.1 Operation Principle

The principle is that fast neutrons that are emitted from a radioactive source are slowed down to thermal speeds (100 eV or less) by collision with hydrogen atoms in the vicinity. Some of the thermal neutrons are reflected toward the BF_3 detector tube and counted. Others miss. In general, the number of thermal neutrons registered by the BF_3 tube is proportional to the amount of hydrogen (free water) in the zone of neutron cloud. There is, therefore, a close linear correlation between the counts per unit time registered on the scale and the moisture content of the area near the moisture probe. High count-rates have been reported in fine-textured soils as a result of hydrogen (absorbed water) in the lattice structure of clay minerals. The effect of the hydrogen content of organic matter in most mineral soils is negligible, however.

2.3.2 Literature Review

This review covers only some of the soil properties that affect the performance of the neutron scattering technique.

Among soil properties, bulk density and soil texture have been found to produce a cumulative effect on the count rate. Olgaard and Haahr (9) reported that apparent moisture content increased with increasing bulk density owing to the impedance of neutron transport, the error being greatest at high moisture content. A change in bulk density from 1.4 to 1.6 g/cm of dry soil caused a 2.4% change in the slope of the calibration curve. Similar result has been reported by Lucbs et al. (5). However, Cannell and Asbell (1) showed that the bulk density effect on the neutron readings was small compared to the effect of soil moisture and its distribution in the soil profile, and, therefore, was not effective in altering the calibration curve. Other investigators (6) emphasized that the linearity of the calibration curve over the range of moisture of practical interest was primarily due to a constant bulk density, and that the form of the calibration curve can be varied by changing the bulk density of the medium. By shifting the calibration curve in response to a change in bulk density, it is possible to operate the neutron probe in a range of soil moisture if the bulk density is kept constant between measurements. In a laboratory study, McHenry (7) demonstrated that errors in neutron readings may occur for soil with wet and dry layers. The error of moisture determination is less when the slope of the calibration curve is greater.

It has been claimed by early investigators that a single calibration curve could be fitted through all the results (10). This is probably due to the fact that clay minerals which retain large amounts of water at oven-drying temperatures also contain an abundance of neutron-absorbing elements (e.g., K, Mg, B, and Cl) as compared with sand and light-textured soil. A positive correlation between the neutron absorbers and the amount of loss-on-ignition water in soils could cancel their respective influence on the calibration curve. This would be especially so when the values for moisture content for the calibration were determined on oven-dry weight (4). However, the effects of these properties are different. Mortier et al. (8) found separate curves for clay and for loam and sand. Cohen (2) reported that the calibration curves for Israel soils varied so greatly that they could not be combined in one calibration, linear or curvilinear. When the neutron measurements extended to thick textural layers and were followed by an abrupt change in the soil physics properties, with a concomitant change in soil moisture the smooth neutron curve may be in error as much as 8% by volume when compared to the soil-sampling curve (1). Furthermore, the soil-moisture-content error may be greater or less than that measured gravimetrically depending on whether the neutron measurement was made on entering or leaving the soil zone. According to Gornat and Goldbert (3), the permissible depth to which a neutron probe may be lowered between consecutive soil moisture determinations without losing accuracy was also influenced by soil texture. They showed that in a fine-textured soil, sampling by 30-cm increments produced a deviation double that obtained in sand using 60-cm increments. It is apparent that different soils may require different calibrations.

Other instrumental and soil properties that influence measurement of soil moisture by the neutron probe have recently been reviewed by Visvalingam and Tandy (10).

2.3.3 Calibration Procedure for the Peach Orchard

There were twenty aluminum access tubes installed in the peach and nectarine orchards, but only 12 of them were used in the routine measurements (fig. 2.10). Four locations were randomly selected in the peach orchard for the purpose of calibration on January 31, 1973. The measurements were made with a Traxler neutron probe (Model RSN 104 A, Serial No. H-1715 and an Am:Be source) and a scaler (Model 1603, Serial No. 163) (fig. 2.11). Neutron readings, CPM, were taken at six-inch increments from surface six inches to a depth of 36 inches. Simultaneously, undisturbed core samples were taken to the same depths, and soil moisture on volume basis, bulk density and other physical properties were determined on these samples in Soil Physics Laboratory. The results were used to construct a calibration curve for the soil in the area. This curve was then compared with the manufacturer's curves and with the previous one made by Dr. Gerber (fig. 2.12). In all locations, relatively low count rates were obtained in the six-inch depth, probably owing to the escape of neutrons from the soil surface. These counts, therefore, were discarded

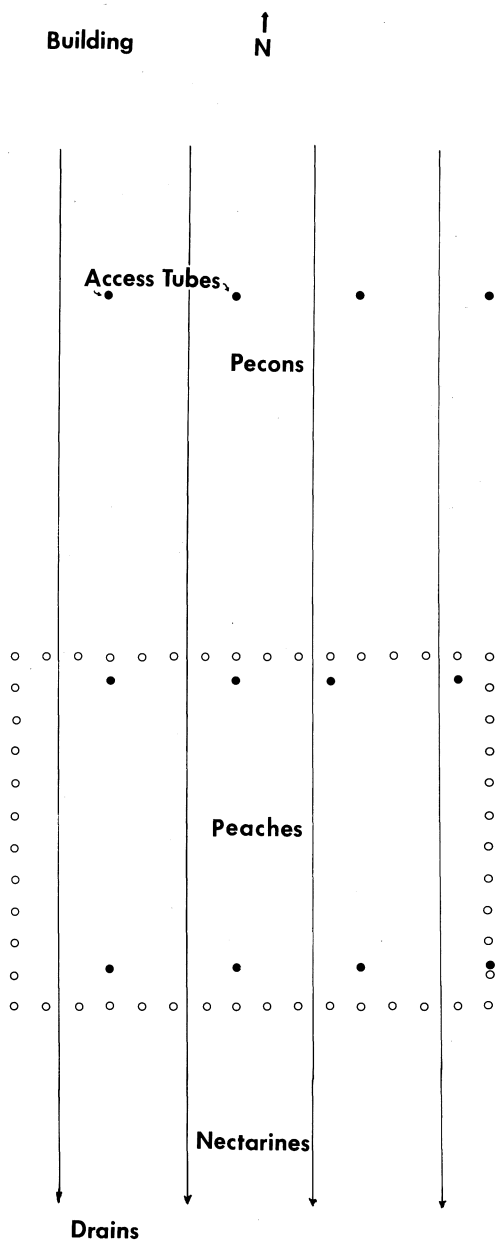

Fig. 2.10. Location of the moisture access tubes used in this experiment at the peach orchard.

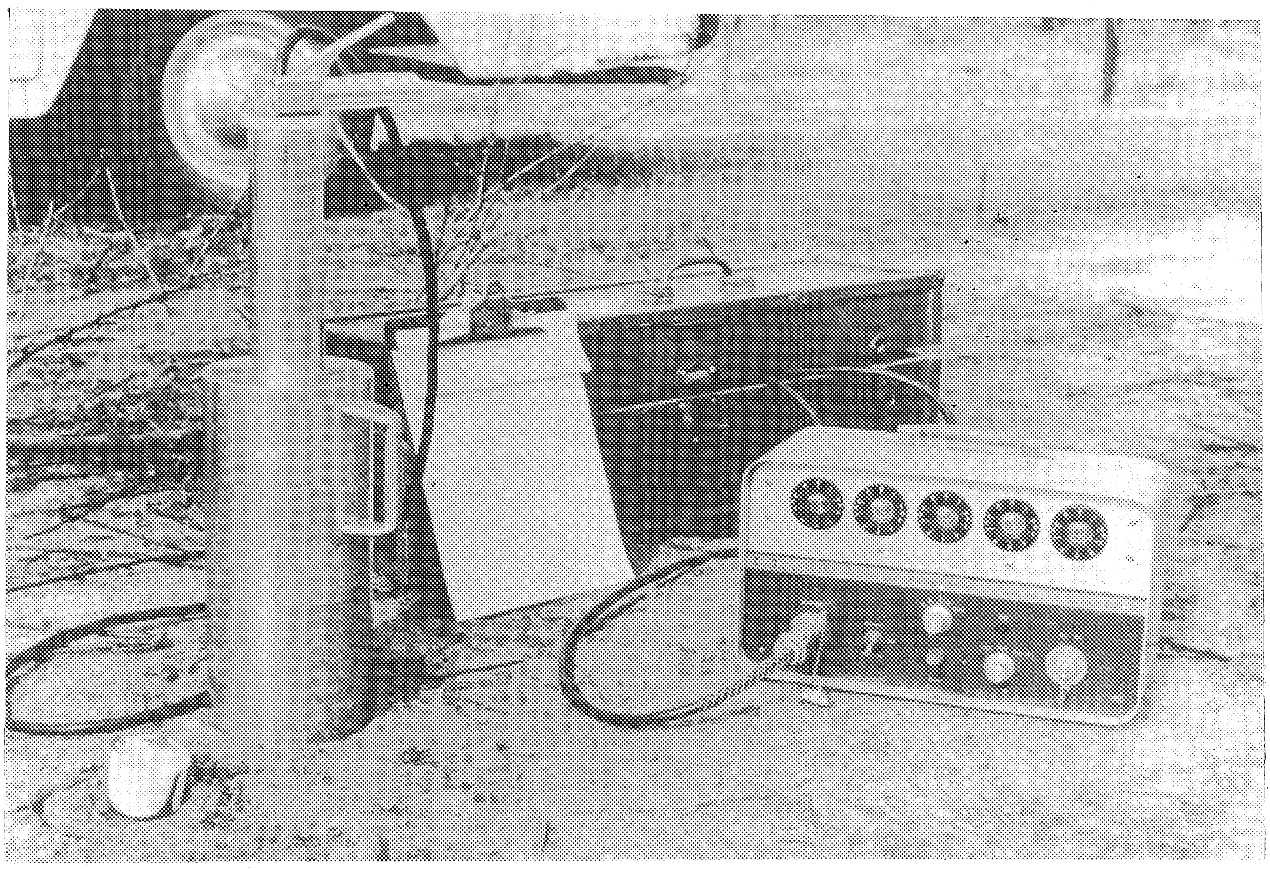

Figure 2.11. Instruments used in soil moisture measurement. At left, the neutron probe sits on tip of the aluminum access tube, and at right, the scaler with cable connected.

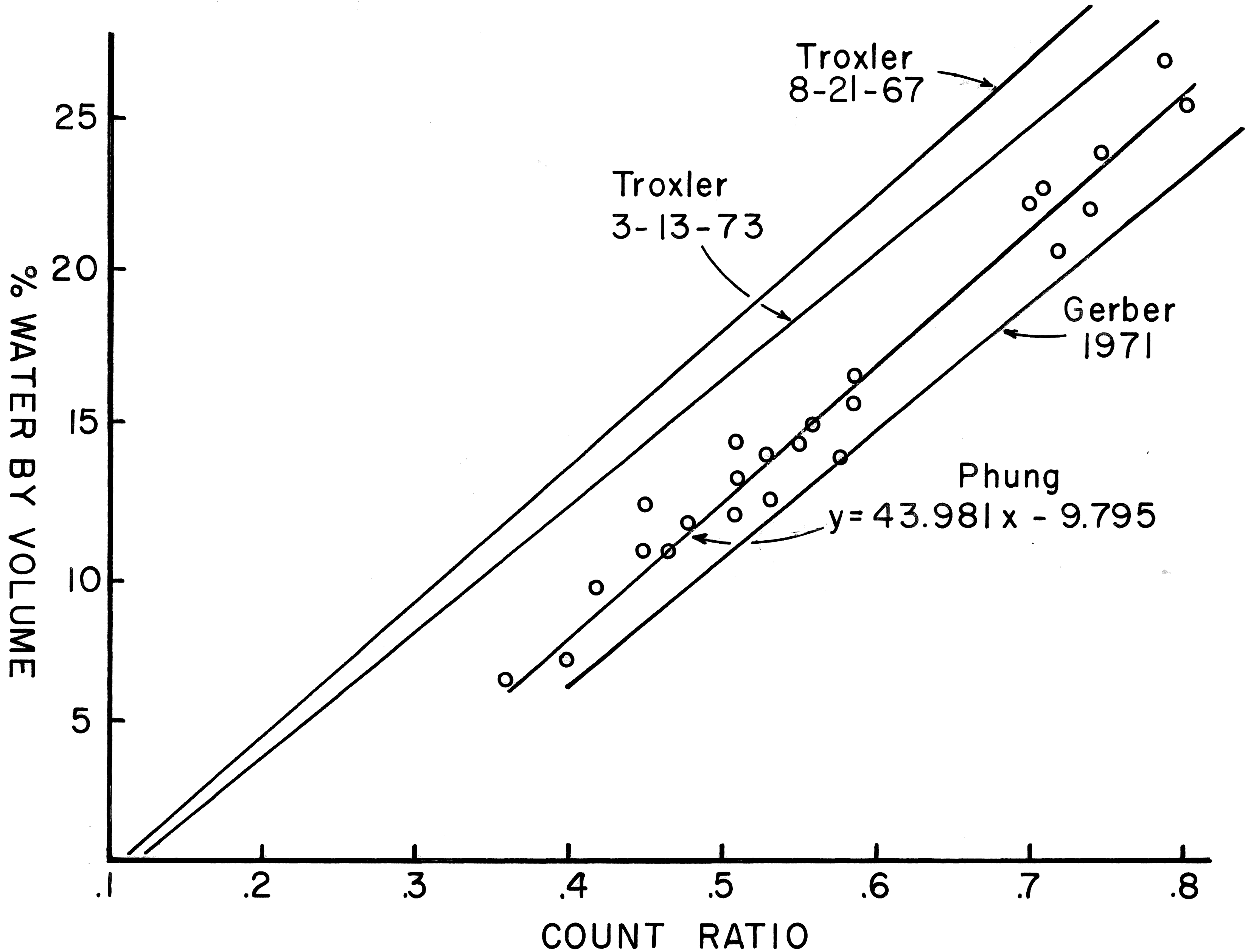

Fig. 2.12. Calibration curves for the neutron probes.

in plotting of the calibration curve. It is noted from fig. 2.12 that the curves prepared in the laboratory by the manufacturer differ slightly from each other in the intercept; so do the ones prepared by Dr. Gerber and by Dr. Phung. However, all four curves have similar slope indicating the sources of deviation from one another may have been due to the operating voltage, background counts and the materials used in the calibration. The equation established by Dr. Phung was $y = 43.981x - 9.80$ ($r = 0.969$) where y is the % moisture by volume and x is the ratio of actual counts: background counts. This equation has been included since in the computer program for calculating soil moisture.

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3. WATER BALANCE AND WATER NEEDS FOR FLORIDA CITRUS

3.1 Water Needs of Florida Citrus

John F. Gerber[1]

During the decade of the 50's and the early 60's researchers showed conclusively that irrigation was a profitable and necessary practice for much of Florida's citrus. Subsequently, irrigation acreage increased continually. Further, there appears to be no decrease in the rate of accumulation of irrigated acreage. This continuing increase has important implications when considering future needs for the industry. Table 3.1 shows the 1973 estimate for acres irrigated by crops and irrigation system. Nearly 60% of the citrus and tropical fruits are presently under some form of irrigation.

No introduction to this subject would be complete without a discussion of Florida's unique hydrologic cycle. In Florida, the cycle is largely one of rainfall (approximately 55 inches per year) falling on the land where it is divided into several components. This rainfall can evaporate (38 to 48 inches per year) with the remainder going into surface runoff or deep percolation for eventual recharge of the aquifer underlying the state. It is from this surface and ground recharge that urban, industry and agricultural needs find their supply of water.

In Florida two factors are becoming increasingly important. The first is increased water demands by all users which taxes the aquifer and surface water supplies and secondly with increased urbanization and building there is a tendency to minimize recharge areas and maximize rapid runoff of water to the oceans, thus making more of our water supply unavailable for later use. These two components could combine to cause serious problems. However, with good water management and planning it should be possible to adequately manage our water resources so a plentiful supply can be made available now and in the future.

3.1.1 Background

The hydrologic cycle can be grouped into four major components. They are evapotranspiration (ET), rainfall,

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[1]A cooperative effort with the Committee on Water Needs for Florida Citrus: A. H. Krezdorn, J. F. Bartholic, J. R. Conner, H. J. Reitz, R. C. Koo, D. S. Harrison, E. T. Smerdon, J. G. Georg, L. D. Harris, and J. T. Bradley.

Table 3.1 Estimate Acres
Irrigated in Florida
1-1-73

Crop	Sprinkler	Seepage & Flood	Total Irrigated
Citrus	434,770	199,510	634,280
Field Crops	49,880	5,000	54,880
Ornamentals	80,000	0	80,000
Pasture	1,500	445,370	446,870
Vegetables	15,350	330,000	345,350
Sugar Cane	0	200,000	200,000
Total	581,500	1,179,880	1,761,380

soil-water storage and water loss through runoff and deep percolation. The approaches used to determine these components are outlined below.

Evapotranspiration (ET) is difficult to measure. For some crops a lysimeter can be used to weigh the soil and water below a crop to obtain daily water loss. For citrus this is either not possible or extremely difficult. The next best approach is to periodically measure soil moisture content to a considerable depth and take differences to obtain the water loss during that period. Some corrections must be made for possible deep percolation or surface runoff. Koo has obtained such data for extended periods of time (2). The data covers grapefruit and some varieties of oranges. He has developed a relationship between mean temperatures and ET (3). From this relationship it is possible to calculate ET in areas where average daily temperatures are known.

Florida has an extensive climatological network. This network provides rainfall data for numerous areas (1). These data and other NOAA rainfall records were used in this study.

Consideration was given to the question of whether just the mean rainfall would be sufficient or whether the mean plus some deviations should also be used in the calculations. It was decided that for the initial calculations two weekly mean values would provide a sufficient guideline for determining water needs. When more detailed information concerning maximum or minimum water needs seems appropriate then some deviations from the mean values should be used.

Water stored in the soil is important in agriculture. A portion of this water is readily available for use by plants. For example, Lakeland fine sand can hold approximately 5.1 inches of water in the top seven feet of soil at field capacity and approximately 4.1 inches of that water is readily available to plants.

From research on citrus irrigation the general guideline has resulted. During the spring period to have water sufficiently available, soil moisture should be maintained at or above one-third of the readily available water. During the fall and winter water supply is not as critical. During this period it is sufficient to maintain soil moisture at or above two-thirds the readily available supply.

Thus, for the Lakeland fine sand there is approximately two inches of water available before half of the readily available supply is depleted. Since ET rates during much of the year can be approximately .2 inches per day, the supply available to the tree could be depleted during a period of about ten days.

Surface runoff and deep percolation depend on rainfall intensity and the degree to which the water storage capacity is filled. These components are the critical ones in the ultimate recharge of the Floridian and Biscayne aquifers.

From the water balance equation, if one knows the ET, rainfall, and soil water storage, it is possible to calculate the water that will be going into the surface runoff and deep percolation. Generally it is estimated that four to five inches of water are available annually for recharge.

3.1.2 Methods

Because of the variation throughout the state in climate, soils and methods of irrigation, it seemed advisable to divide the state into sub-areas. Fig. 3.1 shows the eight areas used in the study. Many of these areas are either predominantly flatwood or ridge citrus. This division was important, since the two have different means of irrigation and water requirements.

Information on types of irrigation and efficiency of irrigation systems was needed. In area 1 sprinkler irrigation is estimated to be 85% of the total irrigated acreage while in the Pompano Beach area, it is estimated that the sprinkler irrigation was 40% and flood irrigation would be at 60%. Efficiency of sprinkler irrigation was the highest at 75%, while the efficiency of flood irrigation was 50% and seepage irrigation was 40%. In any evaluation of water needs for a crop it is not just the need of the crop that must be considered, but rather the efficiency of getting water to the root zone of the crop which is important. These figures, therefore, are important and must be used in determining any values for total water needs.

Basically, in determining water needs for a crop, one has to attempt to keep the soil moisture level adequate. By adequate we refer to the recommended levels during specific portions of the growing season. Whenever soil moisture falls below this level it is necessary to add supplemental water. If rainfall exceeded ET during all seasons, irrigation would not be required. However, as fig. 3.2 shows for the Ft. Myers area, ET exceeds rainfall for all months during the spring, fall and winter. ET could exceed rainfall even during portions of July and August depending on distribution of rainfall.

Ideally, one could just add back the amount of water on a daily basis, that represented a difference between ET and rainfall. This would be the most efficient way of adding water if it were practical. In practice, however, with the possible exception of drip irrigation, this approach is far

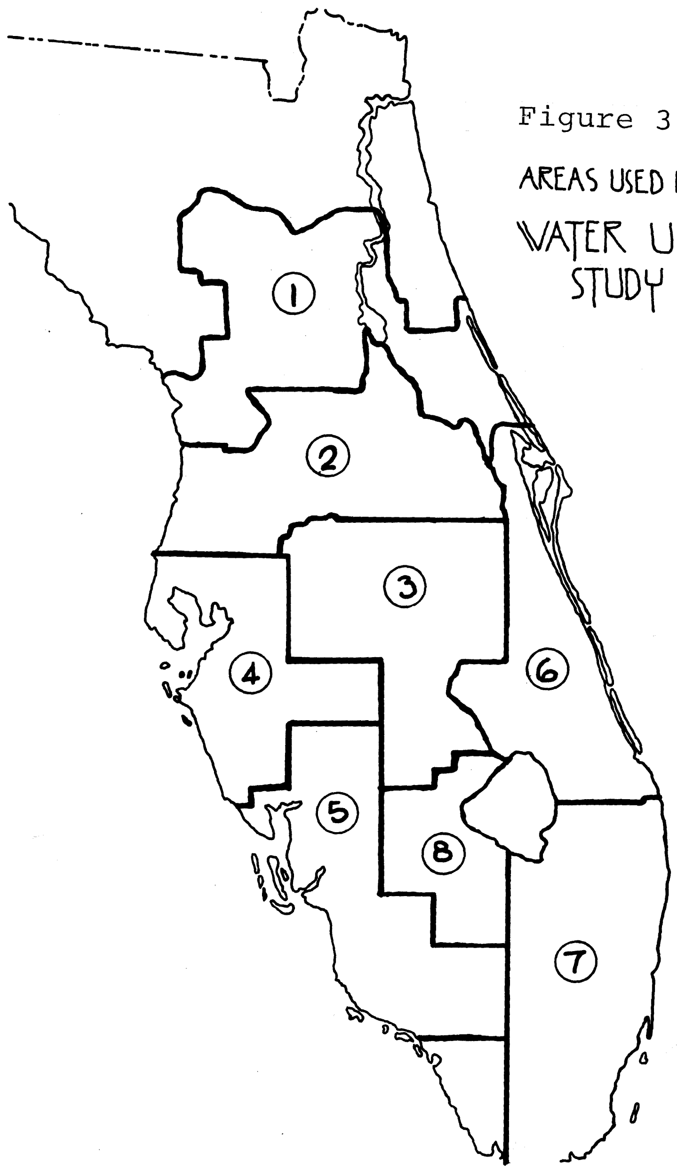

Figure 3.1

AREAS USED IN WATER USE STUDY

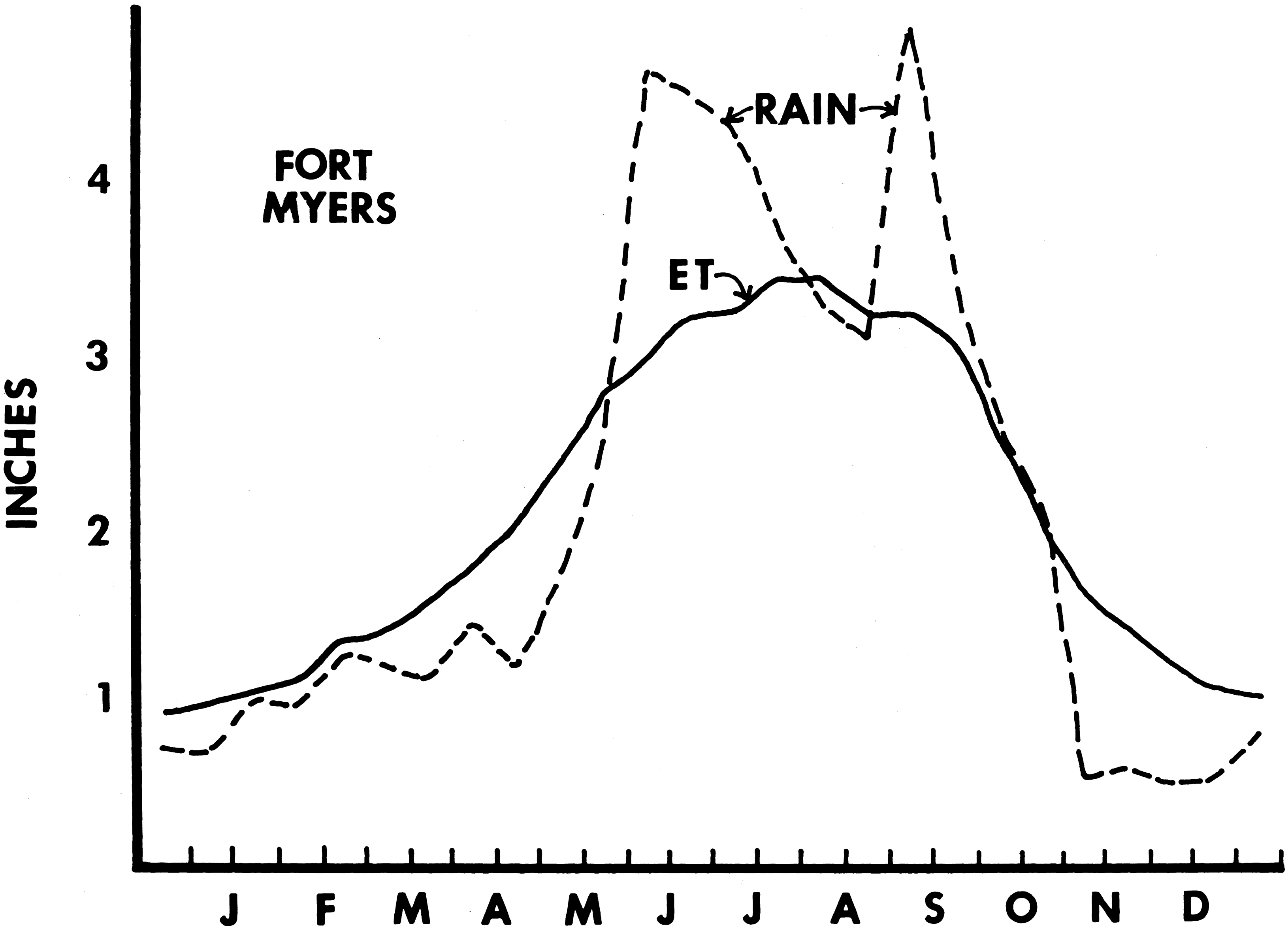

Fig. 3.2. Evapotranspiration and rainfall vs. time of year for the Ft. Myers area.

from possible. Water is generally added in 1 to 2 inch amounts after the soil has been depleted to a moisture level no longer acceptable for efficient production.

In developing a method for evaluating water needs, it is necessary to consider present irrigation methods and their efficiency; soil water-holding capacity; climatic records available and the periods over which the records have been averaged to obtain long-term mean values; and complexity of the approach. In considering these factors we decided that calculations for two-week intervals would be best. That is, ET would be calculated for each two weeks of the year using two-week average temperatures and rainfall so the water balance would be determined biweekly throughout the year. The two-week periods work out fairly well from water holding consideration, since capacity of soils to hold water for a citrus crop can be from approximately ten days to a little over two weeks on the average.

With this two-week approach it was necessary to determine some criteria concerning when irrigations would occur. In addition, the amount to be applied in each irrigation had to follow closely that which would commonly be applied with the irrigation techniques presently used. It was decided that unless the deficit during any two-week period for the flatwoods exceeded .15 inch and for the ridge exceeded .25 inch, irrigation would not be applied. Since two-week average values are used in these calculations and no attempt is made to incorporate distribution of rainfall, these values were found to result in irrigation frequencies similar to those occurring under field conditions. It is realized that irrigation would not normally be applied unless there was at least a deficit of an inch in the soil profile. It was further decided that anytime irrigation was required, one inch of water would be added to the soil profile. This was selected since in practice it would not be practical to irrigate and add less than this amount of water the soil profile.

3.1.3 Results

The water balance on an annual basis is summarized in lines 3 and 4 of Table 3.2. It is observed that rainfall exceeds estimated ET on the annual basis for all areas with the exception of Ft. Myers. Clermont on an annual basis is shown to have nearly the same ET as rainfall. These annual values mean little when considering water needs for citrus. This was pointed out in fig. 3.2 where the two-week ET and rainfall for Ft. Myers are plotted versus time of year. The figure shows that for many two-week periods ET greatly exceeds rainfall despite the annual closeness of ET and rainfall.

Table 3.2 Water Balance Data

Area	[1] Gainesville	[2] Clermont	[3] Mt. Lake	[4] Bradenton	[5] Ft. Myers	[6] Ft. Drum	[7] Pompano Beach	[8] Belle Glade
Total Citrus Acres	26,132	293,533	203,188	113,905	38,937	181,607	31,787	30,321
Present Irrigated Acres	7,207	111,382	136,136	53,181	26,164	158,350	24,115	24,998
Total Annual Rain (Inches) (Acre-In)	 51.8 1,355,000	 51.6 15,143,000	 53.8 10,929,000	 53.4 6,079,000	 53.0 2,063,000	 59.7 10,838,000	 57.2 1,817,000	 57.4 1,740,000
Total Annual Citrus E.T. (Inches) (Acre-In)	 44.6 1,167,000	 51.4 15,073,000	 49.8 10,125,000	 48.8 5,564,000	 54.0 2,099,000	 50.0 9,158,000	 56.0 1,766,000	 48.0 1,447,000
Estimate Irrigation (Inches) (Acre-In)	 5.5 39,900	 9.3 1,039,000	 5.5 744,000	 12 652,000	 21 562,000	 12 1,920,000	 17 407,000	 11 274,000
Sum of 2 weeks period excess (Acre-In)	245,000	1,450,000	1,447,000	1,082,000	252,000	2,099,000	233,000	385,000
Balance	+205,000	+410,000	+702,000	+430,000	-310,000	+178,000	-174,000	+110,000
Estimate Irrigation (Inches) (Acre-In)	 5.5 145,000	 9.3 2,739,000	 5.5 1,111,000	 12 1,397,000	 21 837,000	 12 2,203,000	 17 536,000	 11 332,000
Balance	+101,000	-1,289,000	+336,000	-315,000	-585,000	-104,000	-303,000	+ 52,000

It is the two-week deficits that are greater than .25 inches for ridge areas or .15 for flatwoods that, according to our criteria, result in a need for irrigation. The deficits were calculated for each of the eight areas by two-week periods. When the irrigation criteria is met one inch of water needed to be added to the profile. A general trend for irrigation requirements evolved. During the April-May and October-November periods all areas require some irrigation. The irrigation requirements during late July and early August are not as consistent, but do exist in many areas. Irrigation requirements for winter and early spring are mainly necessary in the southern part of the state and in flatwood soils areas.

Table 3.3 shows the accumulative total two-week deficit and accumulative total irrigation required. These deficits vary from 2.2 inches for the Gainesville area to a maximum of 7.4 inches for the Ft. Myers area. The number of irrigations vary from 4 to 15 per year. To get the actual inches of water required it is necessary to multiply the number of irrigations by the irrigation efficiency factor. The third and fourth lines show the irrigation efficiency and the actual inches of water required. The effect the efficiency has on total irrigation requirements becomes clear. Requirements with 100% efficient irrigation would have been from 4 to 15 inches, however, when irrigation efficiency is considered the inches of water required increased to a minimum value of 5.5 inches and a maximum of 21.5 inches.

Table3.3provides the excess or deficit of water falling on citrus acreage in each of the eight areas. To examine this table Gainesville (Area 1) will be used as an example. The total acreage is over 26,000 acres with 7,000 being irrigated. The average annual rainfall was 51.8 inches yielding rain in the amount of 1,355,000 acre inches of water. Since 44.6 inches of ET are estimated to leave the citrus area 1,167,000 acre inches of water are lost to the atmosphere. Present irrigation area requirements are 5.5 inches (from Table 3.3). This water on the irrigated acreage would require 39,900 acre inches of water. The next line gives the excess water that falls during high rainfall periods and is contributed to surface runoff into lakes and streams or is ultimately added to the aquifer through deep percolation. The sum for each of the two-week periods when an excess of rainfall over ET occurred totals 245,000 acre inches. Since irrigation requirements are taken from either the surface water or aquifer, this amount must be subtracted from the excess, which leaves a balance of 205,000 acre inches of water. This is the net contribution of the citrus acreage in area 1 to surface runoff and deep percolation.

The same approach was used for each of the eight areas. It can rapidly be observed from the balance line that in all areas, with the exception of 5 and 7, the total citrus acreage

Table 3.3 Annual Water Deficits, Irrigations, Efficiency and Inches of Water Required by Areas.

Area	Gainesville	Clermont	Mt. Lake	Bradenton	Ft. Myers	Ft. Drum	Pompano Beach	Belle Glade
Sum of 2 week Deficits	2.2	4.7	3.2	5.0	7.4	2.3	5.7	3.0
No. of Irrigations	4	7	4	8	15	7	11	7
Irrig. Efficiency Factor	1.38	1.33	1.37	1.53	1.43	1.73	1.53	1.57
Irrigation Required (Inches)	5.5	9.3	5.5	12	21	12	17	11

made a net contribution to surface and ground water supplies.

3.1.4 Discussion

There are many ways of determining water needs for an industry. The approach used here is based largely on the water balance (hydrologic cycle) principles. Using this approach the total citrus acreage was a net contributor to the state's water resources. However, in areas 5 and 7 where there is a net utilization of water, unless there is large surface for underground movement of water from surplus areas these deficits could cause localized water management problems.

A factor which is difficult to assess is the length of time it takes for water to eventually recharge the aquifer. Citrus, however, has been in Florida for over a century and hopefully may remain as a viable agricultural crop in this area for centuries to come. Thus, when we are considering water balance and the contribution of citrus we can think in relatively long periods.

No discussion would be complete without some consideration of the weaknesses of the method used to determine the water balance components in this study. One of the weakest components is the criteria used to determine when irrigation will be required within this model; that is, the .25 or .15 inch deficits in the ridge and flatwood areas respectively. Arguments can certainly be made for the rationale behind these values; however, in reality they have never been tested against actual field conditions. The approach does provide valid numbers for comparison of irrigation requirements.

The water lost in irrigation due to line losses or tail waters were considered as losses in this study. If these losses occurred inland it is possible that this water could be reused down stream or find its way back into the ground water supply. On the other hand, if this water runs into a ditch and rapidly moves to the coast, it is lost. Increasingly in some areas these waters are being reused or result in recharge. If resources and time are available, this recycling of runoff waters should be incorporated in future studies. The importance of this can be seen from the example of the Ft. Drum area where to put one inch of water in the soil requires 1.7 inch of water. On the other extreme where largely overhead sprinkler irrigation is used, to add one inch of water to the soil requires an input of only 1.33 inches. It is estimated that a quarter of the water may evaporate when sprinkler irrigation is used during the day. This evaporated water is completely lost. Night irrigation essentially eliminates this loss.

The value of this study would be limited if we considered only present irrigation needs. As pointed out in the introduction, irrigation requirements continue to increase. Table 3.2 shows the water requirements if all citrus acreage is irrigated. The bottom line shows the balance if all citrus were irrigated. The most dramatic point is that if 100% of the citrus acreage were irrigated then this large block of over 700,000 acres would no longer be contributing to the water supply, but would become a net user of water. This could, result in a gradual draw down of surface and ground water supplies, which would ultimately lead to restrictions on water use by all users, or at least a rationing of water based on some priority system set up by governing bodies.

This sobering thought causes us to look hard at how we can keep this condition from occurring. Certainly we must make more efficient use of available water. Thus, inefficient irrigation systems such as flood and seepage, must be improved so that runoff waters can be recycled. With sprinkler irrigation, by irrigating at night or during low potential evapotranspiration conditions the estimated 25% loss could be cut to practically no loss.

At various times throughout this report we have mentioned the possibility of replacing daily the quantity of water that was used by the tree. With this approach it is estimated that water requirement could be cut by a third.

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3.2 Analysis of Climatic Records to Assess Irrigation Needs

Jon F. Bartholic

A meaningful view of agricultural use of water is to consider an area of agriculture land and then think in terms of the water cycle for that land surface. Of the rain that falls, some moves into the soil and a small amount runs off. That in the soil is available for use by plants in evapotranspiration and a portion of it moves down below the root zone ultimately reaching the aquifer.

Of importance in agricultural water use are the distribution of rainfall and the magnitude of the terms in the water cycle. The distribution and magnitude of these terms can be obtained by using daily values for rainfall, air temperature and soil physical properties. With this approach evapotranspiration (ET), runoff and deep water movement can be calculated. Then with a knowledge of the crops' need for water, the number and amount of irrigation water required can be determined.

A simple computer program using daily rainfall and temperatures was developed.

$$S = R - RD + IRR - ET - DP$$

where in inches:

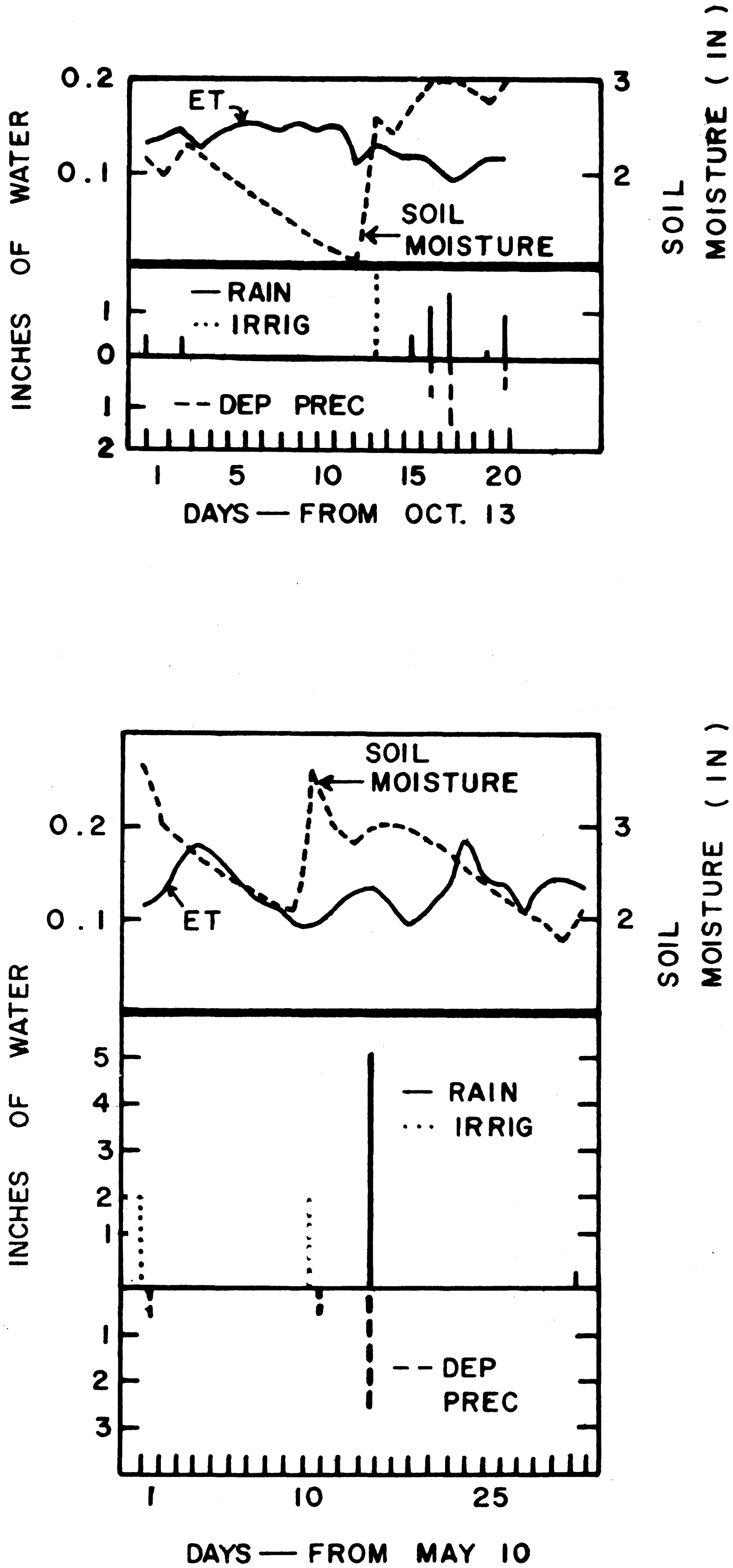
S = water stored in soil,
R = daily rainfall,
RD = portion of rainfall that runs off,
IRR = irrigation,
ET = evapotranspiration and
DP = deep percolation of water below the root zone.

Koo's relationship for calculating ET was used (2). The curve given by Koo (1) was fit to a polynomial and the following equation was obtained:

$$ET = 7.3 - .46*T_a + .0109*T_a^{2} - (.113*10^{-3})*T_a^{3} + (.437*10^{-6}) *T_a^{4},$$

where T_a is the average air temperature. The model yields results on irrigations required and recharge water available from that crop and soil. If rainfall was large then there was some runoff with the remaining water going into the soil. If the water going into the soil was greater than the soil root zone could hold, then the excess water goes into deep percolation. If no rainfall occurs, the soil moisture reserve is gradually depleted until irrigation is required. Then a two-inch irrigation is applied with an efficiency of 85 percent. That is, 15 percent of the water was assumed to evaporate into the air during application.

An example of daily values are shown in fig. 3.3. Daily ET, available soil moisture, rainfall, irrigations, and deep percolation are plotted for a few-week period. Shown is that poor distribution of rainfall resulted in a need for the agriculturalist to irrigate his land and a rain occurred a few days



A

B

Figure 3.3

Daily values for evapotranspiration (ET), soil moisture, rainfall or irrigation and deep percolation of water for consecutive days starting with September 13, 1967 in (A) and with May 10, 1967 in (B) assuming a three-inch soil water-holding capacity. Weather data used was for Arcadia, FL.

later on a moist soil. In this case the water from the irrigation is not lost but much of it goes back into deep percolation and recharge for reuse at a later date.

Averaging data over weekly periods makes it easier to see annual trends for several years, (fig. 3.4). The general trend for these values in Florida is clearly shown. During the summer rainfall exceeds ET and deep percolation is significant. This water, over time, is then stored either in the aquifer or in lakes and is partly withdrawn during the spring of the year when evaporation exceeds rainfall. Because of the relatively low water-holding capacity of Florida soils, it is observed that irrigations are frequently required, sometimes weekly, during periods of high temperatures and no rainfall in the spring. Less or no irrigation is required during the summer with scattered irrigations required in the late fall and winter. Fig. 3.4 gives only data for 2 specific years, but they show the general trends that exist during most years.

Soil water-holding capacity is important since Florida soils vary from 4 to 5 inches for deep sands to 2 inches for shallow flatwood soils. Table 3.4 summarizes annual rainfall, deep percolation, and number of irrigations required for different years assuming different soil water-holding capacities as summed from the daily values calculated by the model. The number of irrigations vary from 3 to 18 depending on weather and soil.

The 1967 60-inch rainfall was above average, yet 18 irrigations were required when a low two-inch soil water-holding capacity was used. In this year the model shows more water was used in irrigation than was resupplied through deep percolation. In 1968, with the same soil moisture holding conditions and five inches less total rainfall during the year, the irrigations required were only 14. This difference is due to better distribution of rainfall. Perhaps, a more typical case using the same daily weather records would be a three-inch soil water-holding capacity in which case, irrigations required varied from 6 to 11 and total water required varied from 12 to 22 inches. Recharge varied from 27 to 34 inches giving a net recharge of water to the aquifer for each year.

3.2.1 Summary

This brief detailed look at the water cycle for a specific area is of value in showing the wide diversity of weather and irrigation requirements that occur. Few generalizations should be drawn. Each grower must keep track of his own specified conditions and use water as required to maximize productivity for the expenditures inputs required. This approach, except in the case of soils with a very low water-holding capacity (2 inches), showed that more water was available for recharge than was withdrawn for irrigation.

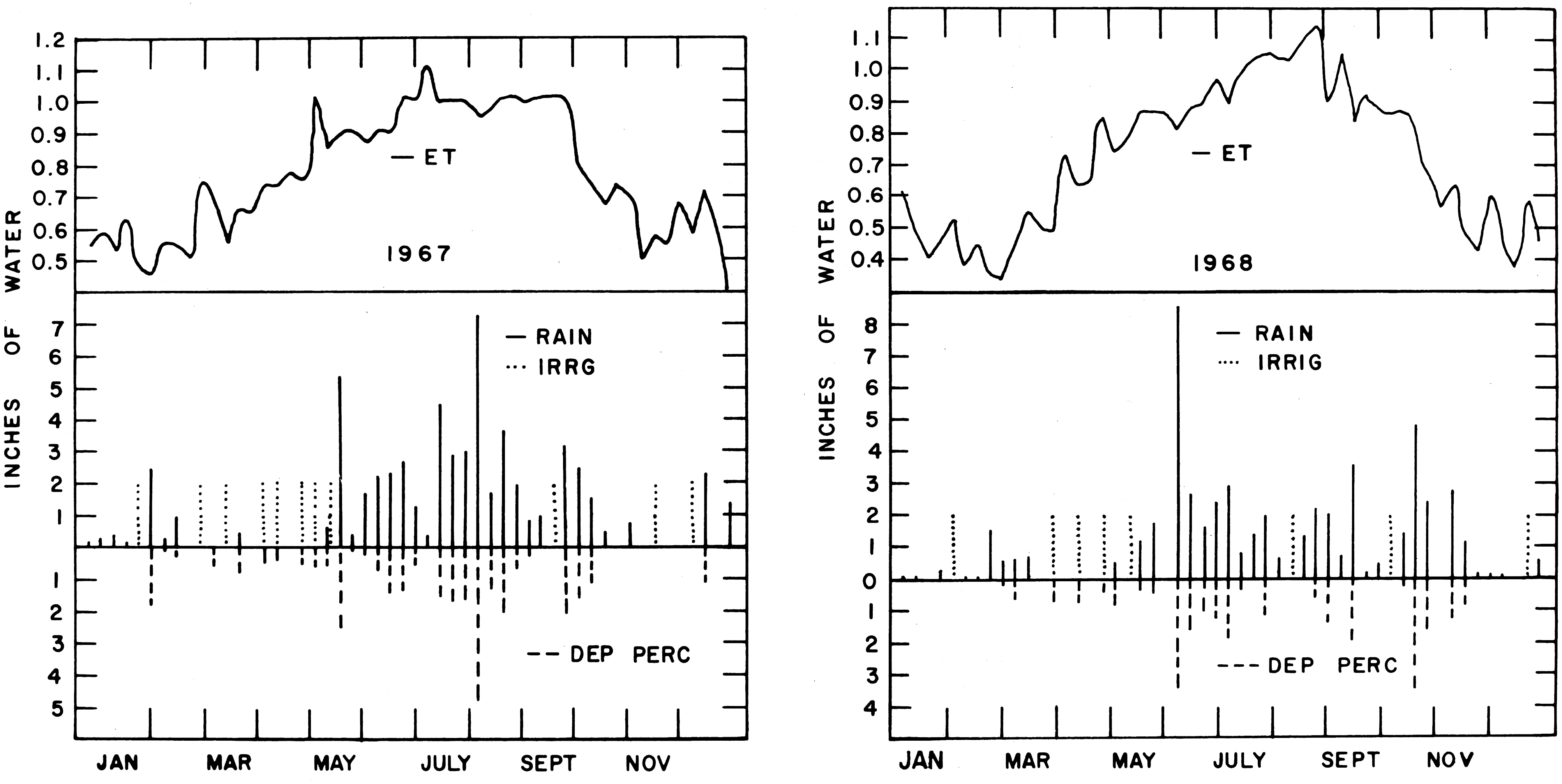


Fig. 3.4. Weekly values for ET, rainfall or irrigation and deep percolation of water for 1967 and 1968, using weather data from Arcadia, FL. and assuming a three-inch water-holding capacity.

Table 3.4 Water Balance Results Assuming Three Different Soil Water Storage Values Using Weather Data from Arcadia, FL, ID Number 80228 (all values are in inches).

Soil Water Storage	ID	Year	Rainfall	Runoff	Rain in Soil	ET	Deep Percolation	Irrigation Amount	Number of Irrigation
2	80228	67	60.0	5.8	54	39.7	30.0	18	18
		68	54.7	4.6	50	37.4	25.4	14	14
		69	64.5	3.3	61	38.2	35.2	13	13
3	80228	67	60.0	5.8	54	39.7	33.3	22	11
		68	54.7	4.6	50	37.4	27.1	16	8
		69	64.5	3.3	61	38.2	34.3	12	6
4	80228	67	60.0	5.8	54	39.7	25.3	12	6
		68	54.0	4.6	50	37.4	23.7	10	5
		69	64.5	3.3	61	38.2	29.2	6	3

Specific examples have been discussed, but for many water planning purposes, it is necessary to look at average value and use statistical approaches to get an estimate of the water required over long periods of time.

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4. STUDIES TO IMPROVE WATER USE EFFICIENCY

4.1 Measure of Water Stress in Citrus

W. D. Bell, M. Cohen, T. B. Crocker, and J. F. Bartholic

The Scholander pressure bomb was successfully used to measure water stress of 'Orlando' tangelo trees growing on different stocks. The water stress appeared to be dependent on the stock used. 'Orlando' tangelos growing on sour orange were under a greater water stress than those on sweet lime. Leaves of trees with citrus blight and "young tree decline" (YTD) were under a greater water stress than leaves from healthy trees.

The Scholander pressure bomb (7) is a modification of Dixon's technique (1) to measure leaf water potential. Earlier work demonstrated that the pressure bomb was useful in evaluating water stress of 'Washington' navel and 'Valencia' orange trees (5). This study was to determine whether Scholander's pressure bomb technique could distinguish between the water uptake capacities of 'Orlando' tangelo on different rootstocks. 'Orlando' tangelo was a convenient test subject which exhibits the normal range of visual water stress responses among citrus species and hybrids in Florida.

Preliminary work in October, 1972 showed that differences could be observed in the pressure required to produce free liquid at ends of petiole xylem tissue among 'Orlando' tangelo leaves from trees on different rootstocks. It was determined that four leaves per tree was the minimum number that would yield reliable results. This number was selected because it provided an adequate representation of leaf water stress variability for the tree (2). Because of the 2-5 minutes required to sample each tree quadrant (4), the number of varieties was limited to five for each of the two locations.

4.1.1 Experiment 1

Trees were located at the University of Florida Horticultural Unit (HU) and in a commercial orchard near Leesburg (LB). The former is situated on Kanapaha fine sand which has a water table that usually varies from 60 to 120 cm (2 to 4 feet). Pressure bomb readings at HU were taken during 1 hour periods between 12:00 and 2:00 p.m., on May 7, 17, 18 and 23, 1973, with random samples taken from a different tree of each rootstock on each sampling date (Table 4.1). The orchard near Leesburg has Astatula fine sand which is underlain with clay loam at depths of 200 to 250 cm (6.6 to 8.3 ft.) (3). This location is typical of commercial citrus areas in respect to soil conditions. Pressure bomb readings at LB were taken of each rootstock (1 tree of each rootstock during a 1 hr. period) between 12:00 and 2:00 p.m. on April 25 and May 29 (Table 4.2).

Data in Tables 4.1 & 4.2 show that the pressure bomb was sensitive enough to detect significant differences between rootstocks for leaf water stress at both locations; however, these differences were not visibly apparent. Results showed that leaf water stress fluctuated with date of sampling, however, the relationship between rootstocks remained relatively constant within each location.

For the HU location, 7 of the 10 possible contrasts between mean pressure bomb readings (converted to bars) indicated significant differences between rootstocks in leaf water stress. Greatest leaf water stress was observed for sour orange (C aurantium L.) with a mean leaf water stress value of -12.03 bars, and lowest for Palestine sweet lime (C limettioides (L.) Raf.) with a mean leaf water stress value of -7.88 bars. At the LB location 4 of 10 possible contrasts between mean pressure bomb readings (converted to bars) indicated significant differences between rootstocks in leaf water stress. Greatest leaf water stress was observed for trifoliate orange with a mean leaf water stress value of -13.67 bars, and lowest for rough lemon with a mean leaf water stress value of -7.87 bars. 'Orlando' tangelo trees at LB showed marked differences in tree size (6) and depth of rooting (3). Trees at HU were approximately the same size regardless of rootstock due to the presence of a high water table which limited root growth. The pressure bomb techniques made a greater number of significant discriminations at the HU location where readings were taken on four different occasions as compared to two occasions at LB.

In a second study leaves from 'Orlando' tangelo trees at HR were tested at 2-hr. intervals to observe diurnal changes in pressure readings for the same trees (fig. 4.1). Leaf water stress increased until the sun reached the zenith and then decreased. Data for this curve were obtained on a day that became cloudy at noon, which would account for a faster than normal increase in water potential. The latter indicates that readings must be taken within a relatively short time to be comparable. A max period of 1 hr. or less under clear sky conditions is suggested. Differences in leaf water potential for rootstocks would also be determined early in the day when very little stress was present.

TABLE 4.1

LEAF WATER POTENTIAL (BARS) OF 'ORLANDO' TANGELO ON DIFFERENT ROOTSTOCKS AT THE HORTICULTURAL UNIT, 1973.[Z]

Rootstock	May 7	May 17	May 18	May 23	Mean
Palestine sweet lime	- 8.25	- 8.63	- 8.16	- 6.46	- 7.88a[Y]
Rough lemon	- 8.21	- 8.21	- 9.10	- 6.58	- 8.00a
Trifoliate orange	-10.24	-10.20	-10.03	- 9.27	- 9.94b
Cleopatra[X]/ mandarin	-10.33	-12.71	-10.90	- 8.25	-10.55bc
Sour orange	-11.44	-13.31	-12.84	-10.54	-12.03c

[Z]Each value is a mean of 4 readings.

[Y]Mean separation by Duncan's multiple range test, 5% level.

[X]*Citrus reticulata* Blanco.

TABLE 4.2

LEAF WATER POTENTIAL (BARS) OF 'ORLANDO' TANGELO ON DIFFERENT ROOTSTOCKS IN A GROVE NEAR LEESBURG, 1973.[Z]

Rootstock	April 25	May 29	Mean
Rough lemon	- 6.89	- 8.84	- 7.8
Palestine sweet lime	- 8.11	-10.09	- 9.1
Sour orange	- 7.91	-12.19	-10.0
Carrizo citrange[X]/	- 8.80	-13.48	-11.4
Trifoliate orange	-11.69	-15.65	-13.6

[Z]Each value is a mean of two trees with four readings on each tre

[Y]Mean separation by Duncan's multiple range test, 5% level.

[X]Citrus sinensis X Poncirus trifoliata.

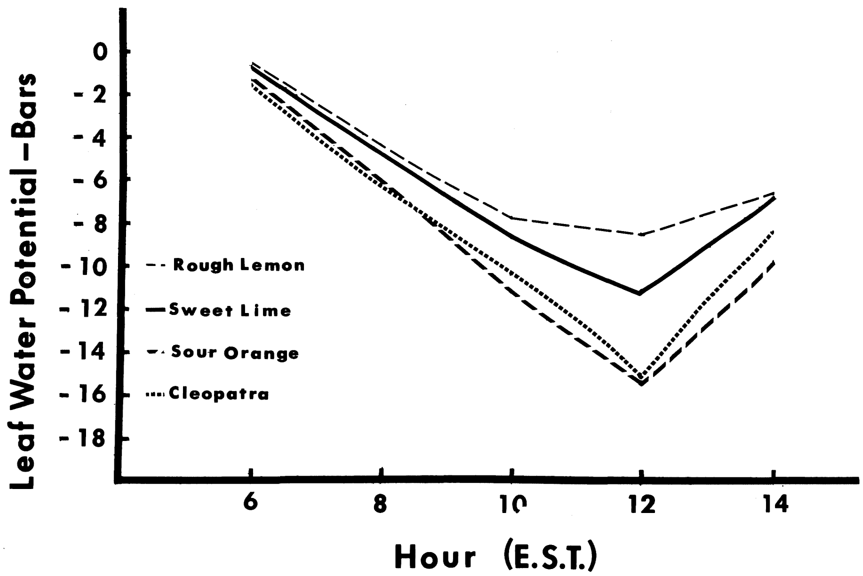

Fig. 4.1. Diurnal study of leaf water potential on 'Orlando' Tangelo at Horticultural Unit, July 18, 1973.

The data suggest that the pressure bomb may be an effective means of evaluating the effect of rootstocks on scion leaf water stress. Differences in leaf water stress could be measured by this technique when it could not be detected by visual observations. Additional research is needed to establish the normal range of leaf water stress for different rootstock and scion combinations to aid in interpretation of leaf water stress values. Such information could be helpful in planning the timing of irrigation for citrus trees on certain rootstocks and in evaluating new rootstock selections. This technique does have limitations because of the time required to execute the measurements. This may limit sample size; but with experience and improved techniques the time required for these measurements can be reduced.

4.1.2 Experiment 2

Four 'Valencia' trees on rough lemon stock, 2 with and 2 without YTD symptoms, were selected from the Cloud grove near Fort Pierce. The second group of 4 'Valencias' on rough lemon was from the Fort Pierce Agricultural Research Center. Two of these trees were diagnosed as having citrus blight.

Pressure bomb readings were taken at intervals of 2 to 5 minutes from each of the four tree quadrants sampled. Leaves were taken alternately from healthy and diseased trees until the four quadrants of all trees were sampled. Only representative results from trees at three locations are cited here. Considerable additional data were taken which further substantiated the findings reported.

Plant-water stress was also measured on two trees with YTD and two healthy trees on February 15, 1973. All trees were 12 years old. These measurements were made several times during the day. The first measurement at 11:40 a.m. was on a clear day, referred to as a high stress day. Shortly after noon a cloud cover moved in, temperatures (80°F) leveled off and atmospheric demand (stress) decreased. When readings were made during the high stress period, water stress on trees with YTD was over two times as great as that of healthy trees (Table 4.3). Readings taken in the afternoon indicated less stress as would be expected under cloudy conditions. However, trees with YTD were under a greater stress than healthy trees. As environmental conditions changed, stress in the trees changed within a matter of 2 to 3 minutes.

Temperature conditions changed rapidly and on February 16, averaged 50°F with relative humidity between 80 and 100%. Measurements were made comparing water stress of healthy trees and trees with citrus blight. Trees with citrus blight, 23 years of age, showed greater water stress than healthy-appearing trees (Table 4.4). Since the water stress was greater for the

TABLE 4.3

LEAF-WATER POTENTIAL OF HEALTHY AND YTD AFFECTED 'VALENCIA' ON ROUGH LEMON MEASURED ON FEBRUARY 15, 1973 (IN -BARS)

			Quadrant				
Tree	Condition	Start Time	NE	SE	SW	NW	Av.
1	YTD (1.0)[Z]	1150	21.	14.	12.	14.	15.
		1420	6.8	9.9	12.	10.	9.7
		1645	9.2	6.8	6.5	7.8	7.6
		2300	2.4		5.1		3.4
2	Healthy	1150	10.2	7.5	6.5	6.8	7.7
		1420	6.8	6.1	9.5	11.	8.3
		1645	4.8	6.5	6.8	4.4	5.6
		2300	2.7		2.7		2.7
3	YTD (1.0)	1215	7.5	8.2	15.	10.	10.
		1450	11.	8.5	9.9	7.8	9.3
		1700	8.2	8.2	7.8	8.8	8.3
		2310	2.7	4.4	4.4		3.9
4	Healthy	1215	7.5	7.5	7.5	7.1	7.4
		1450	8.2	10.	8.2	8.5	8.8
		1700	4.4	4.1	6.8	6.8	5.5
		2310	3.1		2.0		2.6

[Z] A rating of 1.0 represents a tree with some defoliation and die back, but the complete original outline of the tree is still clearly visible.

TABLE 4.4

LEAF-WATER POTENTIAL OF 'VALENCIA' ON ROUGH LEMON,
WITH AN WITHOUT CITRUS BLIGHT, MEASURED AT
12:30 P.M., FEBRUARY 16, 1973 (IN -BARS)

	Quadrant				
Condition	NE	SE	SW	NW	AV.
Healthy	9.5	5.1	5.4	5.7	6.5
Blight	15.	11.	20.	19.	16.
Healthy	8.5	7.5	9.2	6.8	8.0
Blight	13.	14.	19.	14.	15.

trees that were affected by blight of YTD, this would suggest that the vascular system supplying the leaves with water had been restricted.

Water stress of 'Valencia' trees on rough lemon stocks differed greatly between healthy and sick trees. Even greater differences in leaf-water potential than those measured between healthy and YTD infected trees might have occurred if the YTD trees had not had fewer and smaller leaves. Thus, a disturbance in translocation of water may have already resulted in a partial defoliation of the YTD trees.

The Scholander pressure bomb can only be considered as one tool to aid in better understanding how a tree is affected by a particular pathological disturbance or different rootstock.

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4.2 Intermittent Spray and Soaker Hose Irrigation of 'Early Amber' Peach Trees to Alter Plant Water Stress and Fruit Size

Paul L. Ryan (a master's thesis)

Water serves the following general functions in plants: (a) as the main constituent of physiologically active tissue, (b) as one of the major reagents in photosynthesis, (c) as a media which transports salts, sugars, and other solutes from cell to cell and organ to organ, and (d) as the solvent which maintains turgidity necessary for cell enlargement and growth (19). There are probably no plant processes that are not affected by water deficits. Plant water deficits lead to dehydration of the protoplasm lowering the capacity for photosynthesis. Guard cells, as well as other cells in plants, lose turgidity when exposed to a water stress which in turn causes them to shrink and close the stomates. Although closing the stomates reduces water loss by transpiration, it also decreases the gas exchange between the leaves and atmosphere. Therefore, with a lesser amount of carbon dioxide entering the leaves, photosynthesis is greatly reduced. In addition to reducing the rate of photosynthesis, plant water stress sometimes increases the respiration rate. Water stress, coupled with the side effects of reduced photosynthesis, decreases growth of plants over-all.

Water deficits reduce not only the total amount of growth, but also the pattern of growth. The root-shoot ratio, thickness of cell walls and leaves, cutinization, and lignification are often increased by water deficits. Conversely, water deficits usually reduce leaf area (19).

Soil moisture, atmospheric evaporative demand, and rates of water absorption and loss are factors which control plant hydration. In the past, scientists placed major emphasis on the soil water stress phase of the soil-plant-atmosphere water continuum. However, in recent years it has been determined that plant growth is related more to plant water stress than to soil water stress. During hot, sunny days with high atmospheric evaporative demand, measurable water deficits occur even in plants growing in soil near field water capacity or in dilute water cultures (19).

The internal water balance of a plant depends on both the rates of water absorption and water loss. At a given soil moisture content, the rate of water absorption is determined by many factors: extent and efficiency of the root system, free energy of the soil moisture, and certain conditions of the soil such as temperature and aeration (19). The major portion of water lost by plants is by the process of transpiration. The rate of transpiration is affected by leaf area and structure, aperture of stomates, and atmospheric factors such as temperature, wind, and relative humidity which determine the vapor pressure gradient from leaf to air (19).

This experiment attempted to increase fruit size of 'Early Amber' peaches by reducing plant water stress in the trees. Low chilling, short-cycle peaches grown in Florida require from 68 to 70 days to go from bloom to fruit maturity. Selective removal of all but about 350 fruit per tree is required if peaches are to reach the 1 7/8 to 2 inch size required for very early markets. This fruiting situation is unique, since long-cycle, northern peaches have potential for greater size and require less severe thinning. The experiment tested the ability of drip irrigation (soaking), intermittent spraying, and recommended overhead sprinkler irrigation (experimental control) to maintain high water potentials and thus possibly increase fruit size.

Drip irrigation is the application of water at a slow rate through a low pressure plastic tubing system on the soil surface or below ground. Less water is necessary to maintain optimum soil moisture with drip irrigation than with other irrigation systems even though daily irrigations are usually required (13). Although Florida receives a relatively abundant rainfall compared to arid areas, water utilization and conservation are of prime concern to Florida agriculture because of sandy soils which drain and dry out rapidly.

Drip irrigation, developed after World War II, is still without sufficient experimental data to verify its superiority over other irrigation systems (13). Research must be conducted in a particular area to test the effectiveness of drip irrigation under conditions indigenous to the area. The frequency of emitters along the lines and the rate of irrigation depend on variables such as water movement within the soil, shape of crop canopy, and water requirements of the crop. Preliminary data show that yield increases of 30% have been reported for grapes, 20 to 50% for orchard crops, and 50 to 100% for certain vegetable crops (13). Halsall (12) reported an increase in yield of 25% for strawberries due to drip irrigation.

The results of the experiments conducted to date indicate that drip irrigation has the following potential advantages: (a) larger yields, (b) accelerated growth, (c) water conservation, (d) better weed control because weeds cannot grow in dry areas between rows, (e) use of poor quality water, high saline waters cause less damage when applied through drip systems than with sprinklers, (f) no run-off on hillsides or rolling ground, and (g) fertilizers can be applied simultaneously through the system with water (13). On the other hand, drip irrigation has the following potential disadvantages: (a) clogging of the emitters with minerals in the water, (b) salt accumulation in the soil near the emitters, and (c) possibility of waterlogging the root zones which can cause root disorders (13).

Agricultural engineers are designing and testing filtration systems to reduce, if not eliminate, clogging of the irrigation systems. Suspended solids, organic matter, and chemical deposition are the three major types of substances that clog drip irrigation systems (12). Wire screens and other types of relatively simple filters can remove both suspended solids and organic matter from the system. Chemical deposition is the most difficult type of clogging to avoid (12).

Goldberg, Gornat, and Bar (10) observed a concentration of soluble salts near the soil surface, especially midway between nozzles, on carnations growing under drip irrigation. Salts accumulated in the fall beyond recommended limits within the first 6 inches under young, drip-irrigated avocado trees in San Diego County, California (11). However, winter rains effectively leached these accumulated salts.

Nothing but constant vigilance can prevent the potential disadvantage of waterlogging. Waterlogging not only wastes water, but can also kill crops. Further experimentation is needed to determine the water capacity for each crop under a given set of conditions (13).

For countries with limited water supply such as Israel, the advantage of water conservation far outweighs all the disadvantages of drip irrigation (10). Although Florida's water supply is not yet limiting, it is not infinite. As the urban demand for water increases in Florida, the necessity to maximize the use of water for agriculture increases.

Intermittent spraying improves a crop's above-ground environment, as well as soil moisture profile. With its relatively high heat capacity, water is an excellent temperature moderating agent for an environment. Water applied through sprinkler irrigation systems has been used to release latent heat to protect plants from freezing (15). At the other end of plant temperature ranges, researchers have performed experiments testing the cooling effect of applied water evaporating from the surfaces of plants. A review of the frost protecting ability of water will not be presented because this research was concerned with only the ability of sprayed water to relieve heat stress.

The level of incident energy received by plants is directly related to the intensity of solar energy received by the environment of the plants (15). High levels of incident energy can create unfavorable environments for plants by increasing the temperatures of the air, plants, and soil above the optimum for growth (15). Plant temperatures determine both the rates of photosynthesis and respiration but do not directly influence factors such as plant nutrients, CO_2 concentration, and soil moisture (19). Since net assimilation rate is the difference between photosynthesis and respiration rates, it also is affected by plant temperatures.

An increase in transpiration is a major response of plants to net energy flux. Transpiration rate usually exceeds the ability of a root system to supply water during hours of high energy load (15). Water deficits develop under these conditions (15).

Atmospheric evaporative demand (evaporative demand), determined by the radiation flux, relative humidity, and wind velocity along with air temperatures, is the major determinant of transpiration rate (27). However, large evaporative demands on plants result in stomates closing which increases stomatal resistance (27). All terrestrial plants are believed to regulate the flow of water in this manner (29). However, as Teare et al (27) demonstrated, the extent of this kind of control varies among plants. They use a diffusion porometer to show that under the same atmospheric conditions, the stomata of sorghum close more than those of soybeans, even though sorghum has approximately twice the weight of roots per unit volume of soil as soybeans and more water in its soil moisture profile than soybeans due to its reduced evapotranspiration.

Extreme heat stress causes considerable, if not total, damage to a crop. Tiny plants may be stunted or burned off if heat stress occurs during seedling emergence (15). Water shortage during blooming can cause blossom drop with crops such as beans and tomatoes (15). High soil temperatures can force lettuce seeds into dormancy (15).

Although drip irrigation is considered the most efficient means of supplying water to soil, it does nothing more for plants than supply soil moisture. Irrigation water applied by a sprinkler system initiates a complex energy transfer (25). Theoretically, wet-bulb temperature and vapor pressure increase causing an increase in relative humidity as sprinkled water evaporates (25). Very accurate, quick-responding instruments are required to record the extent of increase in relative humidity caused by sprinkling (25). Increases in relative humidity caused by sprinkling have not been successfully measured for tree crops (28). On the other hand, successful measurements of air, plant, and soil temperatures have shown the cooling effect of the evaporation of sprinkled water (6). Sprinkler irrigation may cause other favorable effects. It is becoming increasingly used in California's Imperial Valley because it reduces soil salinity and improves seedling emergence (25). Increases in yield without reduction in quality need to be demonstrated with intermittent spraying irrigation to justify the expense of both extra water and equipment.

In 1968 Chesness and Braud (6) attempted to find an optimum sprinkling rate and cycle for cooling strawberry plants exposed to a given set of weather conditions. They recorded air, leaf, and soil temperatures with copper-constantan thermocouples before and during sprinkling of a Louisiana strawberry field during late May and early June.

The average temperature reduction for ambient air 6 inches above the black plastic ground mulch was 16°F, while leaf temperature reductions averaged 23.9°F. The ground surface temperatures where water was sprinkled continuously for a 30 minute period between 1 and 3:30 p.m. were lowered an average of 7.8°F. Overall, Chesness and Braud found that the sequential cycle of 15 minutes on, off, and on at a rate of 0.08 inches/hr provided the largest leaf and air temperature reductions. Only 45% of the temperature reduction gained during the first 15 min on-period was lost during the first 15 min off-period.

Middleton and Proebsting (20) conducted experiments to test the effectiveness of overtree sprinkling in cooling 'Early Italian' prunes. High temperatures have been suspected as a possible cause for leafcurl and internal browning in 'Early Italian' prunes. Middleton and Proebsting also investigated the possibility of reducing these two diseases by cooling. They tested various sprinkling rates and starting temperatures in Washington during the growing seasons of 1967 through 1969. The temperature of fruit exposed to the sun were reduced slightly more than the temperature of the shaded fruit. Although leafcurl was reduced by sprinkling, no significant reduction of internal browning was observed.

Experienced grape growers in the San Joaquin Valley in California attribute large losses both in yield and quality to the excessively warm and dry conditions indigenous to the area from June through September (9). Gilbert, Meyer, and Kissler (9) attempted to cool both Tokay and wine grapes by evaporative cooling of sprayed water during the growing seasons of 1967 through 1969. Both sequential and continuous spraying operations were conducted. A negligible amount of water was added to the soil because the spraying rates were only 0.01 to 0.06 inches/hr. Analysis revealed that a cycle consisting of a 3 min on-period followed by a 15 min off-period was as effective as other cycles with relatively longer on-periods. This cycle lowered air temperatures 7 to 10°F, raised the relative humidity, and reduced plant (leaf and berry) temperatures 15 to 25°F. Spraying increased the yield of Tokay grapes 20% or more. Although spraying advanced the color formation of Tokays, sugar content was lower than in the unsprayed grapes. Yield measurements of wine grapes were not made because, in wine grapes, quality is considerably more important than quantity. Overall in wine grapes, spraying caused a delay in sugar formation and an increase in acidity. The quality data revealed that wine grape varieties responded differently suggesting variety adaptation.

Howell, Hiler, and van Bavel (14) tested the response of southern peas to mist irrigation. They experimented with a misting system that applied water at the rate of 1.25 mm/hr in cycles with alternating on-off periods of 5 min each during afternoon hours. The only benefit derived from the misting was the improvement of the microclimate by reducing the atmospheric demand because of a plastic covering on the ground under the plants. The misting increased on the average leaf water potentials by 3.8 bars and lowered leaf temperatures by 4.0°C. Up to 60% increase in yield was observed in one treatment.

In sequential articles Unrath (29, 30) described the effects of evaporative cooling in 'Red Delicious' apples. The overtree sprinkler system operated continuously in North Carolina with an application rate of 0.056 inches/hr whenever the air temperature exceeded 87°F. The fruit, rather than leaves, bark, or air, exhibited the largest amount of cooling, with an average reduction of 12.1°F and 8.1°F in 1969 and 1970 respectively. Various fruit quality tests were also performed. Overtree irrigation improved fruit size and shape in 1969 but not in 1970. Although evaporative cooling did not improve size and shape in 1970, it reduced cork spot and bitter pit that year. Overtree irrigation increased total soluble solids but had no influence on internal breakdown measured after four months of storage at 32°F.

From the variety of responses observed on the various crops irrigated with spraying systems, there appear to be no general rules to enable researchers to transpose data from one crop to another. Since crops have different physical characteristics such as metabolic rates and growth patterns, studies on the effects of evaporative cooling must be conducted on each crop (15). Even then, researchers must take into account environmental differences when analyzing data. However, with water becoming an increasingly valuable resource, its use and effect on crops must be carefully evaluated.

Prior to the widespread use of water potential measurements, techniques to measure water content, water deficits, osmotic pressure, and relative turgidity were used as determinants of plant water status (19). Measurements made with these older techniques are less useful than water potential measurements because the same values obtained from different species or even the same plant do not necessarily represent the same water status (19). Also, the experimenter must know several facts about the leaves such as age and species before any meaning can be related to the measurements obtained by the older techniques in terms of plant water status (19). Water potential, conversely, is generally directly comparable for leaves of different species and age (17). Water potential measurements not only indicate the amount of water in a plant, but also the movement of water into and through plants (17).

Water moved from high water potentials to lower ones (i.e., from a less negative to a more negative potential) (17).

"Water potential is defined as the difference between the partial specific free energy of water in the part of the system under consideration and that of pure water at the same temperature and at a pressure of one atmosphere." (7). The water potential of pure water at 1 atm and a given temperature is arbitrarily set at zero (7). Atmospheres of pressure have generally been accepted over dynes per square centimeter, ergs per cubic centimeter, and centimeters of water as the units expressing water potential (7). Since water in the soil-plant-atmosphere system has less free energy than pure water at the same temperature, water potential is expressed in negative atmospheres of pressure rather than positive ones (7).

Since the turn of the century the cohesion theory has generally been accepted as the explanation of how sap is lifted several times higher by a tree than by a vacuum pump. According to the theory a "pull" created by water evaporating from the leaves causes cohesive water to rise up the tree through the xylem (26). The validity of this theory was considerably challenged until a pressure bomb to measure sap pressure of plants was developed by P. F. Scholander et al. (26). Presently, the pressure bomb technique provides the optimum combination of accuracy and practicality for measuring water potentials in the field.

There has been a lot of controversy over the accuracy of the pressure bomb technique. Thermocouple psychrometers are generally considered to provide a more accurate means of measuring leaf water potentials. According to Boyer (5) the major difference in the water potentials measured by the two techniques is probably the difference in the potential between water in the xylem and water in leaf cells. He explains the difference as the resistance to water flow between the leaf cells and the xylem in transpiring plants.

Scientists now agree that calibration curves should be made for each species at particular stages of development because the relationship between xylem and leaf water potentials is not the same for different species and shifts with plant age among plants of the same species (3,8). Xylem water potential measurements made by pressure bombs are usually more negative than leaf water potentials, determined by thermocouple psychrometers. Xylem water potentials include an osmotic potential which leaf water potentials, determined by thermocouple psychrometers, do not have (5). The osmotic potential factor makes the xylem water potential more negative, hence, all the more difficult to explain why the potential in xylem is lower than in the leaves. Barrs et al. (2) suggested that these differences in potential readings are considerably higher than leaf water potentials or pressure bomb readings are lower than xylem water potentials. Both discrepancies may be true. Heat produced by respiration (1) and leaf resistance to water vapor transfer (4) are factors that are believed to cause unexpectedly high leaf water potentials measured by thermocouple psychrometers.

Klepper and Ceccato (17) suggested that pressure bomb readings are possibly lower than actual xylem water potentials. Lag time for water to move from the lamina inside the pressure chamber to the cut surface of the petiole allows the actual xylem water potential reading to be overshot, indicating lower water potentials. In addition to lag time, the tissue in the petiole, made dry at the time of removal by water in the vessels withdrawing from the severed area, reabsorbs some of the water forced by the pressure bomb back to the cut surface (17). If pressure is increased too slowly in the pressure chamber, recorded readings are too high indicating lower water potentials than if the pressure had been increased at a normal rate (31). According to Waring and Cleary (31), this fact is not easily explained. With such inherent errors in the technique, overshooting the actual xylem water potentials is inevitable, and the values obtained by pressure bombs must be accepted as being too dry (17). To help compensate for this error, readings from pressure bombs should be taken to represent xylem water potentials without adding the osmotic potentials (5). Neglecting the osmotic potentials avoids the rather tedious task of determining them.

The use of pressure bombs is a rapid and simple method of determining leaf water potentials. Because thermocouple psychrometers require careful temperature control and a source of electrical power, their use in the field is limited. The dye method described by Knipling (18) is good for field work, but accurate only if the approximate values of water potentials to be measured are known in advance so that the intervals of osmotic potentials of the known solutions can be small. Otherwise, too many leaves and solutions would be required to determine leaf water potential accurately within the short period of time before the potential changes. Overall, the pressure bomb is the best and most practical method to determine leaf water potentials in the field.

There exists a need, however, for nondestructive, continuous measurement of plant water stress under the influence of various environmental factors and how subsequent plant growth is affected. This need has been partially met by linear variable displacement transducers (LVDTs), also referred to as linear variable differential transformers. The use of LVDTs to measure plant water status operates on the assumption that the expansions and contractions of the monitored plants are somehow related to the plant water status. LVDTs are solid state instruments sensitive to 0.00025 inch which is more sensitive than any hand measurement such as with calipers. The wide range tolerance of most field conditions renders LVDTs excellent instruments for field work.

Tukey (28) continuously measured the expansions and contractions of apples, tomatoes, and cucumbers grown in greenhouses and growth chambers. He concluded that a transducer-recorder system assembly can determine (a) the speed and magnitude of plant and fruit responses to environmental changes, (b) growth rates of fruit exposed to various environmental factors, (c) amount of time of fruit enlargement and contraction, and (d) differences in growth of fruit of the same plant, of the same treatment but different plants, and of different treatments.

Namken, Bartholic, and Runkles (23) used an LVDT system to monitor cotton plant stem radii as an indicator of relative plant water stress. They found that plant stem radii were very responsive to changes of incident energy at the evaporating surfaces. The data showed a reversal from expansion to contraction and vice versa, depending on whether the energy received by a plant was increasing or decreasing.

Klepper, Browning, and Taylor (16) illustrated with cotton plants a diurnal hysteresis between stem diameter, measured by an LVDT, and leaf water potential, measured with a pressure bomb. They concluded that there is no single-valued function relating stem diameter and leaf water potential.

In continuing their work with cotton plants, Namken, Bartholic, and Runkles (24) observed leaf water potentials recovered more rapidly than stem contractions late in the afternoon. Stem contractions as measured by LVDTs were found to be more sensitive to plant water stress under conditions of high stress than low stress.

Molz and Klepper (21) assumed that water potential gradients cause radial water flow in cotton plants. As the water potentials of leaves and stem xylem become more negative, water begins to flow along a water potential gradient from the phloem and associated tissues into the xylem in which it rises up to leaves from where it transpires. Water loss by this method causes external tissue to shrink, accounting for the contraction of the stem. As the evaporative demand decreases in late afternoon, the direction of radial water flow is reversed due to a reversal in the relative water potentials causing the phloem and associated tissues to swell.

Continuing their studies with cotton plants, Molz and Klepper (22) recently attempted to establish a direct relationship between stem contractions and expansions with xylem water potentials. They determined for cotton plants that 92% of the stem contractions occurred in the phloem and associated tissues, whereas only 8% in the xylem. Most of the xylem's contraction and expansion is presumed to occur in the immature (living or partly living) xylem.

Although Molz and Klepper were not able to derive a direct relationship between stem diameter changes and plant water status, the work of other scientists allows for determination of relative plant water status with the use of LVDTs. Research with wheat (8) and sorghum (3) have evidenced a linear relationship between leaf water potentials measured by thermocouple psychrometers and xylem water potentials measured by pressure bombs. The possibility of obtaining a direct relationship between plant stem contractions and expansions and plant water status is now increased with either leaf water potential or xylem water potential representing plant water status. Until such a direct relationship can be determined, LVDTs, by measuring stem radial or diameter changes, can still provide a means of continuously monitoring plant water stress.

Willey and Unrath (32) improved Tukey's technique to use LVDTs to continuously monitor fruit growth in the field. The success of their one season experiment using a specially designed mount with an LVDT indicates the versatility of LVDTs to measure more than stem (trunk) growth of a plant.

4.2.1 Methods and Materials

Treatments: In 1973 'Early Amber' peach trees were irrigated using intermittent daily spraying, modified soaker hoses, and recommended overhead sprinklers. Because trees could not be prevented from receiving water from the orchard's overhead sprinkler system without drastically altering their environment, the spraying and soaking systems supplied supplementary water to their respective trees.

Sprayers and soaker hoses were used to water single tree plots of 6-year-old 'Early Amber' peach on 'Nemaguard' stock at the University of Florida Horticultural Unit near Gainesville (Lat. 29° 39' N, Long. 82° 19' W). Treatments were replicated 4 times. The soil of the peach orchard is a Kanapaha fine sand belonging to the loamy, siliceous, hyperthermic family of Grossarenic Paleaquults.

Every 80 ft a clay tile, (placed 3½ to 5½ ft deep), runs the length of the orchard. Soil moisture readings from about 9 to 16% by volume represent field capacity for the soil within the first 3 ft. The orchard's overhead sprinkler system is capable of applying 1 inch of water in about 5 hr of operation.

The spraying system consisted of a 6 ft PVC pipe tied in the bowl of each tree with a Rain Bird Model 2600-F surface spray head. This system was automatically turned on 15 sec every 10 min between 8 a.m. and 6 p.m. EST spraying 30 gal of water on each tree every day of the experiment. This cycle was determined by trial and error so water evaporated or ran off to the ground just before the next spraying.

A 25 ft commercial soaker hose encircled the base of each tree of the soaking treatment. Stiff wire holders kept the hoses inverted to ensure the most direct application of water to the soil. Water was periodically added through the soaker hoses to maintain a soil moisture profile similar to that under the sprayed trees.

Thinning: Trees were thinned on April 14, 1973, when ovules were 12 to 15 mm in length, indicating that cytokinesis had started and that fruit were in Stage 3 of growth. The number of fruit on each tree was counted before thinning to determine the number of fruit that should be removed from each tree in order to equalize the fruit load among treatments. After thinning, one tree of each treatment had about 79 fruit, one about 200, and two trees about 300 fruit each (normal fruit load). The unusually poor set in the orchard provided relatively few trees with the normal fruit loads.

Irrigation and Soil Moisture: The irrigation treatments were started on April 13, 1973. In attempting to maintain at least 50% of field capacity, a total of about 500 gal of water was applied to each tree in two irrigations by the orchard's overhead irrigation system from the middle of April to the last picking on May 15. In addition, between April 13 and May 15, the spraying and soaking systems each applied about 1000 gal of water to each tree in their respective plots averaging approximately 30 gal daily. The orchard's overhead irrigation system applied about 400 gal of water to each tree on May 24. The spraying system supplied about 30 gal daily to each tree (about 500 gal per tree) during the experiment's 16-day postharvest period (May 16-31). With about 3 inches of rainfall during the last half of May, only 100 gal were needed for each soaked tree to maintain soil moisture profiles similar to those under the sprayed trees.

Soil moisture was monitored in the treatments with a neutron moisture meter (Troxler "depth moisture gauge") at depths of 1, 2, and 3 ft. Readings were taken twice per week from April 20 to May 31 in an aluminum access tube under one tree of each treatment.

Monitoring Plant Water Status (LVDTs and Pressure Bomb): Two techniques were used to monitor plant water stress. A Daytronic Model DS200 "linear variable displacement transducer" (LVDT) mounted on the trunk of one tree of each treatment 1 ft above the ground was used to continuously monitor relative changes of the trunk radius (fig. 4.2). The monitored trees had fruit loads of about 300. A Scholander pressure bomb was used to determine leaf water potentials hourly from 6 a.m. to 6 p.m. EST on May 1, 1973.

A 4-inch galvanized steel strip was the major part of each LVDT mount. A hole was threaded with a ½-inch-20 tap at one end of the steel strip. An LVDT was screwed into this hole and secured firmly into position with a holding nut. A smaller hole was drilled through the other end of the steel strip through which a 4-inch-long, ¼-inch lag bolt was later placed to firmly hold the steel strip so that the LVDT could be pressed against the tree trunk. The head of the lag bolt was removed, and the remaining stud threaded with a ¼-inch-20 die before the bolt was screwed 2 3/8 to 2 3/4 inches into the tree trunk. By screwing into the heartwood, the lag bolt provided a stationary frame of reference. Before fastening the steel strip to the protruding end of the lag bolt with a pair of nuts and lock washers, the steel strip was curved to follow the curvature of the tree trunk. Having the lag bolt screwed into the tree trunk several inches horizontally away from the point of contact where the LVDT probe touched the tree was an improvement over a previous LVDT mount used. If the lag bolt had been placed vertically above or below the LVDT sensing probe, the flow of tree sap in the phloem tissue and water in the xylem tissue might have been obstructed in such a way as to effect changes from the normal contractions and expansions of the tree trunk.

A Daytronic Model DS100 LVDT was used to monitor relative diameter changes of one fruit about 7 ft above the ground on the north side of each tree with an LVDT on its trunk. About a 2-inch strip of 1/16-inch strap metal and two commercial hose clamps, a 2¼-inch and a 1-inch one, were used to make mounts for the smaller LVDTs. The two hose clamps were brazed to the metal strip on opposite ends of the same side. The metal strip was bent into a right angle near the 2¼-inch clamp with the two clamps on the outside. A hole was threaded with a 3/8-inch-24 tap at the junction of the metal strip and the 2¼-inch hose clamp. The end of the LVDT casing nearest the sensing probe was threaded with a 3/8-inch-24 die before the LVDT was screwed into the hole in the LVDT mount. The 1-inch hose clamp secured the mount to a branch on a tree, while the 2¼-inch hose clamp firmly held a peach. Thin, narrow foam rubber strips were carefully placed to cushion the branch and peach from the hose clamps. The fruit LVDTs were mounted on May 4, when most of the fruit were already too big to fit, and were removed on May 11.

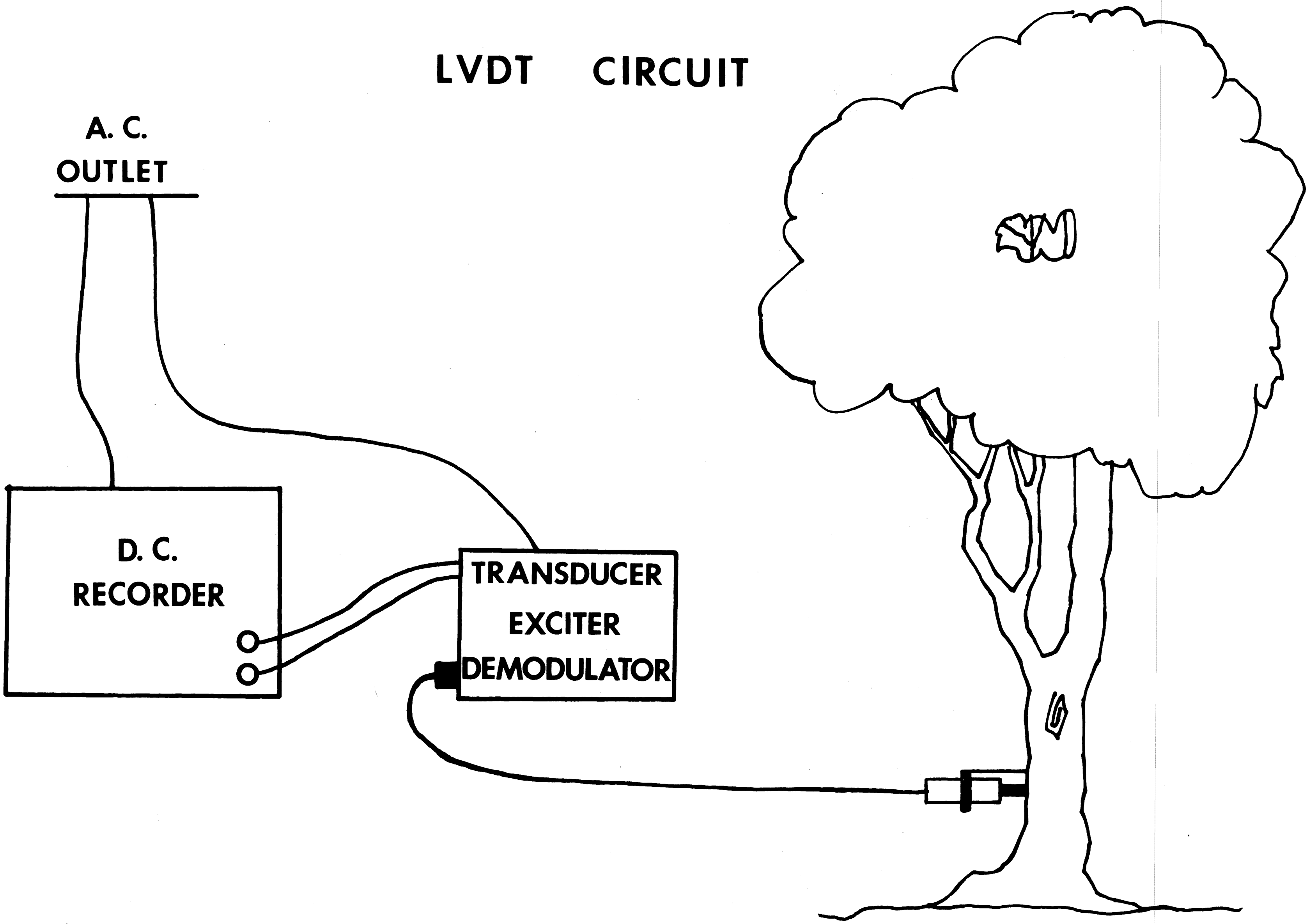

Fig. 4.2. Schematic showing the generalized circuitry and use of the linear variable differential transducer.

The six LVDTs from the three monitored trees were wired directly to a stepping switch in a nearby equipment shelter. The shelter also contained a Daytronic Model 201B "transducer esciter demodulator" and an Inter-Matic clock with a 10 min cycle. The demodulator converted ordinary 60 cycle current into 3 kc current. The high frequency current then went to the LVDTs where voltages proportional to the mechanical displacements of the sensing probes returned to the demodulator. The demodulator then converted the output signals to D.C. millivolts which were transmitted to an Esterline Angus Model T171B millivolt recorder where they were recorded on chart paper (fig. 4.2). Because the LVDTs of this experiment and another experiment shared the same demodulator, the stepping switch and Inter-Matic clock were set so a 1 min reading from each LVDT was recorded every 20 min during the experiment.

A Scholander pressure bomb was used to measure leaf water potentials. In order to make comparisons between trunk radial changes and leaf water potentials, leaves from only the trees with LVDTs were used for leaf water potential measurements. A razor blade was used to cut the leaves from the trees. Two leaves from each of the three monitored trees were removed for measurements hourly between 6 a.m. and 6 p.m. EST on May 1. Pressure bomb readings were attempted on another day, but May 1 was the only cloudless day on which readings were taken. Clouds shadowing the trees reduce the energy load on the trees. Care must be taken on partly cloudy days to take readings only after a tree has been exposed to direct sunlight for several minutes. To minimize the variability due to physiological characteristics and age, only shaded, mature leaves at chest height from the north side of the trees were used. The leaves were removed and transferred to the pressure bomb as rapidly as possible where the petiole was carefully placed through the air-tight rubber compression gland in the screw-on lid of the pressure bomb. After securing the lid, pressurized nitrogen with a maximum pressure of 400 lb was released into the pressure bomb until tree sap exuded from the xylem tissue at the cut surface of the petiole. The negative values of the noted gauge readings converted to bars were considered the leaf water potentials.

Hand Caliper Trunk Measurements: Trees were marked 1 ft above the ground on the north and south sides of the tree trunks. Trunk diameters were measured at these points with a hand caliper periodically throughout the experiment.

Fruit Growth Measurements: On April 13, the day before thinning, samples of 15 fruit at chest height were randomly selected around the perimeter of each tree to determine if irrigation treatments influenced the rate of peach growth. All of the designated fruit ranged from 2.5 to 4.0 cm in diameter on April 13. Diameters of these fruit were again measured on April 25, May 2, and May 7.

Fruit Analysis: Mature fruit were harvested in three pickings, using color as an index on May 8, May 11, and May 15. Fruit were sized and weighed after each picking. Ten fruit from each tree after each harvest were pressure tested for firmness with a Magness-Taylor pressure tester using a 5/16-inch plunger. Fruit with the skin intact were used and five fruit were analyzed with a refractometer for total soluble solids.

Statistical Analysis: Statistical analysis of all data was carried out in all cases where such proceedings were valid. Comparative data analysis of treatments applied only to trees with about the same fruit load because of the interacting effect of treatment and fruit load. Fruit data from trees with fruit loads of about 79 and 200 were not analyzed because of lack of replications. Data only from trees with about 300 fruit (normal fruit load) were statistically analyzed because there were two replications per treatment.

4.2.2 Results

Summary of Experiment: LVDTs were used to measure both growth and relative plant water status in both tree trunks and fruit. Trunk and fruit diameters were measured with hand calipers. A pressure bomb measured leaf water potentials. Fruit sizing, maturity, and quality tests were also conducted.

Tree Trunks: The measurements from the LVDTs showed that trunks of the peach trees all followed a similar diurnal water stress cycle. On most days when the orchard's overhead sprinkler system was not used, the trunks increased in radius throughout the nights and decreased starting shortly after sunrise. The desorption (shrinking) phase began shortly after sunrise and continued as the energy load on the trees increased until afternoon. The absorption phase, an increase in trunk radius, started in the late afternoon as the amount of energy incident to the trees decreased and lasted until the following morning when the next desorption phase began (fig. 4.3).

The only significant differences noted from the trunk LVDT data can be related to growth. Diurnal trunk growth is defined as the difference in radial trunk measurements from midnight to midnight. The trunk growth of the sprayed and soaked trees equaled or exceeded that of the control tree most of the days of the experiment. The number of days that the trunk growth of the soaked tree equaled or exceeded the growth of the sprayed tree was almost as many as the number of days that the sprayed tree grew at least as much as the soaked tree (Table 4.5).

Apparently hand calipers were not accurate enough to detect differences in trunk growth which were apparent from

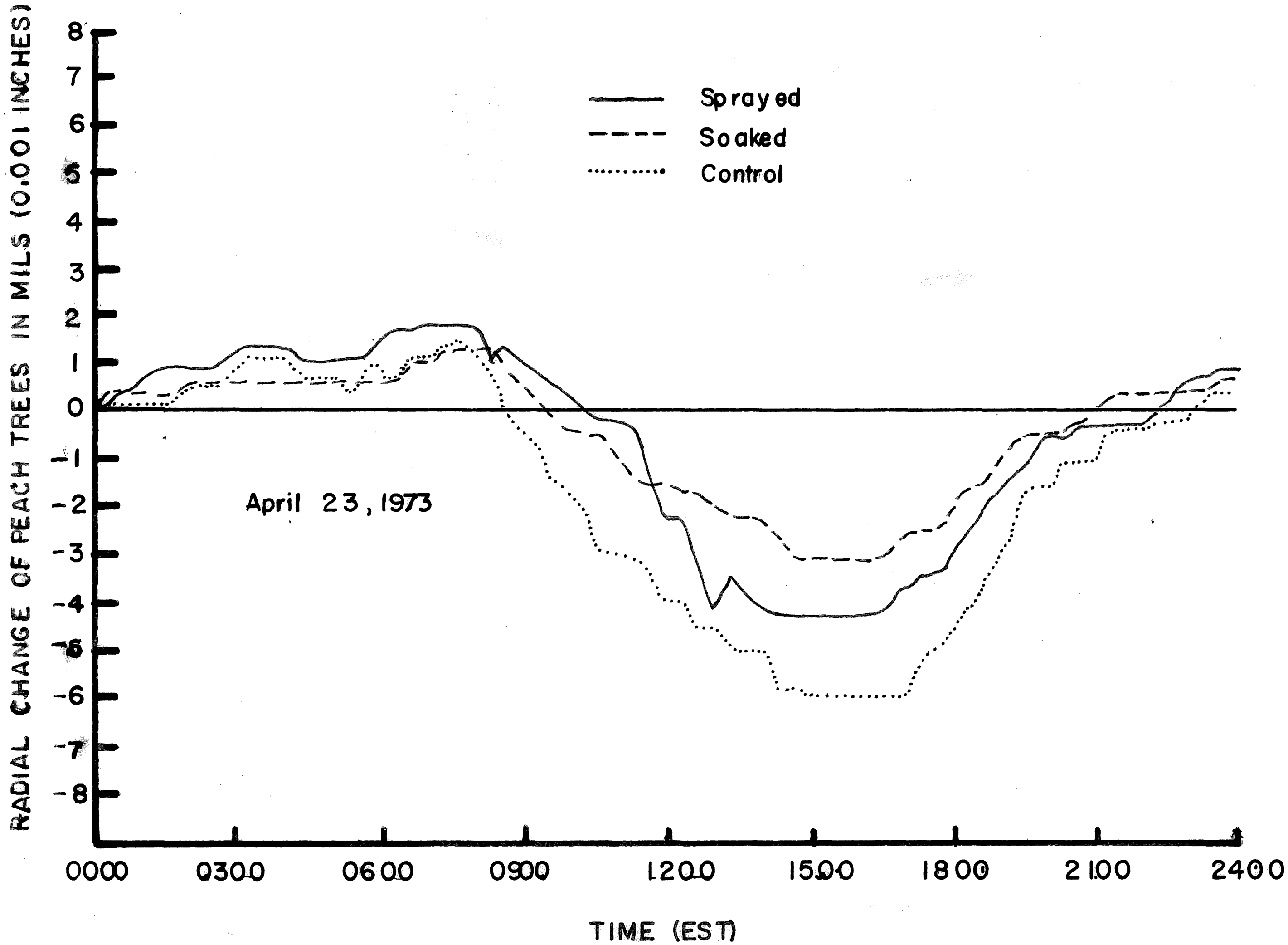

Fig. 4.3. Diurnal plot of peach trunk radii on April 23, 1973. Typical diurnal water stress cycles occurred in the monitored tree of all three treatments.

Table 4.5 Comparison of growth of tree trunks during 33 days of experiment with fruit on trees.

Treatments (Trees monitored with LVDTs)	No. of Days
Sprayed ≥ Soaked	23
Sprayed ≥ Control	24
Soaked ≥ Sprayed	20
Soaked ≥ Control	26
Control ≥ Sprayed	11
Control ≥ Soaked	13

Table 4.6 Comparison of diurnal trunk decreases during 33 days of experiment with fruit on trees.

Treatments (Trees monitored with LVDTs)	No. of days
Sprayed ≥ Soaked	25
Sprayed ≥ Control	17
Soaked ≥ Sprayed	11
Soaked ≥ Control	15
Control ≥ Sprayed	18
Control ≥ Soaked	24

the LVDT measurements. For this reason the hand caliper measurement data were discarded.

A plot of the radial trunk growths of the trees monitored with LVDTs is shown in fig. 4.4. The least square lines were determined for plots of the three treatments by using the method of least squares. The least square line for the control treatment has a slope of 0.41. The growth of both the soaked and sprayed treatments had two linear regressions with point of intersection unknown. Both the sprayed and soaked tree trunks accelerated in growth about a week after the last picking. The slopes of the two least square lines representing the trunk growths of both the sprayed and soaked trees were determined by using a technique described by Draper and Smith.[1] The accelerated trunk growth started on May 21 and 22 for the sprayed and the soaked tree respectively. The slopes of the least square lines representing the sprayed tree are 0.79 for the first line up to May 21 and 1.95 for the second line. The slopes of the lines representing the soaked tree are 0.64 for the first line up to May 22 and 2.39 for the second line. The control tree had not started accelerated trunk growth by the end of the experiment. A monitored tree in the same orchard, with an irrigation treatment similar to the one of the control tree, showed in 1972 accelerated trunk growth several days after the last fruit were removed. The observed increased trunk growth after harvest indicates the beginning of a period of increased vegetative growth. The length of time after harvest for this period to begin in a tree depends on the condition of the tree. The fact that the two treated trees began their accelerated growth after harvest, while the control tree did not, illustrate the importance of soil moisture for vegetative growth. The soaked and sprayed trees commenced accelerated trunk growth about the same time even though the sprayed tree received about 5 times as much irrigated water during postharvest period as the soaked tree. The apparent improvement of the sprayed tree's environment by spraying had no effect on the commencement of the accelerated trunk growth. If spraying had had an advantage over soaking during the postharvest period, this should have become obvious in trunk growth (fig. 4.4). The soil moisture profiles under both the sprayed and soaked trees were near field capacity during the postharvest period. Thus, it appears that only adequate soil moisture is required for trunk growth in the absence of fruit.

Diurnal trunk decrease is defined as the decrease of the trunk radius from the morning maximum, usually around 6 a.m., to the minimum diurnal reading which usually occurs between

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[1]Draper, N. R. and H. Smith, Applied Regression Analysis (New York, 1966), pp. 136-142.

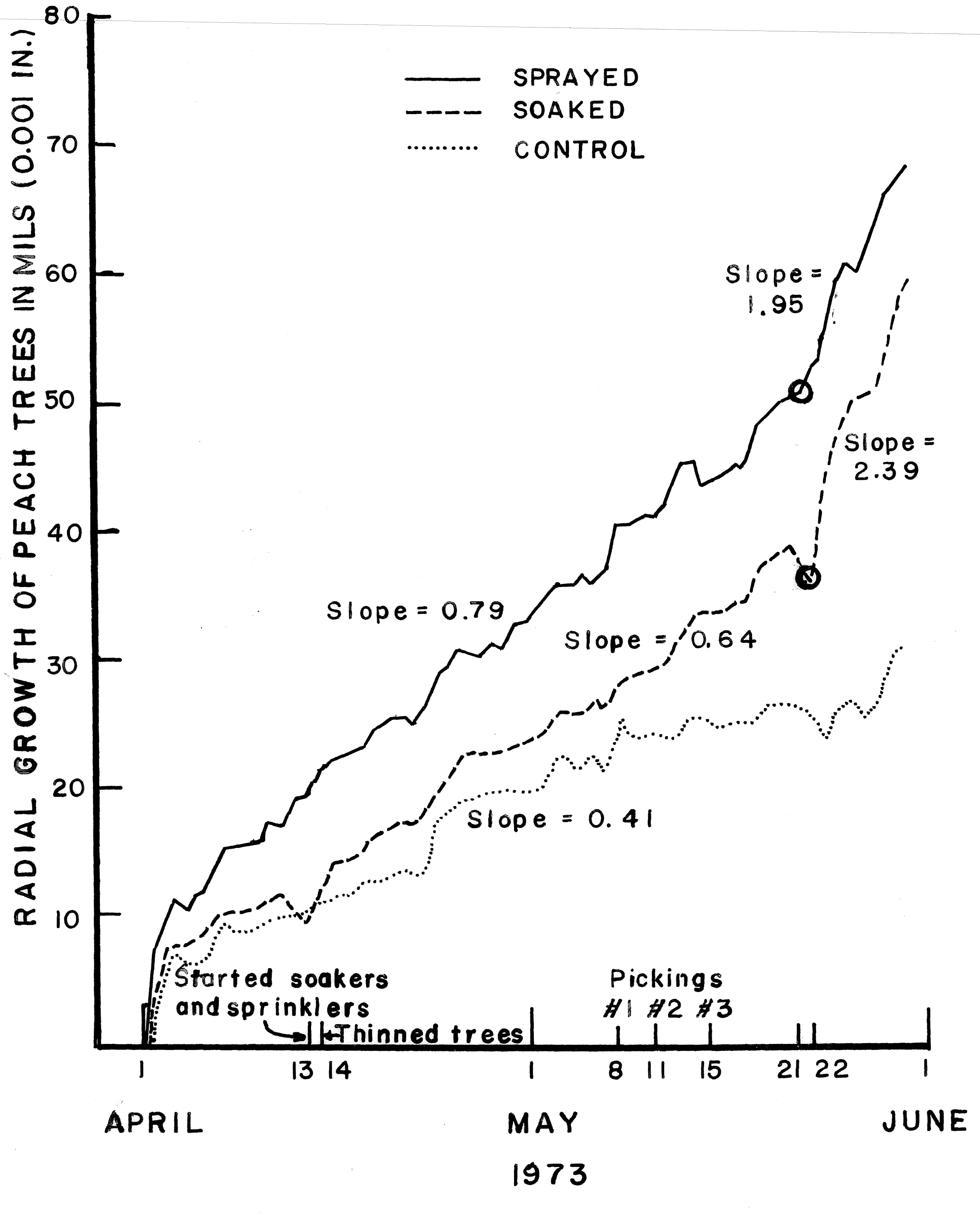

Fig. 4.4. Plots of radial trunk growths. Accelerated trunk growth commenced on May 21 for the sprayed tree and on May 22 for the soaked tree. O indicates intersection of least square lines of growth curves.

2 and 6 p.m. This measurement is the amount of trunk radial shrinkage that occurs during the desorption phase of the diurnal water stress cycle. Diurnal trunk decreases are usually considered to be an indication of water stress; the greater the decrease, the greater the stress. If spraying or soaking or both had relieved water stress, the diurnal trunk decreases should have been less in the trees with the relieved stresses. Although the data in Table 4.6 suggest that the soaked tree had the smallest diurnal decreases, (and, thus, the lowest stress), there exists the possibility of yet another interpretation: the relatively great diurnal trunk decreases in the sprayed trees were due not so much to water stress as to the amount of young, elastic tissue. Presumably, this tissue contracts more when exposed to a given stress than older tissue. Thus, even if the spraying partially relieved plant water stress, the observed diurnal trunk decreases in the sprayed tree may have been as great as those in the control because of the new growth in the sprayed tree.

The diurnal plot of trunk radii on April 24 clearly illustrates the orchard's overhead sprinkler system relieving plant water stress (fig. 4.5). Commencement of the desorption phase was delayed in the monitored trees of each treatment until around 2 p.m. after the overhead irrigation system was turned off. Neither the intermittent spraying nor the soaking treatment noticeably delayed the desorption phase on any day of the experiment. These facts indicate that the supplementary irrigation treatments at most only partially relieved plant water stress.

Leaves: Pressure bomb readings indicate that sprayed trees were under less water stress throughout most of the day than other treatments (fig. 4.6). The water potentials of the sprayed and soaked trees were about equal until around 9 a.m. because both treatments had ample soil moisture to maintain high water potentials during nighttime and other hours of low energy periods. As the energy load on the trees increased around 9 a.m., the water potentials dropped (fig. 4.6). A high water potential was not maintained during the day, but it was higher throughout most of the day in the sprayed tree than in the soaked and control trees. Although no temperature and humidity readings were made, it is believed that spraying reduced the atmospheric evaporative demand on the trees by reducing leaf and air temperatures and increasing the relative humidity. Leaf water potentials of all treatments rose almost as rapidly as they had dropped in the morning as the energy demand on the trees decreased in the afternoon.

Fruit: There was no correlation between the fruit and trunk LVDT data. Most of the fruit were too large to fit inside the 2¼-inch hose clamp on each mount when the LVDTs were finally mounted. Although three types of diurnal water stress

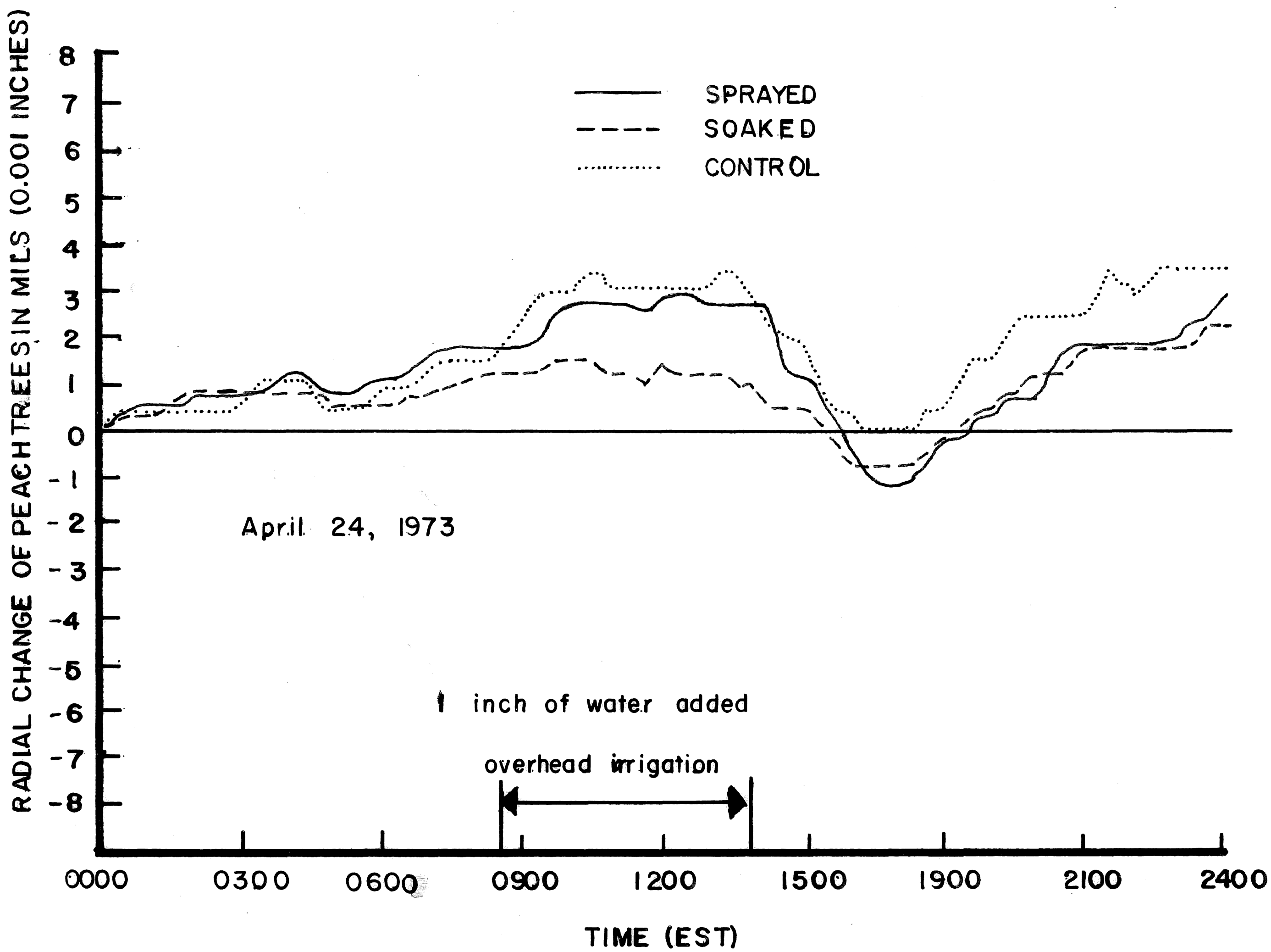

Fig. 4.5. Diurnal plot of peach trunk radii on April 24, 1973. Commencement of desorption phase was delayed until after overhead irrigation system was turned off.

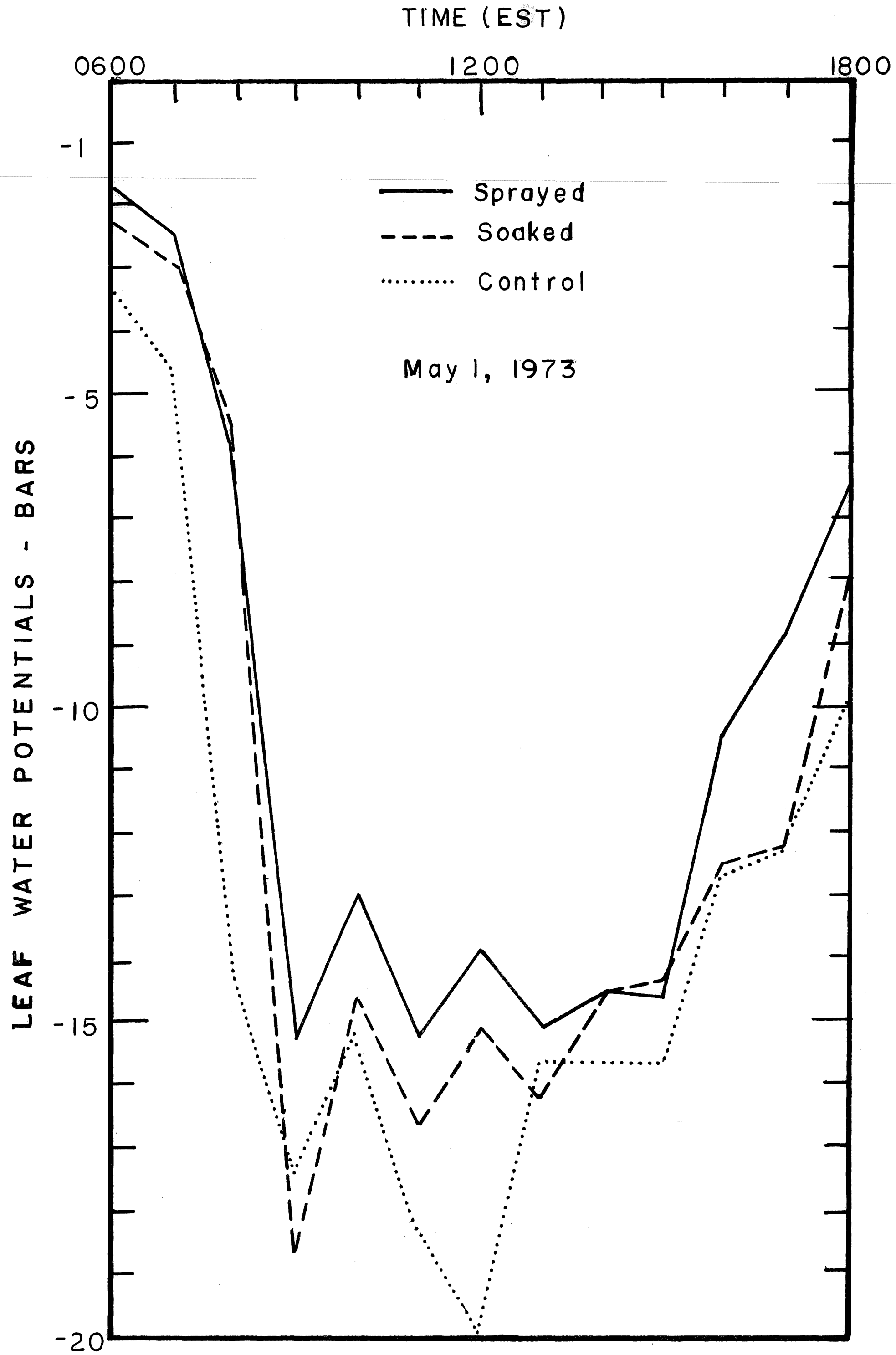

Fig. 4.6. Pressure bomb readings taken on May 1, 1973. Each hourly reading for each tree represents the average of two measurements.

curves were observed before the fruit outgrew the mounts, all three patterns showed considerable daily growth. Because no single diurnal pattern was observed, fruit LVDT data could not be interpreted.

Fruit measurements made periodically with hand calipers indicate that there were no significant differences in the amount of fruit growth between treatments during any of the three periods (Table 4.7). The F-Test was used to analyze data from only trees with normal fruit loads. The average fruit sizes for the treatments were almost equal at the beginning of the experiment. The fact that no significant differences were found may be due to the limited number of test trees. It is apparent that appreciable differences exist, particularly in the first period (April 13-25). The data for the first period showed greater differences in fruit growth between treatments than the sum of differences of the three periods.

The final size data for all the harvested fruit are shown in Table 4.8. To be able to analyze the data with the Chi Square Test, a stronger test for experiments with few replications, the data were separated into two classifications: large and small. Because healthy (normal) peaches 2 inches and larger in diameter are considered commercially valuable peaches, normal fruit, 2 inches or more in diameter, were classified as large (Table 4.9). Similarly, split or diseased or both split and diseased fruit were classified as split and/or diseased fruit and the remainder as normal fruit (Table 4.10).

Both spraying and soaking increased the number of large and split and/or diseased fruit on trees with normal fruit load, but spraying had a greater effect. Increases in the number of large fruit from the trees with about 79 fruit were non-significant. A close look at the data in Tables 4.9 and 4.10 for trees with about 200 fruit reveals that the control tree produced both more large and more split and/or diseased fruit than the soaked tree. These unexpected results were probably caused by the variations in the physiological factors of the trees involved. The data for the trees with normal fruit loads are more reliable than the data from the trees with smaller fruit loads because there were two trees providing fruit replications rather than only one. Because of the greater number of replications and the high significance of the data from the trees with normal fruit loads, it appears that spraying both enlarged the fruit and increased the percentage of split and/or diseased fruit.

Fruit firmness is also an indication of maturity. Spraying and soaking had no effect on fruit maturation, as indicated by the non-significant differences between treatments in the pressure test (Table 4.12).

Table 4.7. Fruit growths for three periods during final swelling of the fruit.

Treatments[z]	Av. Diam. 13. APR (cm)	Fruit Growths During 13-25 APR (cm)	25 APR-2 MAY (cm)	2-7 MAY (cm)	13 APR-7 MAY (cm)
Spraying[y]	3.09	0.84	0.59	0.42	1.85
Soaking	2.87	0.65	0.50	0.44	1.59
Control	2.89	0.58	0.50	0.46	1.54

[z]Treatment values represent average of two trees with normal fruit loads (15 monitored fruit per tree).

[y]No significant differences between treatments using the F-Test.

Table 4.8. Percentage of harvested fruit in each category.

Treatments	Fruit harvested (no.)	Split and/or diseased (%)	Less than 1 3/4" (%)	1 3/4" (%)	1 7/8" (%)	2" (%)	2 1/4" (%)
Spraying	79	8.9	3.8	8.9	17.7	40.5	20.2
Soaking	79	16.5	2.5	0.0	6.3	35.5	39.2
Control	76	14.5	3.9	2.6	9.2	38.2	31.6
Spraying	215	10.7	2.8	9.3	17.2	47.9	12.1
Soaking	212	3.3	8.9	30.2	33.5	22.2	1.9
Control	193	7.2	7.2	14.0	28.0	36.4	7.2
Spraying[z]	298 302	6.15	6.20	15.40	25.50	37.95	8.80
Soaking	285 322	2.15	19.80	33.95	26.45	16.80	0.85
Control	321 216[y]	1.40	24.95	42.25	21.85	9.60	0.25

[z]Treatment values represent average of two trees with normal fruit loads.

[y]Fruit remaining after inadvertent prior harvest.

Table 4.9. Number of harvested fruit classified Large vs. Small

Treatments	Large (2 in or more) (no.)	Small (Less than 2 in) (no.)	Fruit harvested (no.)
Spraying	48	31	79
Soaking	59	20	79
Control	53	23	76
Chi Square Value = 3.638 with df = 2 which is non-significant.			
Spraying	129	86	215
Soaking	51	161	212
Control	84	109	193
Chi Square Value = 56.506 with df = 2 which is highly significant at 0.05%.			
Spraying[z]	281	319	600
Soaking	108	499	607
Control	51[y]	486[y]	537[y]
Chi Square Value = 236.702 with df = 2 which is highly significant at 0.05%.			

[z]Treatment values represent sums of two trees with normal fruit loads.

[y]Fruit remaining after inadvertent prior harvest of one of the trees.

Table 4.10. Number of harvested fruit classified Normal vs. Split and/or diseased.

Treatments	Split and/or diseased (no.)	Normal (no.)	Fruit harvested (no.)
Spraying	7	72	79
Soaking	13	66	79
Control	11	65	76
Chi Square Value = 2.130 with df = 2 which is non-significant.			
Spraying	23	192	215
Soaking	7	205	212
Control	14	179	193
Chi Square Value = 8.866 with df= 2 which is significant at 2.5%.			
Spraying[z]	37	563	600
Soaking	13	594	607
Control	8[y]	529[y]	537[y]
Chi Square Value = 23.339 with df = 2 which is highly significant at 0.05%.			

[z]Treatment values represent sums of two trees with normal fruit loads.

[y]Fruit remaining after inadvertent prior harvest of one of the trees.

Table 4.11. Percentage of fruit harvested during each picking.

Treatments	Fruit harvested (no.)	Picking First 8 MAY (%)	Second 11 MAY (%)	Third 15 MAY (%)
Spraying	79	51.9	38.0	10.1
Soaking	79	40.5	46.8	12.7
Control	76	36.8	25.0	38.2
Spraying	215	60.0	33.5	6.5
Soaking	212	30.7	41.0	28.3
Control	193	40.4	35.2	24.4
Spraying[z]	298 302	40.55	41.60	17.85
Soaking	285 322	30.15	51.15	18.70
Control[y]	321 216[x]	43.60	39.60	16.80

[z]Treatment values represent average of two trees with normal fruit loads.

[y]Treatment values represent values of only one tree with normal fruit load (tree with 321 harvested fruit).

[x]Fruit remaining after inadvertent prior harvest.

Table4.12.Pressure test results in pounds for harvested fruit.

Treatments	Fruit harvested (no.)	Pressure[x] (lbs.)
Spraying	79	15.30
Soaking	79	14.86
Control	76	14.13
Spraying	215	14.83
Soaking	212	12.43
Control	193	16.87
Spraying[w,z]	298 302	15.65
Soaking	285 322	17.12
Control	321 216[y]	16.47

[z]Treatment values represent average of two trees with normal fruit loads.

[y]Fruit remaining after inadvertent prior harvest.

[x]Numbers represent average for 30 fruit (10 from each picking). In the last group where numbers are averages for two trees, the numbers represent the average for 60 fruit (20 from each picking).

[w]No significant differences between treatments using the F-Test.

Irrigation treatments had no significant effect on the total soluble solids, contrary to findings in other experiments (Table 4.13). This finding is encouraging because the desired effect is to increase the fruit size without reducing fruit quality.

The percentage-of-fruit-harvested data in Table 4.11 and the fruit weight data in Table 4.14 were not statistically analyzed because one of the control trees with a normal fruit load was unexpectedly picked before the last picking. Estimated figures could have been substituted for the missing data if the trees had been arranged in randomized blocks (one tree of each treatment in each block of trees). However, this was not the case since each treatment was performed on a block of four adjacent trees.

4.2.3 Conclusions and Discussion

The most relevant data for commercial peach production are from the trees with fruit loads of about 300 (normal fruit load). Intermittent spraying on trees with about 300 fruit increased both the percentage of large (2 inches or larger) 'Early Amber' peaches by about 37% and the percentage of split and/or diseased fruit by almost 5% over the control. Soaking almost doubled the percentage of large fruit over the control on trees with about 300 fruit by producing approximately 18% in this category. Just over 2% of the fruit from the same soaked trees were split and/or diseased compared to 1.4% for the control. Although the increase in split and/or diseased fruit was highly significant, the percentage was still relatively small. The absence of reduced fruit quality characteristics along with the sizeable increase in the percentage of large fruit are the kind of data necessary to make intermittent spraying worthwhile.

Whether the supplementary irrigation treatments were started at the optimum point of fruit growth is not known. The spring rains maintained a relatively high soil moisture content in the soil of the peach orchard during March and April. Had the treatments been started earlier, the irrigation water probably would have had little or no effect. Despite the orchard's soil being classified as a fine sand, the soil maintains a high water table which is generally only 50 to 60 inches deep.

The trees were thinned about as late as possible for thinning to have any effect. The trees should have been thinned about a week earlier before cytokinesis had occurred, or even better, at bloom. On the other hand, the late thinning helped make it possible to better equalize the fruit load between treatments because the fruit were larger than if they had been thinned earlier. When peach trees are

Table 4.13. Percent soluble solids in harvested fruit.

Treatments	Fruit harvested (no.)	Percent[x]
Spraying	79	10.54
Soaking	79	14.10
Control	76	12.84
Spraying	215	10.69
Soaking	212	12.08
Control	193	11.63
Spraying[w,z]	298 302	10.74
Soaking	285 322	11.72
Control	321 216[y]	12.51

[z]Treatment values represent average of two trees with normal fruit loads.

[y]Fruit remaining after inadvertent prior harvest.

[x]Numbers represent average for 15 fruit (5 from each picking). In the last group where the numbers are averages for two trees, the numbers represent the average for 30 fruit (10 from each picking).

[w]No significant differences between treatments using the F-Test.

Table 4.14. Total weight of peaches in pounds.

Treatments	Fruit harvested (no.)	Weight (lbs.)
Spraying	79	14.4
Soaking	79	16.5
Control	76	15.4
Spraying	215	35.2
Soaking	212	32.9
Control	193	30.6
Spraying	298	43.3
	302	50.5
Soaking	285	35.7
	322	39.1
Control	321	34.7
	216[z]	25.4[y]

[z]Fruit remaining after inadvertent prior harvest.

[y]Weight of fruit remaining after inadvertent prior harvest.

thinned, it is not uncommon to have differences of about 100 or 200 between the number of expected fruit and the number of fruit actually harvested. The relatively low fruit set observed in the orchard this year was another factor in reducing the error between the expected number and the number of harvested fruit. Counting the peaches on the experiment's trees was easier with low fruit set than if they had had a normal fruit set.

The fruit LVDTs were used in this experiment mainly to test a new technique of monitoring fruit growth. This part of the experiment was a failure because the LVDTs were mounted too late, and the hose clamps for the fruit should have been larger.

Root systems cannot provide enough water to adequately meet evaporative demand. Because both the sprayed and soaked treatments maintained similar soil moisture profiles near field capacity, any observed differences can be attributed to the technique of water application. The purpose of the intermittent spraying was to have the sprayed water at least partially meet the evaporative demand placed on the trees by the atmosphere. Intermittent spraying hopefully reduces the amount of water transpired from plants and helps maintain higher water potentials throughout the trees. With higher water potentials, trees are expected to produce larger fruit. Although only slightly higher water potentials were maintained in the sprayed trees, the effect on fruit size was considerable.

Intermittent spraying of high-value crops should be considered as an option when establishing an irrigation system. Data have evidenced variety adaptations to the technique. Also, local conditions such as soil type and salt content of water affect the feasibility of using intermittent spraying. If a soil is too sandy, excessive leaching may occur. Excessive salt in the water would cause salt accumulation on leaves and kill plants. The increase in fruit size and yield without reducing fruit quality must be great enough to pay for the required equipment and extra water.

4.2.4 Literature Cited

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4.3 Drip Irrigation Increases Yield and Size of 'Sunrich' Nectarines

J. F. Bartholic and D. W. Buchanan

The use of drip irrigation to increase yield and minimize water use has received considerable interest in the past few years. During this period, conferences devoted to the use of drip irrigation in various commodities have been held (1, 10). In addition, general information is available in the form of engineering reports on installation, pipe size and well capacity requirements for trickle irrigation (7,8). Reports of yield response have been limited, but some have shown higher yields with drip irrigation (2). The data on yields for fruit crops with drip irrigation has been quite limited (6,9); however, a positive response of peaches to overhead irrigation has been reported (3). For these reasons, an experiment using drip irrigation on fruit trees was initiated in 1972. This paper summarizes the data acquired thus far including yield results.

4.3.1 Methods and Materials

A 'Sunrich' nectarine orchard on 'Nemaguard' rootstock was established at the IFAS Horticultural Research Unit 10 miles north of Gainesville in the spring of 1972. The trees were planted on a spacing of 20 by 20 ft in a 3-acre orchard. A drip irrigation system with 1 emitter per tree within 6 inches from the trunk was installed concurrently with the planting on 2 acres and an overhead sprinkler system was installed on the remaining acre. The entire area was drained with tile drains at a depth of 5 ft. Drains were spaced at 80-ft intervals and were 830 ft long. Soil in the area was classified as an Arredondo loamy fine sand.

Intermittent measurements of trunk diam at 1 ft above the soil were taken throughout the experiment. Root density and distribution for the 2 treatments were evaluated during the spring of 1974. Three trees of similar size, in both drip and overhead irrigated areas were selected for root sampling. Samples were taken from 6 successive 6-inch deep layers below the emitter and 1 ft away from the emitter, using a core sampling technique. At each tree with an emitter, 4 samples were taken at each depth, 1 under the emitter and 3 at 1 ft out from the emitter. For trees without emitters, 3 samples were taken at each depth 1 ft out from the base of the tree. Roots were separated from soil with running water and dried at 80°F for 24 hr. Root densities were calculated from known sample size (4, 5).

The first crop year for this orchard was 1975. Twenty trees were harvested in both treatments. The trees were selected to be visually as uniform in size and fruit load as possible. All fruit was harvested at one time and then sized, weighed and counted. Statistical analyses were performed on the data comparing continuous drip irrigation with overhead irrigation. For each method the weight of marketable and cull fruit and no. of 2 1/4", 2", and 1 7/8" size fruit were made from 10 trees from each of 2 rows. Analysis of variance was performed.

One gal was applied daily throughout the 1972-1974 growing seasons, except for a few high rainfall periods and during the winter months. During 1975, 3 gal per tree per day were applied. The rate of application was 1 gal per 20 min. Overhead irrigation used only when half the available soil moisture was gone during the fruit season. Two to 3 irrigations were required each year.

4.3.2 Results and Discussion

Water use for the first 3 years showed that drip irrigation required only about a third as much water as conventional overhead irrigation. During 1973 for example, 3.5 inches of irrigation water were required with the overhead system, as compared to 1.5 inches per acre with drip. In addition to water savings, weed control was considerably easier with the drip irrigation since only the areas directly around the emitter and under the fruit trees were wet. With overhead irrigation, vegetation was encouraged in the rows.

Trunk diam measurements showed no general difference in the rate of tree growth (fig. 4.7). This was also concluded from visual observations of top growth. Because of the difficulty of measuring trees at exactly the same spot there is some scatter in the data; however, with the 8 trees measured in each treatment, the data shows a consistently similar trend in growth.

Roots penetrated to the greatest depth directly under the emitter (Table 4.15). Roots were concentrated in the upper ft of soil in the overhead sprinkler area with 78% of the roots in this area. Only 41% of the roots found directly under the emitter and 51% of the roots measured 1 ft out from the emitter were in the top ft. Since all samples were taken within 1.5 ft from the base of the tree, comparisons in root concentration can be made. No attempt was made to recover all roots, so only rooting patterns and not total root amount can be discussed.

Yields were low in 1975 due to the young age of the trees and probably as a result of insufficient chill hours and some spring freeze damage. However, the data on size and yield provided information on irrigation treatment effects. Table 4.16 gives values of the total wt and no. of fruit on a size basis. Total fruit wt and no. were much greater with drip

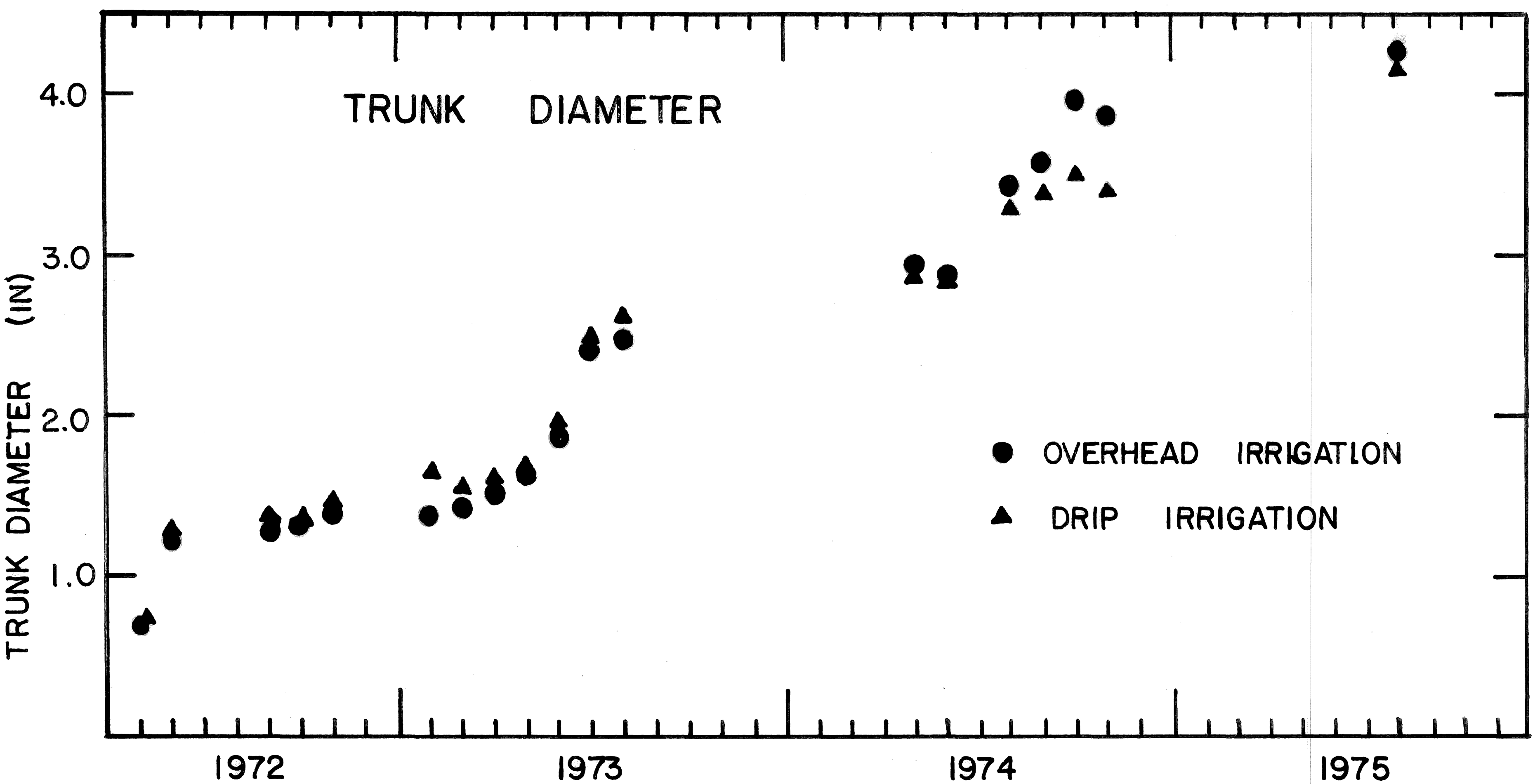

Fig. 4.7. 'Sunrich' Nectarine trunk diameter vs. time for drip and overhead irrigation treatments

Table 4.15 Comparison of root densities of nectarines receiving drip irrigation and irrigation from overhead sprinklers.

Depth in.	Drip irrigation Below emitter			Drip irrigation Around emitter			Overhead sprinkler Around base		
	g	%	mg/cm^3	g	%	mg/cm^3	g	%	mg/cm^3
0-6	7.8	8.6	5.6	12.4	24.2	8.9	25.3	30.8	18.2
6-12	29.6	32.7	21.3	16.0	31.2	11.5	38.8	47.2	27.9
12-18	15.0	16.6	10.8	10.7	20.8	7.7	7.8	9.5	5.6
18-24	18.0	19.9	13.0	7.3	4.2	5.5	6.8	8.3	4.9
24-30	24.7	14.1	9.1	2.5	5.1	1.9	3.4	4.1	2.4
30-36	7.3	8.1	5.3	2.3	4.5	1.7	0.1	0.1	0.1
Total	102.4			51.2			82.2		

Table 4.16 Yield of Sunrich Nectarines. 1975.

Treatment	Rows	Weight (in lbs.) Total	Weight (in lbs.) Culls	Number of fruit by size[z] 2 1/4	2.0	1 7/8
Drip	1	117.2	9.5	159	333	162
	2	137.1	24.6	133	345	248
		254.3[ay]	34.1[a]	292[a]	678[a]	410[a]
Overhead	3	76.4	16.6	75	151	136
	4	77.1	17.7	80	167	118
		153.5[b]	34.3[a]	155[b]	318[b]	254[a]

[z]Total of 10 trees in each row.

[y]Means not sharing the same letter within columns are significantly different at the 1% level.

irrigation. The results revealed highly significant differences between methods for no. of 2 1/4" and 2" fruit. In each case the use of drip irrigation increased the response significantly at the 1% level in these categories. No difference was detected in the methods with respect to cull wt. Since the total no. of fruit per tree was greater with drip, it is not surprising that total wt and fruit no. were significantly higher. The % of fruit in 2 1/4", 2" and 1 7/8" for drip were 21, 49 and 30% and for overhead were 21, 44 and 35%, respectively. Thus, even with drip with a larger fruit load, the percentage of larger fruit was slightly higher.

4.3.3 Conclusion

A 'Sunrich' nectarine orchard was established in 1972 with drip irrigation on 2/3 of the orchard with 1 emitter per tree and permanent overhead irrigation on the remaining 1/3. Drip irrigation required about 1/3 less water during the first 3 years of the experiment. Tree growth during this period was similar; however, root studies show there was a difference in rooting patterns between drip and overhead irrigation. Roots were concentrated between 6 and 24 inches in the soil under drip irrigation and in the top ft where overhead irrigation supplemented rainfall. Even with only 3 gal per day applied to trees during the 1975 fruiting season, there were significant increases in yield and fruit size with drip irritation.

4.3.4 Literature Cited

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CONCLUSIONS

The water balance study in the peach orchard (Chapter 2) took many man-hours of data collection and analysis. However, it provides a set of reliable water balance data for an entire year. These data show the many variations that occur in evapotranspiration (ET), inflow and outflow. Thus, it provides much detailed information on water requirements throughout the year under Florida's climatic conditions. The inflow amounted to 142 cm (56 inches) of rain and irrigation; of this, 4.5 inches were from irrigation. The outflow available for surface or aquifer recharge amounted to 55 cm (22 inches). This value is very important since it is this water that may ultimately become available for reuse by other agricultural, industrial or urban water needs. Very few actual values of this type have been acquired. The ET amounted to 91 cm (36 inches) of water. Of specific importance is the fact that ET from the orchard was shown to be 0.7 of pan evaporation during much of the summer months when the soil was moist, the grass was green and leaves were on the peach trees. However, in the fall with leaves off the trees and the grass dormant the ratio of actual ET to pan dropped to as low as 0.3. This great variation has important ramifications in our concepts of water management. For example, if the cropping pattern were changed to a "super" grass that would remain lush all year round or to some other tree crop that continued to transpire throughout the year, then water loss from the surface could have been considerably greater. Thus, it appears we could manage in a general sense the amount of water available for recharge by modifying some of the evaporating surface of the State.

Water balance and water needs for Florida citrus (Chapter 3) showed that there was a slight general contribution to the aquifer with present irrigation acreage and irrigation practices. However, it appeared that if 100% of the citrus acreage was irrigated, then there would just be a balance and no general contribution to the aquifer. Section 3.2 deals with the use of daily climatic records to estimate irrigation needs and the disposition of water. This section shows the wide variation that can occur from year to year in the number of irrigations depending upon the distribution of rainfall. Even though total rainfall is important, it is really the distribution and soil water-storage capacity that makes a difference in the irrigation requirements for a crop. For a two-inch soil water-storage capacity the number of irrigations could be as high as 18 while for the same climatic conditions, if the water storage capacity was 4 inches, as little as 6 irrigations might have been required. Of particular importance in this analysis is that since ET remained relatively the same, the more irrigations required, the more water that went into deep percolation. With an available water-storage capacity of

4 inches it was found in this analysis that deep percolation and run-off varied from 28 to 31 inches annually. The distribution of rainfall, ET and deep percolation during the year is shown clearly. Most irrigations were required in the spring months when plant water stress can significantly affect yield and the driest weather of the year occurs. Less irrigation is required later in the year when rainfall is higher and more evenly distributed.

Studies on water use and needs are important but they do not make more water available. Chapter 4 reports findings of possible ways of improving water use efficiency. In Section 4.1 the water stress was measured with a pressure bomb device. Water stress of leaves of the same scion (top of tree) on different rootstocks were evaluated both in shallow-rooted zone areas and in sandy soils which allow for deep root penetration. Significant differences in the plant water stress of the treetop resulted from different rootstocks. In some cases the plant water stress in the top was -11 bars with one rootstock while with another rootstock less capable of acquiring water from the soil the stress was a -15 bars. This difference is important because when plant water stress approaches -15 bars, some stomatal closure can occur and photosynthetic efficiency can be reduced. Thus, with the same atmospheric demand, the same scion and just different rootstocks that varied in capability for extracting water from the soil, the treetops vary significantly in their plant water stress. This indicates a valuable tool and potential capability for growing trees on rootstocks that would be better able to extract water from the soil and thus minimize water stress in the top and require less water from irrigation.

Under many conditions adding water directly to the soil might not be the optimal way to utilize water resources in agriculture with Florida's high atmospheric demand and sandy soils. The possible use of intermittent water spray directly on leaves was investigated extensively (Section 4.2). It was found that the plant water stress was reduced somewhat and growth of the tree and fruit yields were significantly increased by using water as intermittent sprinkling rather than by putting it directly on the soil. The yield of large peach fruit (2 inches and over) was increased 37% with intermittent sprinkling compared to using the same amount of water on the soil. Thus, this research tends to lend some evidence toward possible almost revolutionary ways of using water directly applied to the tree as opposed to our traditional ways of wetting the soil. Another approach for using water more efficiently is the use of drip irrigation. The final report in Section 4.3 gives results on tree growth and yield with drip irrigation. Three years of data were acquired on tree growth that showed no difference in growth for trees irrigated with drip or overhead sprinklers. However, during the experiment less than two-thirds as much water was required through the drip system as with the overhead sprinklers. The third year of the experiment it was possible to acquire yield information. Drip irrigation significantly increased yields and fruit size so water use efficiency was increased with drip irrigation.