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Water Transfer from Soil to the Atmosphere as Related to Climate and Soil Properties

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WATER TRANSFER FROM SOIL TO THE ATMOSPHERE AS RELATED TO CLIMATE AND SOIL PROPERTIES

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Preface

This report concludes Project A-006-TEX of the Texas A&M University Water Resources Institute. None of the project research has been published. Reprints of research on this project will be supplied to OWRR as soon as they are available.

Appreciation is expressed to Mr. O. H. Newton, USWB, Department of Commerce, for supplying much of the equipment for studies in the project, to Dr. O. C. Wilke for his suggestions on the project, to Mr. Md. Idris, a graduate student who has collected much valuable data, which is yet to be analyzed, and to Dr. J. R. Runkles, who has furnished much advice and assistance.

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Description of Symbols

Symbol	Units	Definition of Terms
A	cal cm^{-2} min^{-1}	Sensible heat flux
B_v	g cm^{-2} min^{-1} mb^{-1}	Turbulent transfer coefficient
Cp	cal g^{-1} $°C^{-1}$	Specific heat of dry air at constant pressure
d_a	mb	Saturation vapor pressure deficit of the air
e_a	mb	Actual vapor pressure
H	cal cm^{-2} min^{-1}	Sum of energy imputs at surface (R_n + S)
k		Van Karman constant
K_h	cm^2 min^{-1}	Eddy diffusivity for heat
K_w	cm^2 min^{-1}	Eddy diffusivity for water vapor
L	cal g^{-1}	Latent heat of vaporization
LE_m	g cm^{-2} min^{-1}	Measured evaporation rate
LE_β	g cm^{-2} min^{-1}	Evaporation rate estimated using the Bowen Ratio
LE_r	g cm^{-2} min^{-1}	Estimate of evaporation due to radiation
LE_{VB}	g cm^{-2} min^{-1}	Evaporation rate estimated using the van Bavel combination model
LE_w	g cm^{-2} min^{-1}	Estimate of evaporation due to wind
P	mb	Ambient pressure
R_n	cal cm^{-2} min^{-1}	Net radiation

Symbol	Units	Definition of Terms
R_s	cal cm^{-2} min^{-1}	Solar radiation
S	cal cm^{-2} min^{-1}	Soil heat flux
T	$^{\circ}C$	Temperature
U	cm min^{-1} or m sec^{-1}	Windspeed
U_a	cm min^{-1} or m sec^{-1}	Windspeed at height Z_a
Z_a	cm	Height above surface
Z_o	cm	Roughness parameter
γ	mb C^{o-1}	Psychrometric constant
Δ	mb C^{o-1}	First derivative of e versus T
ε		Water/air molecular ratio
β		Bowen Ratio
ρ	g cm^{-3}	Density of air
Δt	$^{\circ}C$	Average air temperature differences between elevations
Δe	mm	Average vapor pressure differences between elevations

Project Summary

Facilities and Systems - Design of the lysimetric facility of the project began in 1966. During 1967, soil cores were taken for the lysimeters, and in 1968 an unforseen temperature problem in the lysimeters was solved. A total of 9 undisturbed soil cores were made into lysimeters. Since cores were procured, the lysimeters have the "natural" soil properties. Such lysimeters will be valuable tools for further studies. The lysimeters were designed for either visual or recorded readout of data.

Initially, plans were made to use a datalogger owned by the USWB to collect the data. However, it is not reliable, and a system of strip chart recorders had to be procured to record the data. This proved to be time consuming, and subjected the data to possible human error when it was reduced to numerical form from the strip charts.

Research Results - Either the combination method of van Bavel or the Bowen Ratio will provide a fair estimate of evaporation from a wet soil surface in the area. In general, the combination method tends to overestimate while the Bowen Ratio tends to underestimate evaporation. This is due to the fact that the combination method places a strong emphasis on this parameter. Average wind speeds in the area commonly exceed 4 m/sec.

Conductivity Studies - The conductivity of the Olton loam soil is very low at fairly low soil water pressures corresponding to high contents. This is an asset in preventing evaporation losses, but may be deterimental to crop production in that the crops need to develop extensive root systems to use the stored soil moisture.

Canopy Effects on Evaporation - Evaporation within a cotton crop canopy following rains is related to the net radiation reaching the soil surface. After the surface dries, the moisture content of the soil surface is the limiting parameter.

Effects of Crude Oil on Evaporation - Crude oil applied to the wet soil surfaces of the lysimeters following rains suppressed evaporation immediately following the rains. However, the value of the crude oil in preserving soil moisture over long periods needs further investigation.

Diurnal Changes in Soil Moisture - Soil water content in the upper 30 cm (12 inches) of the soil apparently changes diurnally with major diurnal changes in soil temperature. Such changes may cause stress in young crop seedlings.

Chapter I. Instrumentation

A. Lysimeters

To study the water transfer from soil to atmosphere as related to climate and soil properties, weighing lysimeters provide a direct measurement of evaporation which can be compared with micrometeorological methods used to estimate vapor flux.

Numerous reviews are available on lysimetry (14) (15) (25). Some of the first weighing lysimeters were those installed in Cashocton, Ohio by Harold and Dreibellis (13). A mechanical balance was used as the weighing mechanism. More recently, electronic loadcells (18) (28) and hydraulic loadcells (24) (25) have been used for weighing lysimeters. Electrical output from such transducers has been recorded on stripchart recorders and data loggers.

In this study, information was desired on the amount of water evaporated from between rows of growing crops. Such a lysimeter needed to be small, accurate, easy to service, and relatively mobile so that normal cultural practices could be conducted on the growing crops.

The lysimeters employing loadcells as a weighing device require underground access for servicing. Due to the small area available between crop rows (approximately 80 cm), a system was required which provided for the sensing portion above ground. The hydraulic system was most desirable to meet these constraints.

One of the first lysimeters using a hydraulic system for weighing was constructed by Ekern (7) using a pivot and automobile innertubes. Tanner and Swan (24) have made extensive an investigation of the hydraulic weighing lysimeters. They noted hystersis and temperature effects with systems using vinyl and butyl nylon pipe. Recently, Black, Thurtell, and Tanner (3) reported on a very sensitive (± 0.02 mm) hydraulic loadcell lysimeter.

For these studies, it was decided to use a modification of the design by Hanks and Shawcroft (11). A description of the design and problems encountered follows.

1. Design Description

    a. Soil containers and retaining tanks. The site chosen for the study was classified as an Olton loam (Aridic Paleustoll, fine, mixed thermic). As seen in Table 1, this soil is characterized by well defined blocky structure in the subsoil. It was therefore decided to use monoliths rather than fill lysimeters. Previous data by Flodkuist (15) showed that the premeability of fill lysimeters was higher than that of the surrounding soil even after 48 years.

       To construct such monoliths two sizes of steel boxes were constructed of 10 gauge steel; 0.625 meter x 0.800 meter x 1.00 meter deep and 0.45 meter x 0.30 meter x .60 meter deep. The boxes were set on the soil surface and soil was dug from around the boxes. The boxes were allowed to slide over the interior soil core. When the top of the box was 0.5 cm from the soil surface, the core was broken off and a steel plate placed under it. Another steel

Table 1. Profile Description of the Olton Loam Soil in the Lysimeters.

Classification	Horizon	Depth from Surface (cm)	Texture	Color and Structure	Reaction	Underlying Material
Order - Zonal Great Soil Group Reddish Chestnut Soil Type - Olton loam	Ap	0-17	loam	Brown-weak subangular blocky	Neutral	
	B_{21}	17-32	Clay loam	Reddish-brown moderate, fine subangular	Neutral	The underlying material contains soft and hard material and is many feet thick.
	B_{22}	32-62	Clay loam	Reddish-brown moderate, fine subangular blocky	Neutral	
	B_3	62-87	Clay loam	Reddish-brown moderate, fine blocky	Mildly Alkaline	
	C_{ca}	87-100	Clay loam	Pink-weak subangular blocky	Weakly Calcareous	

plate was placed on the top of the box. The box was inverted so that the bottom of the box could be fitted with porous bulbs (-75 mb bubbling pressure) in a layer of sand and gravel. The bottom was then welded and tested for leaks. A total of 6 large and 3 small lysimeters were constructed.

In each box, tensiometers were installed at depths of 15, 30, 60, and 90 cm in the deeper lysimeters and 15, 30, and 60 cm in the small lysimeters. Access tubes for taking neutron probe and gamma attenuation probe measurements were installed in each lysimeter.

Retaining tanks were also constructed on 10 gauge steel. The bottoms of the retaining tanks were filled with concrete while the retaining tanks of the small lysimeters had a steel bottom. Both types of retaining tanks were fitted with a vacuum drainage system.

b. Measuring system. As previously mentioned, a modification of the design by Hanks and Shawcroft (11) was used as the basic design. The modified lysimeter design is indicated in Figure 1. The units are smaller than the unit of Hanks and Shawcroft so as to fit them in growing crops. The rubber bags were insulated and covered with plastic. Although some temperature problems still existed, this insulation was a major aid in cutting down on temperature variations. However, it was still necessary to use

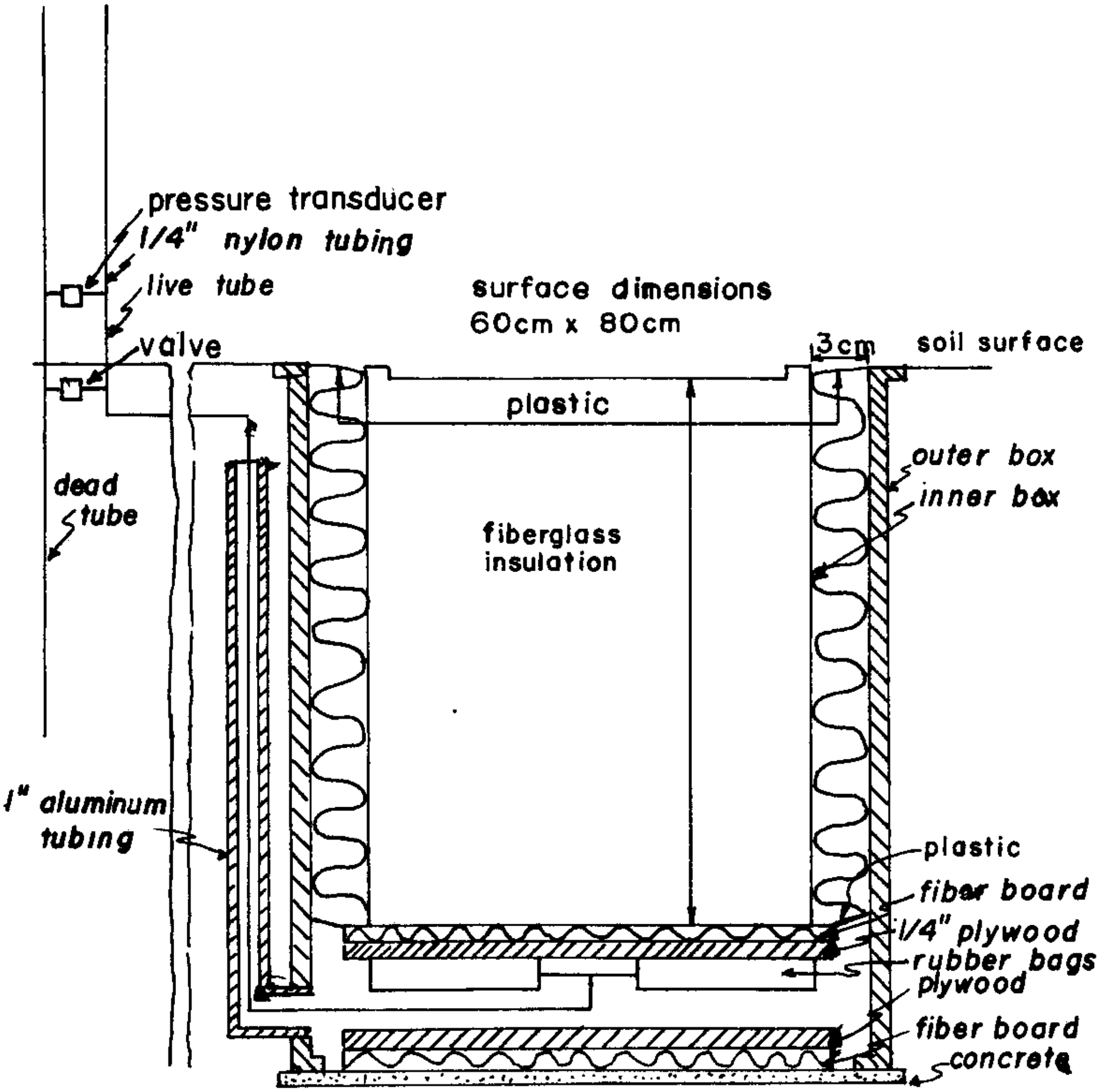

Figure 1. Schematic of the Lysimeters.

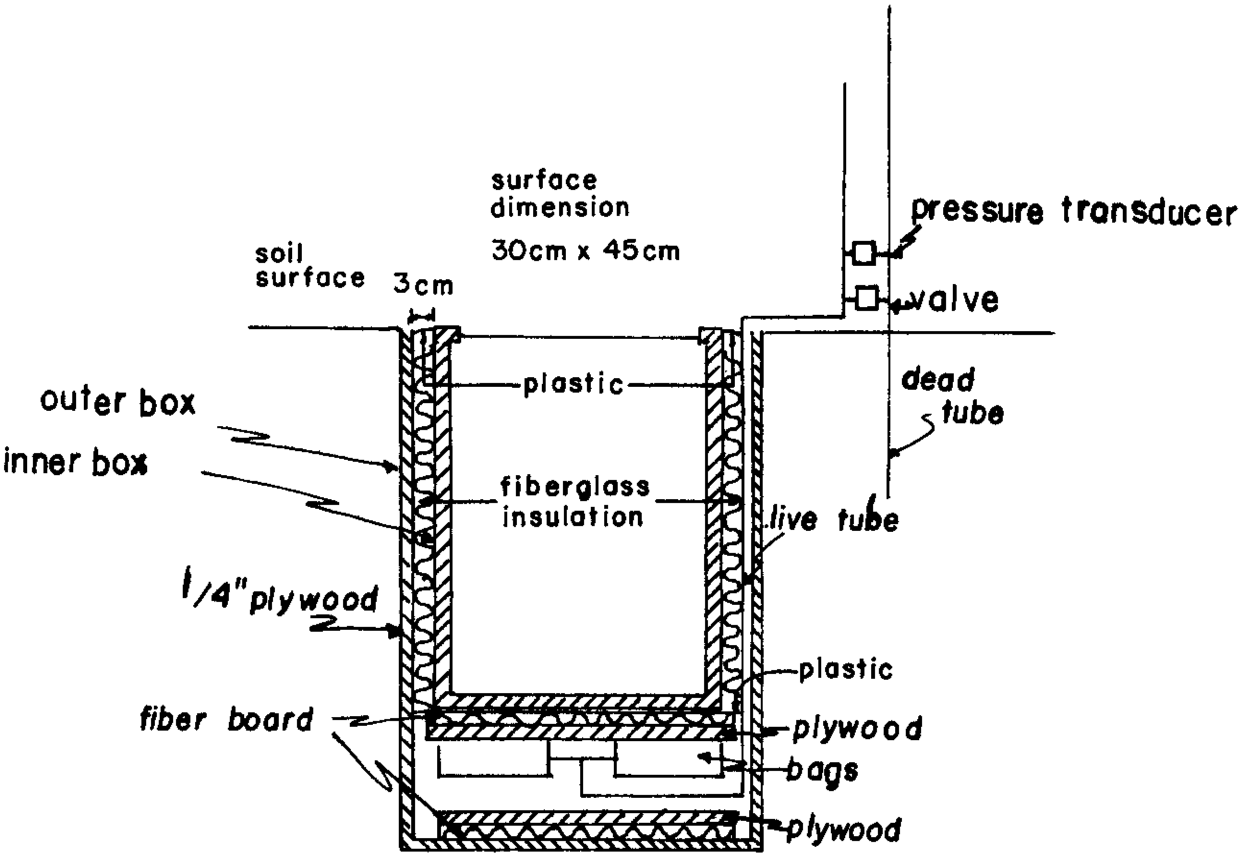

Figure 1 continued. Schematic of the Lysimeters.

temperature correction of .1 mm/°C.

As indicated in Figure 1, the lysimeter is resting on two butyl rubber bags, each containing a gallon of 1:4 antifreeze to water mixture. The butyl rubber bags are then connected by means of a .625 cm tubing to a pressure transducer[1/] which senses the increase or decrease in pressure and produces a voltage output.

These signals are then relayed via a three stranded shielded cable to the trailer which houses the recording system (Figure 2). The input from the transducer is plugged into the carrier demodulator[2/] which enables regulation of the signal from the transducers, so that all transducers produce the same output per unit of weight change. From the carrier demodulator, the signal is carried to a meter relay[3/] and recorder[4/]. When the lysimeter loses or gains the equivalent of 1 cm of water, the meter relay opens a motor valve[5/] which allows the system to rezero and measure another equivalent gain or loss.

The transducers had an output of 10 VDC/inch of column height change. The maximum sensitivity that was possible with the system a long period of time was ± 0.10 mm evaporation.

[1/] Model P 90 Mfg. by Whittaker Corp., North Hollywood, California
[2/] Model CD 10 Mfg. by Whittaker Corp., North Hollywood, California
[3/] Model Mark II Paneline Mfg. by PMF Electronics Inc., Dayton, Ohio.
[4/] Model AW Mfg. by Esterline Angus Inst. Co., Indianapolis, Indiana.
[5/] Model 7115G2S Mfg. by Hoke Inc., Cresskill, N. J.

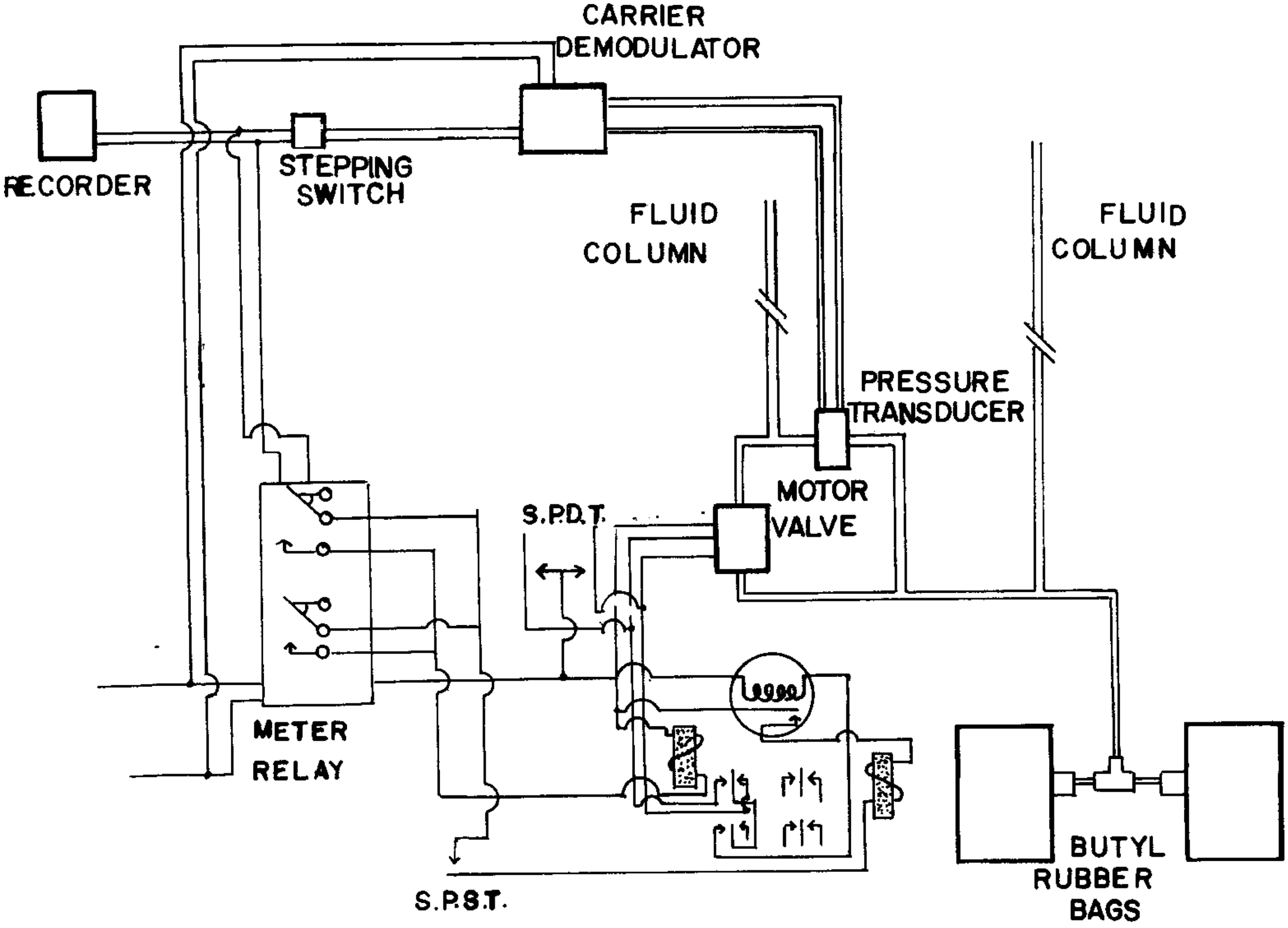

Figure 2. Schematic of lysimeter measuring and switching circuit.

It was possible to obtain visual readings from the fluid columns to an accuracy of ± .25 mm evaporation.

The lysimeters were calibrated with known weights each morning during periods when hourly measurements were being made. If major differences in calibration occurred, the data were discarded for that particular day.

c. Problems which occurred with the system included the following:

   (1) Leaks - Numerous leaks occurred in the tubing connections between butyl rubber bags to the transducer unit. By using "o" ring seals and teflon tape, it was possible to solve these problems.

   (2) Air - It is imperative that an air free system be used. Deaeriated water was used for the antifreeze solution and the fluid system was filled with CO_2 before filling with antifreeze solution. Small air bubbles were one of the major causes of temperature fluctions.

   (3) Other - It was necessary to insulate the entire fluid system including the lysimeter column and the area between the lysimeters and retainer walls, to minimize the effect of temperature on the hydraulic system. The recorders, meter relays, and carrier demodulators were located in a temperature controlled trailer.

   (4) Wind - As other workers (18) (29) have indicated, wind may have a major indluence on lysimeter data. By

having "bumpers" in each corner and a low fluid level in the butyl rubber bags, the effect of wind was minimized.

As can be seen from Chapters IIA and IIC in this report, reasonable data were obtained with the lysimeters. However, due to the temperature effects, wind effects, problems encountered in obtaining an air free system, and the time consumed in obtaining intact soil profiles, considerable time and trouble was involved in obtaining the lysimeter data in the studies.

B. Tensiometers

Continuous measurements of soil moisture changes are desirable to evaluate models for unsaturated flow in evaporation studies. The continuous measurement of soil water pressure is a parameter common to such models and has received considerable attention by several workers as a parameter from which continuous data could be procured. Bianchi (2) has described a system using a strain gauge in conjuction with a porous cup. Watson (30) pointed out the importance of considering experimental requirements in choosing the proper ceramic tensiometer bulb. Other work by Watson and Jackson (31) shows the importance of insulating against temperature changes.

Recently, Rice (17) has proposed a system using one transducer to moniter up to 12 or more locations using tensiometers, one transducer, and a scanning valve. Such valves are quite expensive and would require large amounts of nylon tubing in order to use a single valve for all lysimeters. As pointed out by Watson and Jackson (31), such tubing must be well insulated to be free of temperature problems. It was, therefore, decided to design a system using ball type zero displacement valves1/ for each tensiometer to eliminate much of the tubing in the scanning valve system. The original design for the tensiometers is indicated in Figure 3. When the system was closed, zero tension was indicated. When the valve on a particular tensiometer was opened, the pressure was sensed by a

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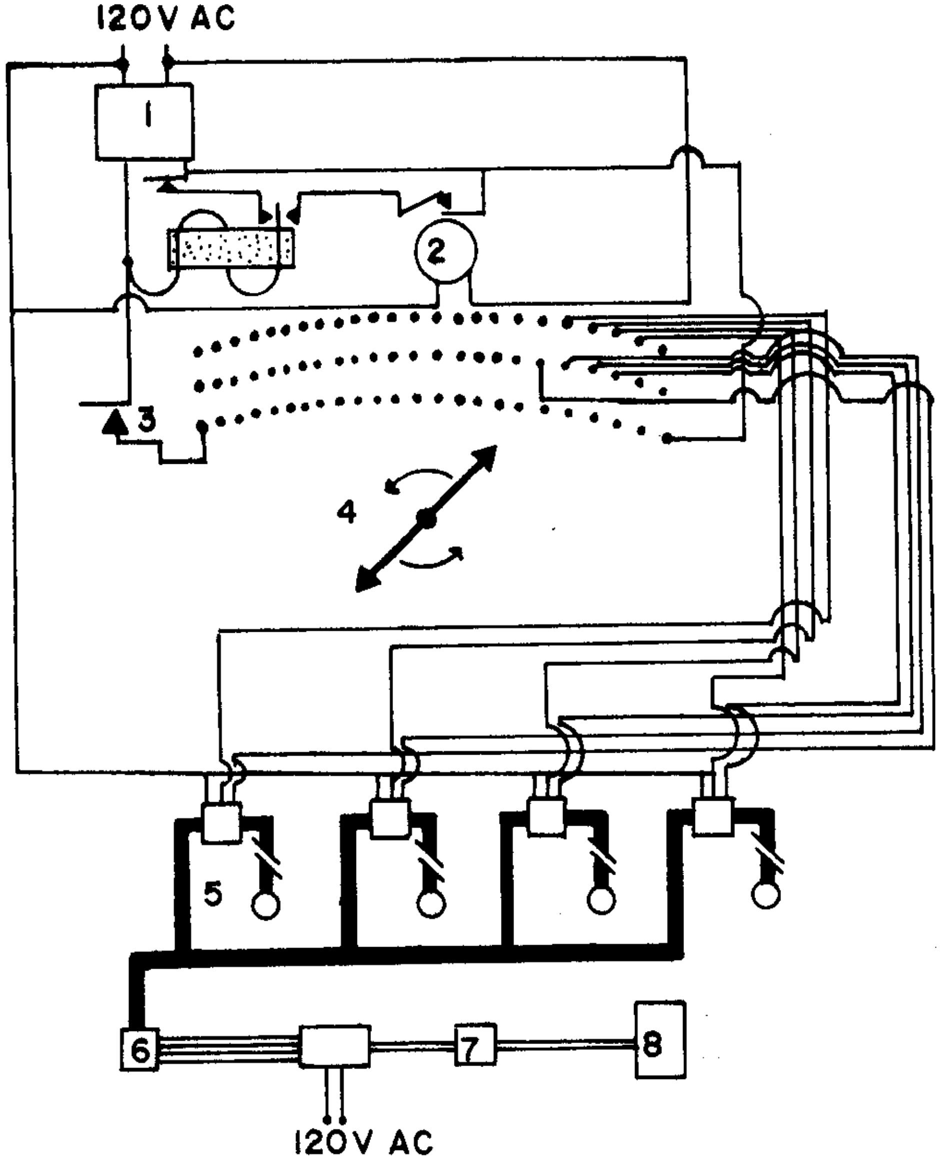
1/ Model 7115G2S Hoke Manufacturing Company, Cresskill, N. J.



Legend

1.	Rectifer	5.	Tensiometer
2.	Timer	6.	Pressure Transducer
3.	Interrupter Springs	7.	Stepping Switch
4.	Stepping Switch	8.	Recorder

Figure 3. Design for Automated Tensiometer.

transducer[2] carrier demodulator[3] system and an adjustable output of 0-10 VDC/0-75 cm Hg was obtained.

Initially, the system was designed to have one valve opening as one was closing. However, due to pressure changes between valves, it was necessary to install a thermal delay relay to allow closing of the previous valve before another valve opens.

The system was installed on tensiometers at depths of 15, 30, 60, and 90 cm in each lysimeter. Each of these tensiometers was connected by 0.32 cm O.D. nylon tubing to the 0.32 cm ball valve. The four valves were connected by tubing into a common manifold which was connected to a transducer. A stepping switch was used to open and close the valves between the pressure transducer and the tensiometers.

However, a pressure change still occurred when switching from one tensiometer to another. As indicated in Figure 4, it was possible to get a relationship by plotting the tensiometer reading before switching (B) minus the tensiometer reading after switching (A) versus the tensiometer reading after switching versus the previous tensiometer or manifold reading (C). Thus, it was possible to solve for the actual tension by the following:

$$B - A = A - C$$

$$B = 2A - C$$

The actual tensiometer reading was thus a function of the previous manifold or tensiometer reading and the current manifold

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[2] Model CD-10 Whittaker Corp., North Hollywood, California

[3] Model P-7 Whittaker Corp., North Hollywood, California

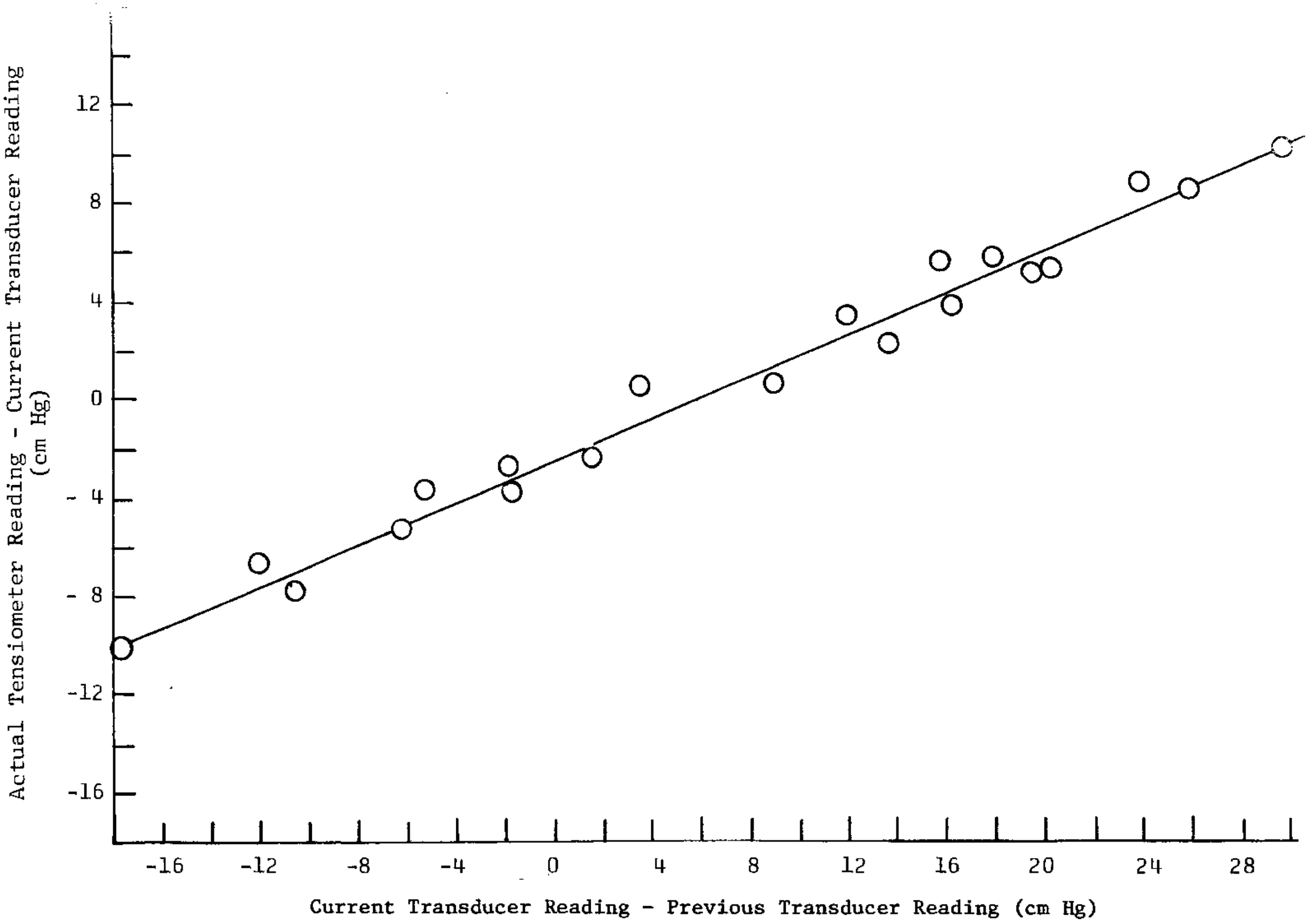

Figure 4. Relationship between actual tensiometer readings and current and previous transducer readings.

or tensiometer reading. However, this relationship was accurate to only ± 1 cm Hg. Since rigid wall nylon tubing was used and only a small displacement was required by the transducers, (.001 cm^3 full scale), the only explanation for the changes was the sealing system of the ball valves.

Due to the error of the above system, only the tensiometer at 15 cm in each lysimeter was fitted with a pressure transducer and the column tensiometers as the other depths (30, 60, and 90 cm) were read daily. As indicated in Chapter IIB, the daily changes at the lower depths were minimal so that it was possible to take reliable daily readings at 30, 60, and 90 cm depths provided readings were taken the same time each day to minimize temperature effects.

C. Other Instrumentation

Other parameters measured in the studies are as follows:

1. Wind Profile

The wind profile was measured at 1 and 10 meters in the northwest corner of the lysimeter area on all studies using sensitive cup type anemometers[1/] owned by the USWB, Department of Commerce. The data were recorded on a strip chart recorder[2/] to an accuracy of ± 2%. Other wind measurements were made in the lysimeter and crop areas as needed with similar instrumentation.

2. Air temperature, relative humidity, and soil temperature

The temperature and relative humidity was measured on all studies at 1 meter above the ground in the northwest corner of the lysimeter area. The pyschrometers were constructed of polyvinyl chloride and properly lined and painted to give a low absorption of solar short wave radiation and high sensitivity for long wave radiation. Output from the 30 gauge copper-constantan thermocouples were recorded on a strip chart recorder[3/]. Accuracy of the record was ± .2°C for the dry bulb temperature and ± .5°C for the wet bulb temperature. Other units were located in the lysimeters and crop areas as needed for

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[1/] Model 403A, Science Associates, Inc. 230 Nassau Street, (P.O. Box 230) Princeton, New Jersey 08540.

[2/] Model AWG (modified) Esterline Angus Div. Esterline Corp. P.O. Box 24000 Indianapolis, Indiana 46224.

[3/] Model Electronic 15, Honeywell - Industrial Products Group, Wayne and Windrin Aves. Philadelphia, Pennsylvania specific studies. The same recorder was also used to record soil temperature.

3. Net Radiation

Net radiation was measured with 2 types of radiometers[4/] [5/]. The data from the radiometers were recorded on strip chart recorders to an accuracy of ± 2%. The radiometers were located above the bare soil surface in the lysimeter area and above and within the crop canopies as needed for the different studies.

4. Solar Radiation

Solar radiation was measured with a pyranometer[6/] by the USBW to an accuracy of ± 2%. Initial measurements were made with a 50 junction Eppley pyranometer[7/] until it was destroyed by hail.

5. Soil Heat Flux

Flux measurements were made with flux plates[8/] and recorded on a strip chart recorder with a voltage divider to an accuracy of ± 3%.

[4/] Model TCN-188, Beckman and Whitney Inc., San Carlos, Calif.

[5/] Model 601, C. W. Thornwaite Associates, Route 1, Centerton, Elmer, New Jersey 08318.

[6/] Model I-G, Talley Industries, Inc., P.O. Box 920, 4551 East McKellips Road, Mesa, Arizona 85201.

[7/] Model 50 junction, The Eppley Laboratory, Inc., Newport, Rhode Island.

[8/] Model L)-7 Hy Cal Engineering, 12105 Nietos Road, Santa Fe Springs, California

6. Soil Moisture Content

Calibrated neutron moisture and gamma attenuation probes[9/] were used to obtain the soil moisture content data to an accuracy of ± 5%.

[9/] Model 104 neutron probe Model 1376 two-probe depth density gauge, and Model 200B scaler Troxler Electronic Laboratories Inc., P.O. Box 5887, North Carolina 27607.

D. Field Plot Layout

Fiuure 5 shows the field plot layout of the bare soil area and location of micrometeorological sensors and recorders. Figure 6 gives the location of the lysimeters in the cotton. As previously mentioned, the micrometeorological sensors were relocated as needed for the measurements in Section II.

Most measurements of evaporation from the bare soil were made when the area surrounding the lysimeter area was also bare or when the crops were in the seedling stage of growth. This was done in order to have the same evaporative potential in both the lysimeter area and the area surrounding the lysimeters. The only exception was when the evaporation from the bare soil was compared with the well developed cotton crop.

There might be some question concerning the influence of the bare soil area north of the cotton on the air mass passing over the cotton with the small lysimeters. Such an area could conceiveably influence the evapotranspiration of the cotton and the evaporation from the small lysimeters. However, the prevailing winds are from the southwest and no major differences in evaporation rate between lysimeters within the cotton canopy during the intervals studies. No doubt there was some influence of the surrounding transpiring crops on the evaporation rate from the bare soil in lysimeters in the open area.

Figure 7 shows a small lysimeter being installed in a cotton crop and Figure 8 shows a lysimeter located in the bare soil area.

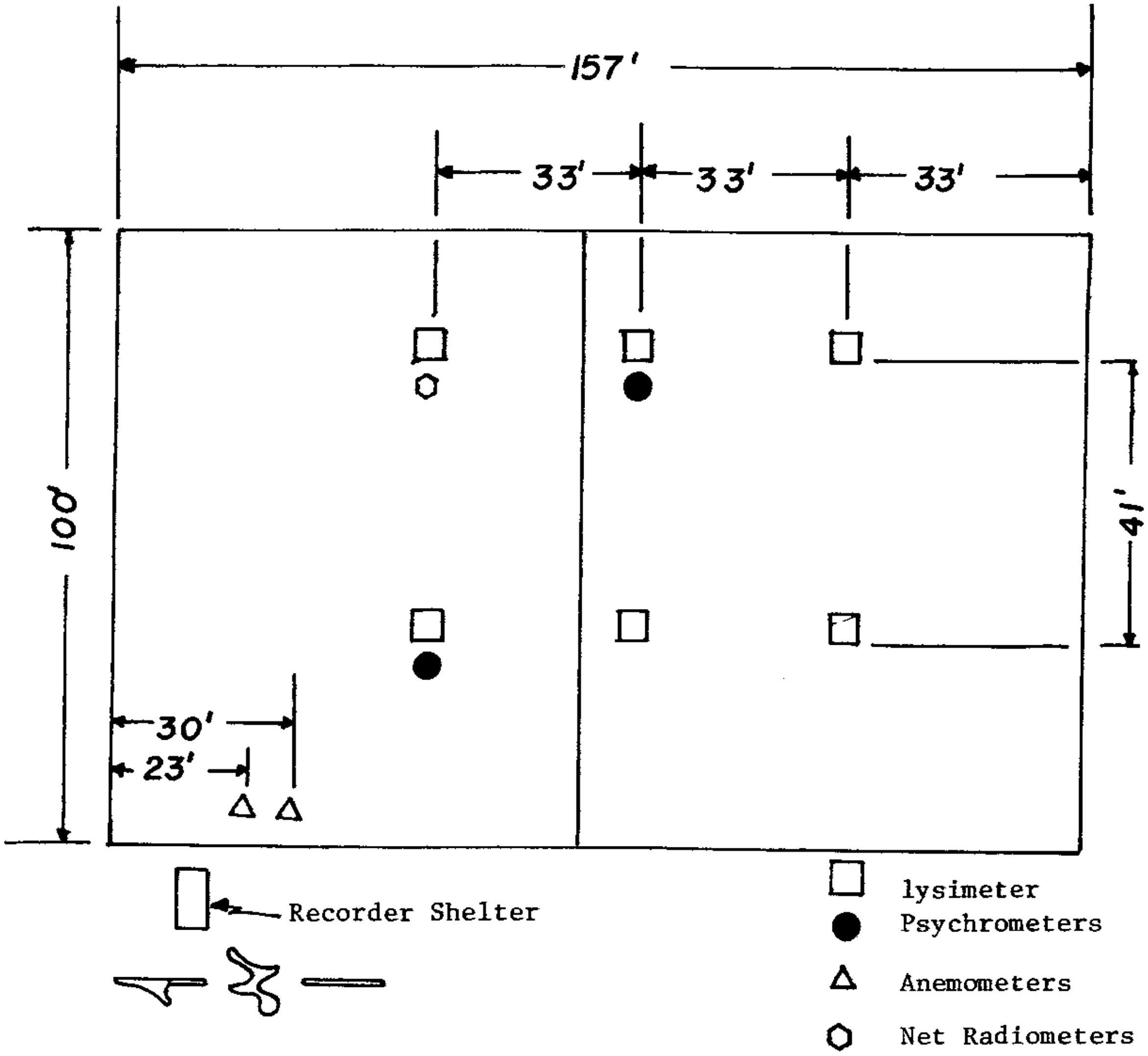

Figure 5. Field Plan of bare soil plots.

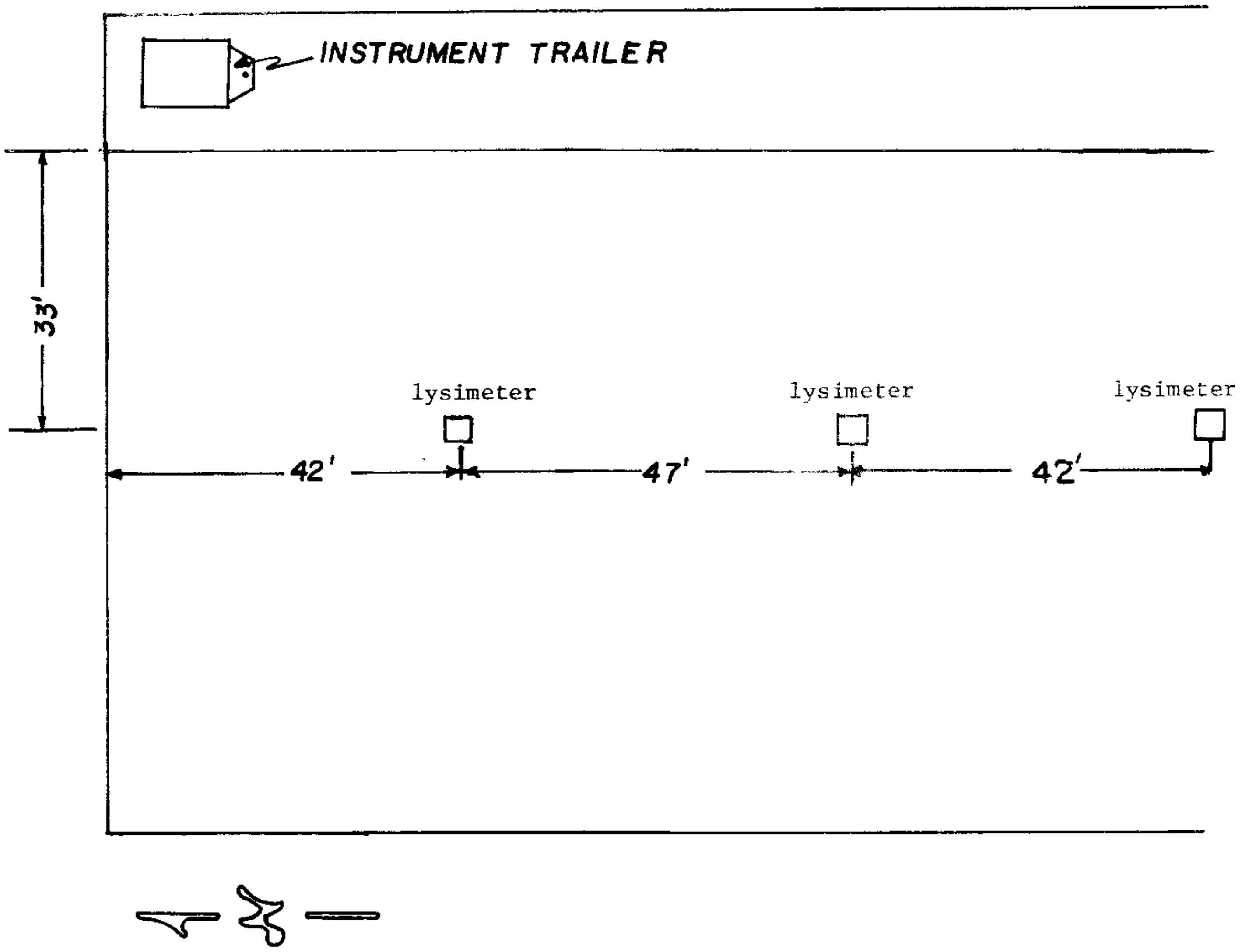

Figure 6. Field plan of the lysimeters in the cotton

Figure 7 Installation of a small lysimeter in cotton.

Figure 8 Lysimeter in bare soil location.

Chapter II. Field Experimentation

A. Predicting Evaporation from a Wet Soil

Water is a limiting parameter in the production of most crops in the High Plains of Texas. With the diminishing supply of irrigation water, it is imperative that existing supplies be used more efficiently to maintain the agricultural economy of the area as the competition for water supplies becomes more keen.

A knowledge of the evaporative demands placed on the soil water supplies would be most helpful in determining the most economical use of water supplies. In an extremely variable climate such as the High Plains, such knowledge could save as much as 1,000,000 acre feet of water yearly through proper application of irrigation water.

Pan evaporation measurements can give some clues to the evaporative potential of the atmosphere of a particular area. However, a better estimate of the potential evaporation is obtained with well watered weighing lysimeters. Furthermore, such lysimeters can be used to calibrate micrometeorological methods for short term and longer estimates of ET. After such methods are adequately tested and proven to be adequate to indicate evaporative potential, they can be used to predict evaporative potential of locations away from the lysimeter locations.

Models

In arid and semiarid climates, advective energy is a major source of energy for evaporation. Recent studies in Arizona (29), Colorado (12), Nebraska (22), and Oklahoma (23), have shown that the energy used in evapotranspiration may exceed that from net radiation. Those models chosen to be evaluated in this study were those which have been shown to be adapted to areas which have large amounts of advective energy.

The energy balance Bowen Ratio method has been shown by Fritschen (9) (10) to be adequate to obtain short term evapotranspiration rates under field conditions where soil water was not a limiting parameter in conditions of strong advection where $LE/(R_n + S)$ was 1.8.

The evaporative flux (LE) is given by

$$LE = \frac{-(R_n + S)}{1 + \beta} \qquad [1]$$

The Bowen Ratio β is given by

$$\beta = \frac{CpP}{LE} \frac{K_h}{K_w} \frac{\Delta T}{\Delta e} \qquad [2]$$

Another model which has been shown to give calculated values of LE which agree well with measured values of LE in areas with large amounts of advection is the combination model of van Bavel (28) which is

$$LE_{VB} = - \frac{\Delta/\partial H + L\ B_v d_a}{\Delta/\partial + 1} \text{ cal cm}^{-2} \text{ min}^{-1} \qquad [3]$$

$$B_v = \frac{\rho E K^2}{\rho} \frac{Ua}{\ln(Z_a/Z_o)^2} \qquad \text{g cm}^{-2}\ \text{min}^{-2}\ \text{mb}^{-1} \qquad [4]$$

Both models have been used to obtain estimates on a daily basis using averages as well as short term basis.

Furthermore, the combination model by van Bavel has been separated into two terms in a paper by Skidmore (23) to get estimates of the evaporation due to radiation and wind respectively:

$$LE_r = \frac{\Delta/\partial H}{\Delta/\partial + 1} \qquad \text{cal cm}^{-2}\ \text{min}^{-1} \text{ and} \qquad [5]$$

$$LE_w = \frac{L\ B_v\ da}{\Delta/\partial + 1} \qquad \text{cal cm}^{-2}\ \text{min}^{-1} \qquad [6]$$

An estimate of advection (A) was made from the equation

$$R_n + S + LE_m + A = 0 \qquad [7]$$

Since R_n, S, and LE_m were measured A was obtained by subtraction.

The experimental setup described in Chapter I was used in the studies. Data was procured during 1-5 day periods over a period of 14 months from the lysimeters. As pointed out by Hanks (12) except for a short period of 1-5 days following water additions, the supplying power of the soil limits evaporation from the soil. It was, therefore, necessary to evaluate the models during the short periods when the soil was fully wet.

Results and Discussion

Figure 9 gives the hourly evaporative fluxes calculated from van Bavel combination and Bowen Ratio models (Equations 2 and 3) as compared to the measured flux on July 28, 1969. It can be

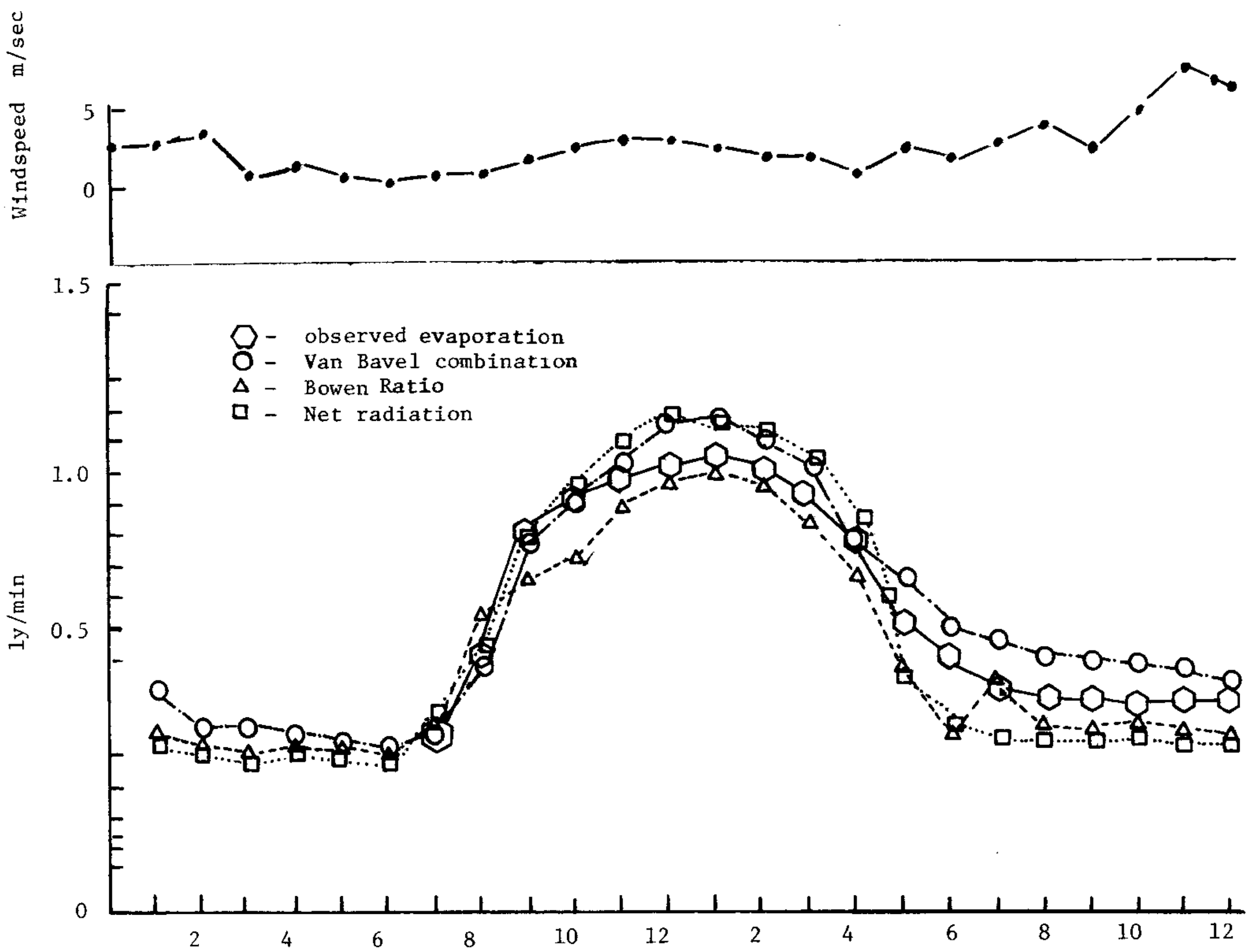

Figure 9. ‘ - Net radiation wind speed observed and calculated evaporative fluxes on July 28, 1968.

seen that the combination model (Equation 3) overestimated the evaporative flux during mid-day and the early part of the night. This was probably due to the windy conditions which existed. Other workers have reported that the van Bavel model tends to overestimate evaporation when windy conditions exist.

The Bowen Ratio (Equation 2) tends to underestimate evaporation during the same period. This was probably due to the fact that the model does not include a direct measurement of wind. The winds were gusty both from the north and southwest and there was considerable variation in the roughness parameter as calculated from wind profile measurements. They varied from .003 to .3 or 100 fold due to the gusty conditions. These measurements were rather crude and there could very well be an error in the values. The inability of the soil to supply water to the soil surface in the late afternoon and evening may have also been a factor in fitting the models during this period of time.

As other workers (23) have found, the Bowen Ratio underestimated the evaporative flux under the windy conditions under which the data were taken. This was especially true in this study during the evening hours when windy conditions existed.

To adapt these models to the high wind speeds and gusty conditions, they will have to have either (1) a variable roughness parameter determined at the time of the measurement in case of the combination model or (2) a coefficient for gusty high wind conditions in case of the Bowen Ratio.

Skidmore has broken the van Bavel combination model into two components to some estimate of the contribution of wind evaporative potential in Kansas. A similar breakdown of the data obtained in this experiment (Figure 10) shows that the wind component of the model is a dominant factor at night and late afternoon while the radiation component of the equation is dominant from midmorning until midafternoon.

Although there was more difficulty in fitting the models to hot, gusty, windy days, the models provided a fair estimate of the evaporation on other days following moisture additions due to rainfall or irrigation.

Following showers on December 26-27 totaling 9.6 mm of rain, the lysimeters were watered on the 28th of December, 1968. As can be seen in Table 2, both the combination model and the Bowen Ratio provided fairly good estimates of the actual evaporation. The showers apparently did not influence the entire area too much because there was advective energy on December 29 and December 30. However, when the winds switched to the south, the vapor pressure deficit dropped and sensible heat was added since evaporation did not equal net radiation. When drier north winds invaded the area on January 2, 1969, the advection again increased.

Following a shower of 19.1 mm on February 14, 1969, the evaporation was again measured. There was considerable discrepency between the measured and calculated values from both models. Both models are very net radiation dependent and it is possible that

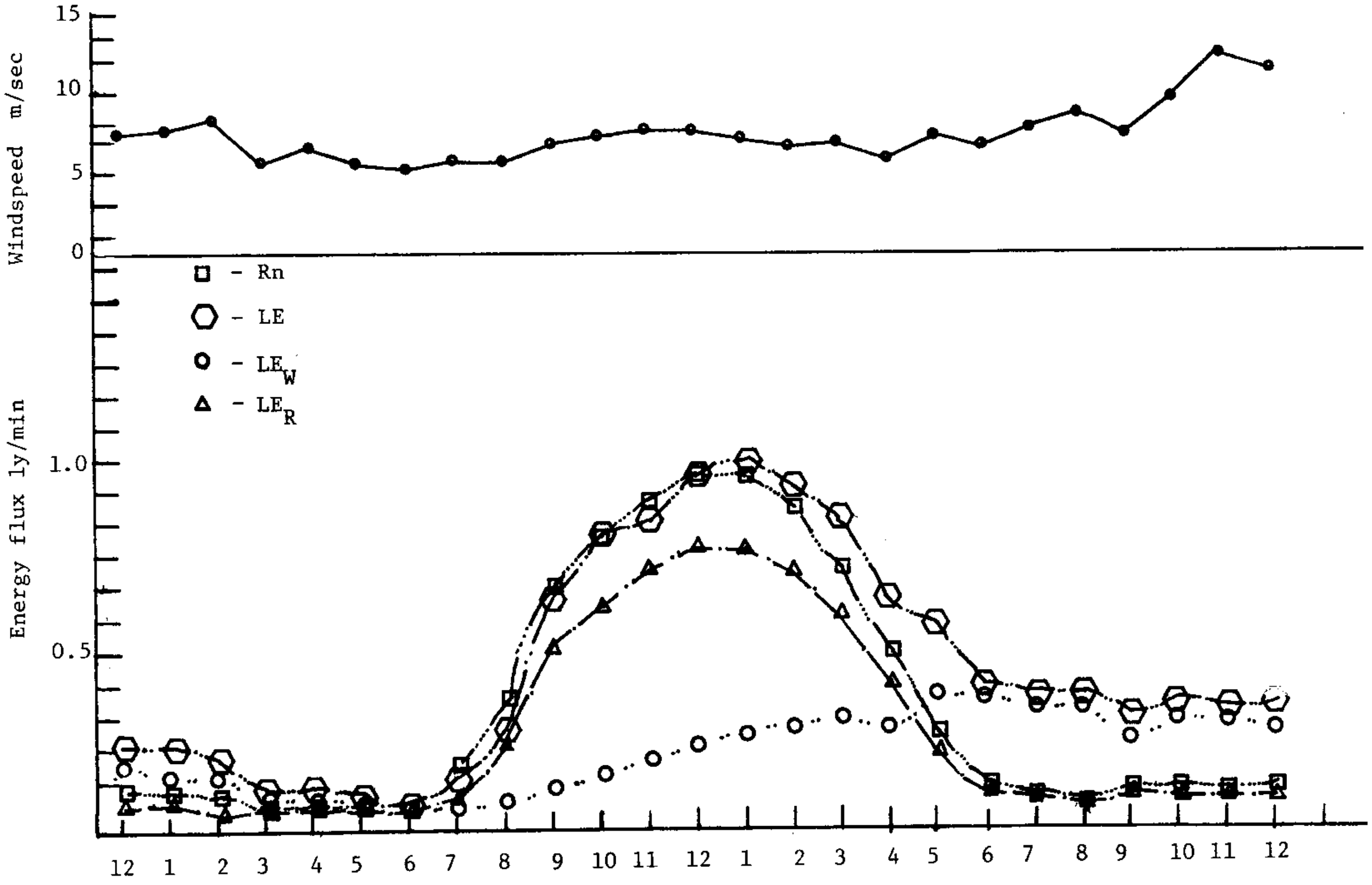

Figure 10. Hourly variation of net radiation (Rn) Calculated evaporation (LE), calculated evaporation due to radiation (LE_R), calculated evaporation due to wind (LE_W) and windspeed.

Table 2. Summary of 24 Hour Test of the van Bavel Combination Method and Bowen Ratio

Date	Solar Radiation (RS)	Net Radiation (Rn + S)	Average Temperature (T)	Average Vapor Pressure (e)	Average Wind Speed & Direction (U)	Observed Evaporation (LE_m)	Advective Energy (A)	van Bavel Model (LE_{VB})	Bowen Ratio (LE_β)
	ly	ly	°C	mb	m sec^{-1}	ly		ly	ly
12-29-68	325	195	10	6.7	5.3 W	-221	+26	242	210
12-30-68	310	178	5.5	5.0	5.8 WNW	-183	+5	210	170
12-31-68	335	198	5.5	1.8	4.0 S	-120	-78	110	120
1-2-69	370	216	7.8	4.4	4.1 N	-191	+25	185	190
2-15-69	163	93	4.4	1.7	4.2 NNW	-149	+56	75	80
3-19-69	396	233	12.8	4.9	5.2 W	-215	-18	225	188
3-20-69	430	262	7.2	3.9	3.4 NNE	-325	+63	188	204
3-21-69	482	289	10.0	6.2	4.4 S	-279	+10	289	240
4-14-69	404	238	13.3	6.4	5.8 SSE	-250	+12	270	230
4-15-69	662	379	18.3	12.6	6.2 SSW	-418	+39	474	330
5-8-69	473	280	12.8	4.7	5.6 WNW	-290	+10	315	260

Table 2. Summary of 24 Hour Test of the van Bavel Combination Method and Bowen Ratio (Continued)

Date	Solar Radiation (RS)	Net Radiation ($R_n + S$)	Average Temperature (T)	Average Vapor Pressure (e)	Average Wind Speed & Direction (U)	Observed Evaporation (LE_m)	Advective Energy (A)	van Bavel Model (LE_{VB})	Bowen Ratio (LE_β)
5-9-69	722	397	16.1	7.9	3.7 SW	-389	-8	369	405
6-14-69	516	293	27.2	16.0	4.2 ENE	-350	+57	360	303
7-24-69	774	444	30.0	23.3	3.3 S	-610	+166	589	572
7-25-69	688	421	30.0	27.2	4.4 S	-530	109	550	450

some errors in measurement of this parameter occurred due to intermittent cloudiness. Only about 17 percent of the rainfall was evaporated during the following day.

Snowfall of 307.0 mm (31.7 mm of moisture) occurred from 6 p.m., March 14, 1969 to 12 noon, March 16, 1969. After the snow melted, hourly evaporation data was procured March 19, 20, and 21 to determine how close the measured and calculated evaporation fit. As can be seen in Table 1, there was fairly close fit between the measured evaporation and that calculated by both the combination model and the Bowen Ratio. In general, the combination model overestimated the evaporation for the period. This is probably due to the uneven snow cover in the area of the lysimeters which presented both wet and dry areas at the time of the measurements.

Following rains of 27.7 mm in June and 67.4 mm in July, considerable advection was indicated. The combination model better estimated evaporation than the Bowen Ratio during these periods.

Although the precipitation was above normal during 1969, considerable advective energy was apparently available for evaporating soil water during periods immediately after rains. This is probably due to the fact that few rains cover the entire area and that most rains are isolated leaving many relatively dry areas in the High Plains. With the relatively high average wind speed in the area, it is probable that sensible heat is transported considerable distances to provide advective energy for evaporation from areas that receive large amounts of rain.

As has been pointed out by Rosenberg (22) and Hanks (12), advection is a major factor in evapotranspiration in the Great Plains. It apparently is also a major factor in soil water evaporation. Even though the combination method overestimates and Bowen Ratio underestimates soil-water evaporation, it appears that either can be used to estimate soil-water evaporation for those short periods immediately after rains.

The evaporative flux exceeded net radiation on several of the days studied (December 29, 30, March 15, April 14, 15, May 8, June 14, July 24, and 25). The highest LE_m/R_n of 1.37 occurred on July 24. It is doubtful if values greater than this will be obtained for a bare Olton loam soil. Values greater than this have been reported for crops by Fritschen (10). However, crops are rougher and better able to extract energy from the air mass. Also, as will be shown in other sections of this report, the conductivity of this soil decreases rapidly at rather low suctions and high moisture contents. Therefore, the so called "constant" high rate stage of drying lasts for only a short period of time and bare soil evaporation decreases rapidly after a rain even though the conditions for high evaporation exist.

B. Canopy Effects on Evaporation

The question has arisen many times concerning the amount of water evaporated from a soil surface within a crop canopy. Lemon (16) points out that Brown and Covey have estimated the evaporation from the soil surface using micrometeorological methods. Begg et al (1) has also estimated the evaporation in bulrush millet.

None of these studies, however, had actual measurements of the evaporation with which to determine the accuracy of their methods. Information on actual measurements would give credence to the micrometeorological techniques previously applied and give some idea of the canopy effects on actual soil-water losses. It was, therefore, decided to measure evaporation from the soil surface within crop canopies using small hydraulic lysimeters previously described. Although it is realized that the lysimeters actually occupy part of the root zone that would normally be occupied by a crop, it was felt that such lysimeters would provide an estimate of the importance of canopies in preserving small showers.

Methods and Materials

Six lysimeters with associated micrometeorological equipment were used in the area study. Three of the lysimeters were located in Dunn 56-C cotton planted two rows per bed and three lysimeters were located in an area with bare soil. Measurements of wind speed, wet bulb-dry bulb measurements, lysimeter weights, net radiation were recorded on strip chart recorders. Data were taken from the strip charts on an hourly basis. The van Bavel (28) combination method was used to estimate evapotranspiration from the cotton and evaporation was determined from the lysimeters in the open and in the cotton. Measurements of the soil moisture content was determined gravimeterically in the 0-3 cm soil layer in each lysimeter.

Results and Discussion

Hourly estimates for the energy balance components for the cotton and bare soil are indicated in Figures 11-13 for August 28 and Figures 14-16 for September 4.

As can be seen from the solar radiation (R_s) curves (Figures 11-13), there was intermittent cloudiness on August 28. This was especially true between the hours of 11 a.m. and 5 p.m. It is difficult to get good estimates of net radiation (R_n), soil heat flux (S) and LE_m under such conditions when the data is obtained on an hourly basis. Consequently, there is probably some error in the calculated values of sensible heat (A). Similar conditions existed on August 29 and 31 and September 1.

Evaporation from the bare soil exceeded the calculated evapotranspiration from cotton on August 28, (Table 3). As was expected, a crust formed on the open bare soil and the evaporation rate decreased a few days after the rain (Figures 11, 15, and Table 3). As the evaporation (LE_m) decreased, the calculated advection (A) increased.

Calculated evapotranspiration of the cotton remined high throughout the period studied. The cotton was approaching maturity and had a dense canopy and extensive root system.

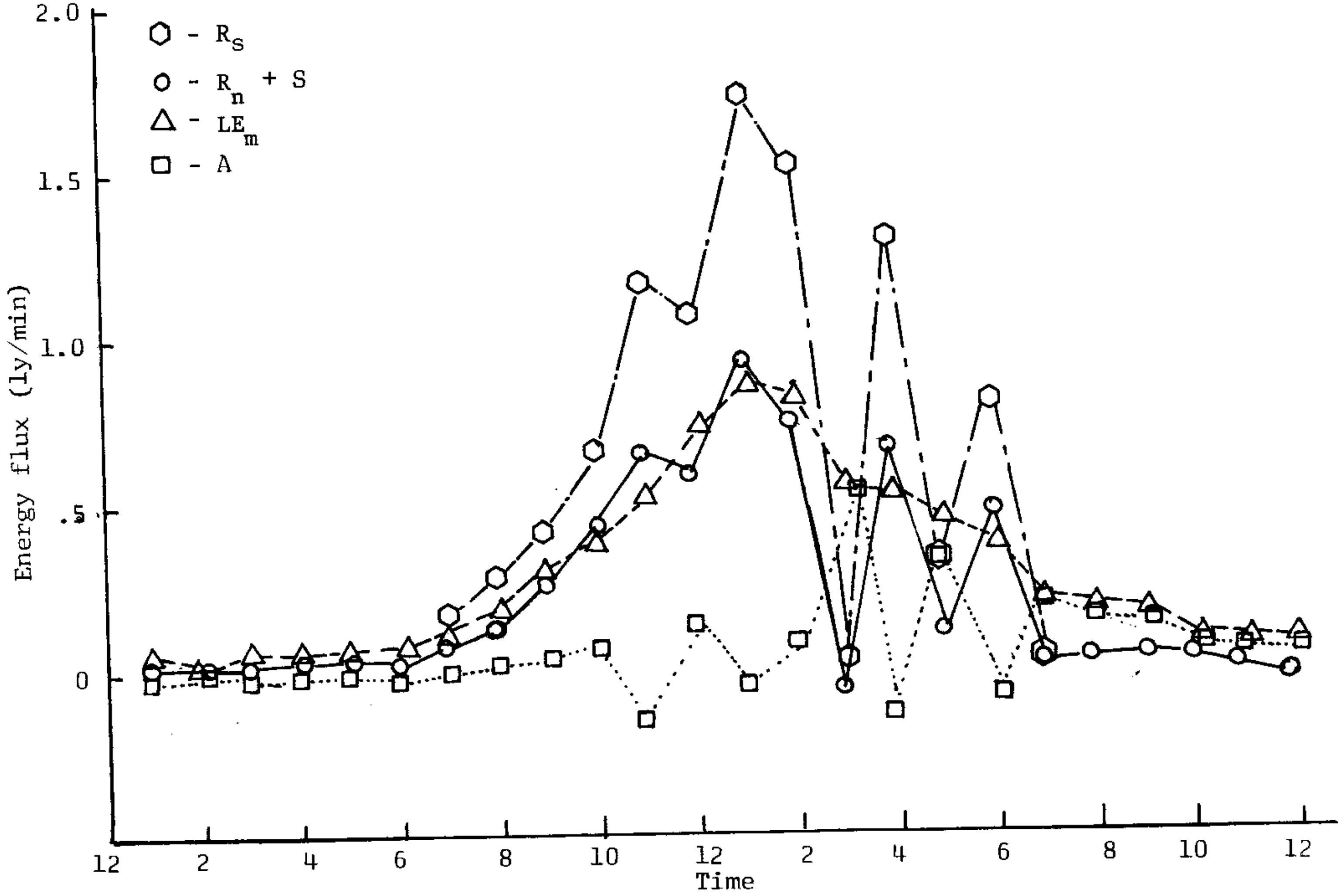

Figure 11. Energy budget components from bare soil on August 28, 1969.

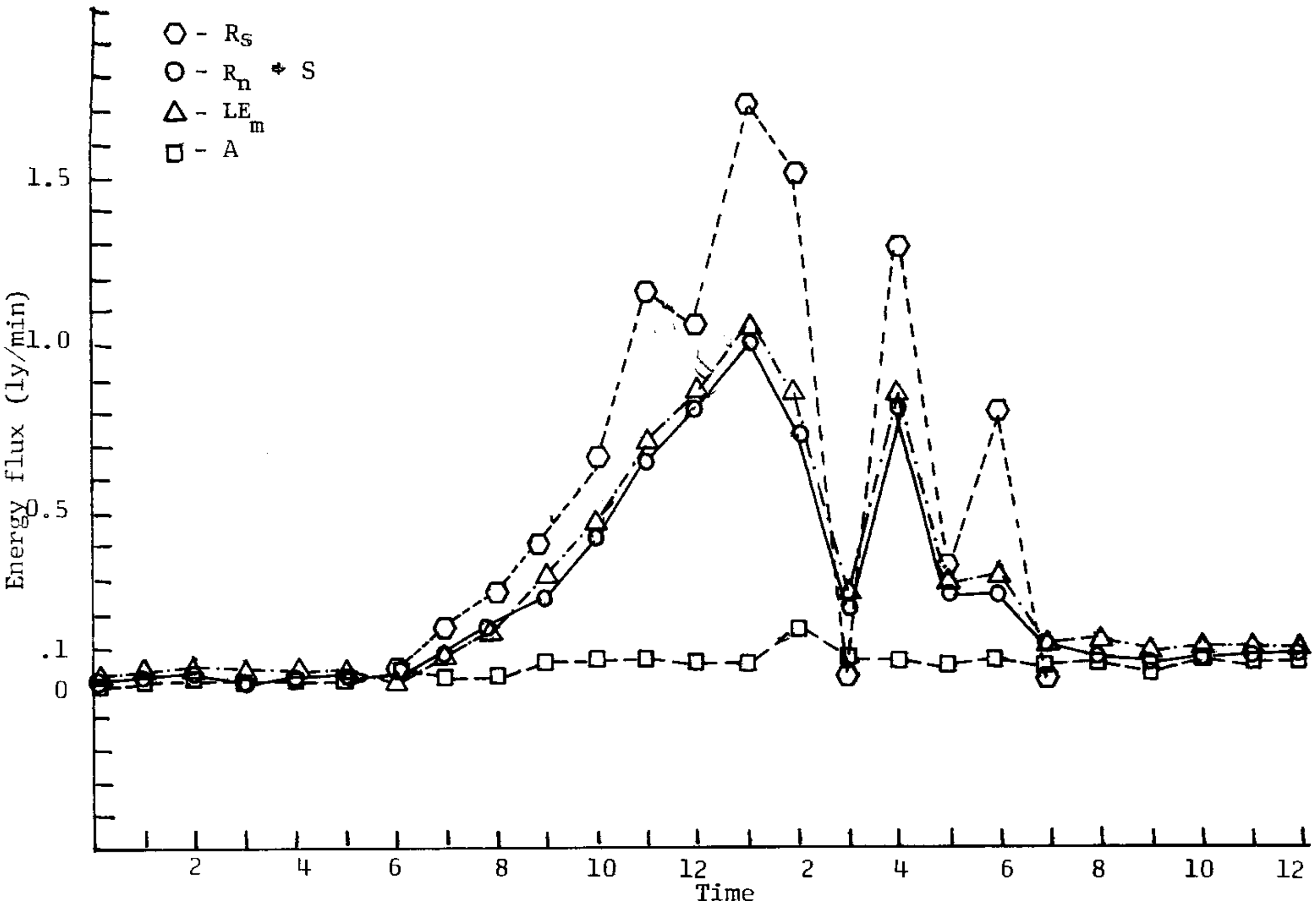

Figure 12. Energy budget components from cotton on August 28, 1969.

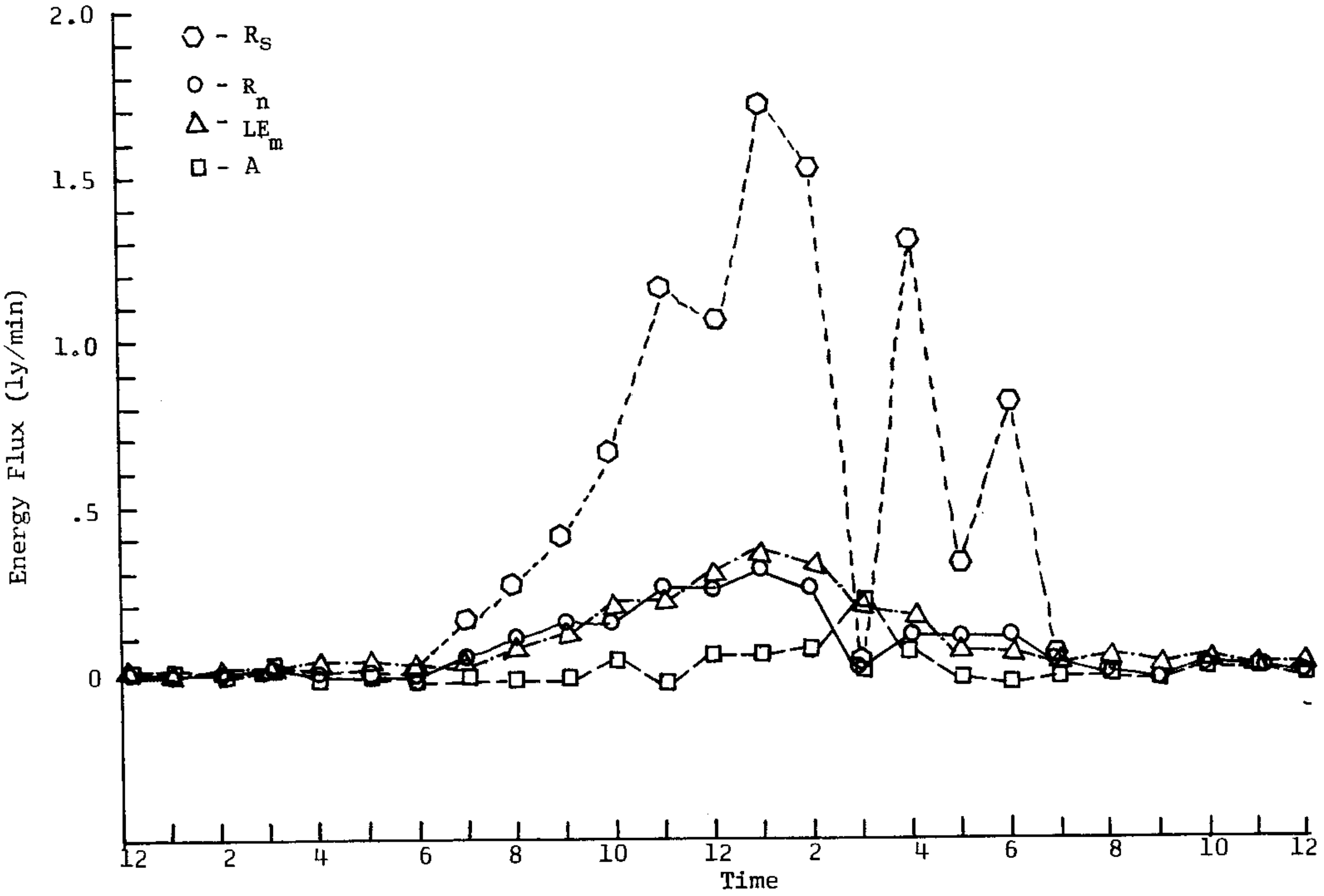

Figure 13 - Energy budget components for bare soil in cotton canopy on August 28, 1969.

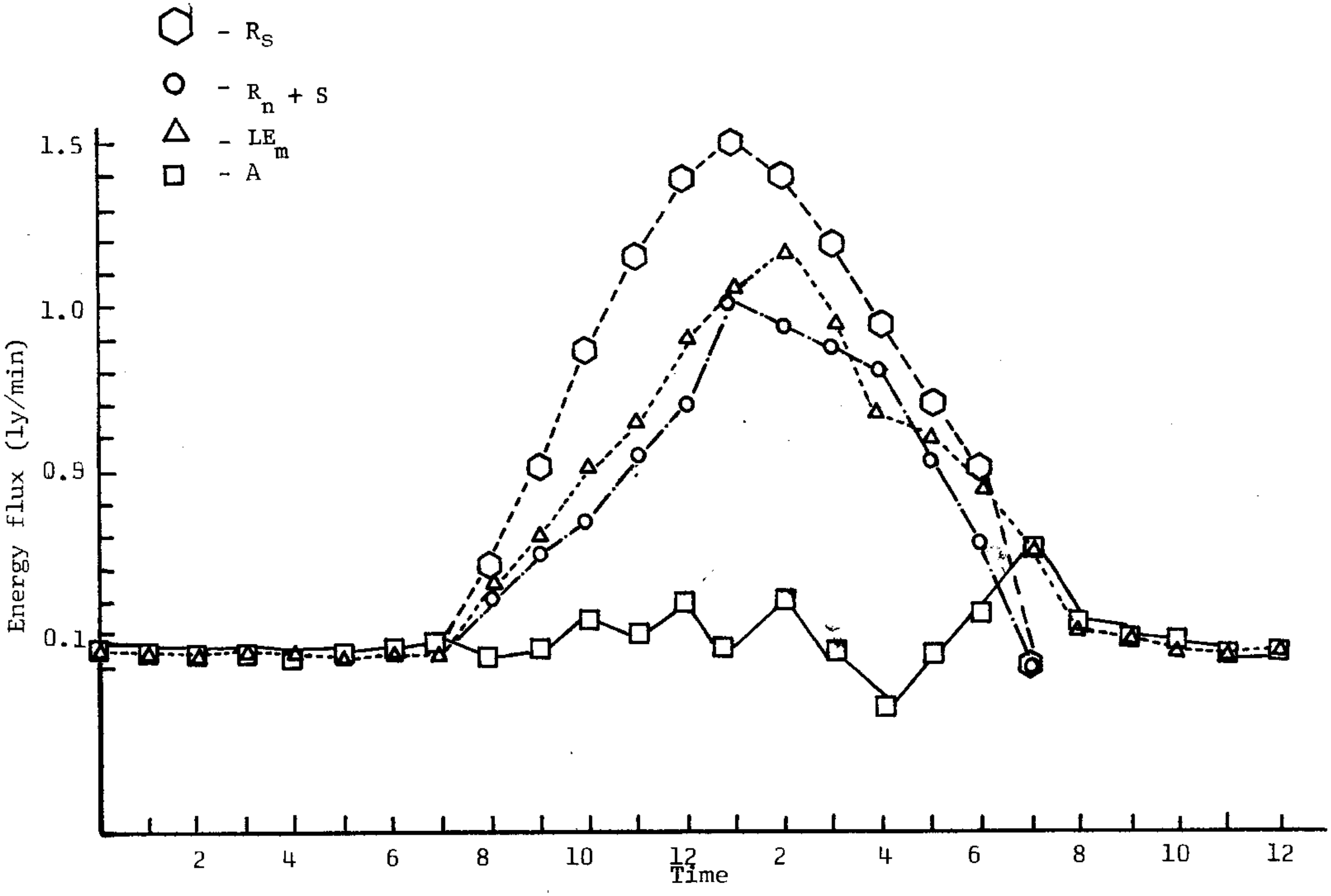

Figure 14 - Energy balance components for cotton on September 4, 1969.

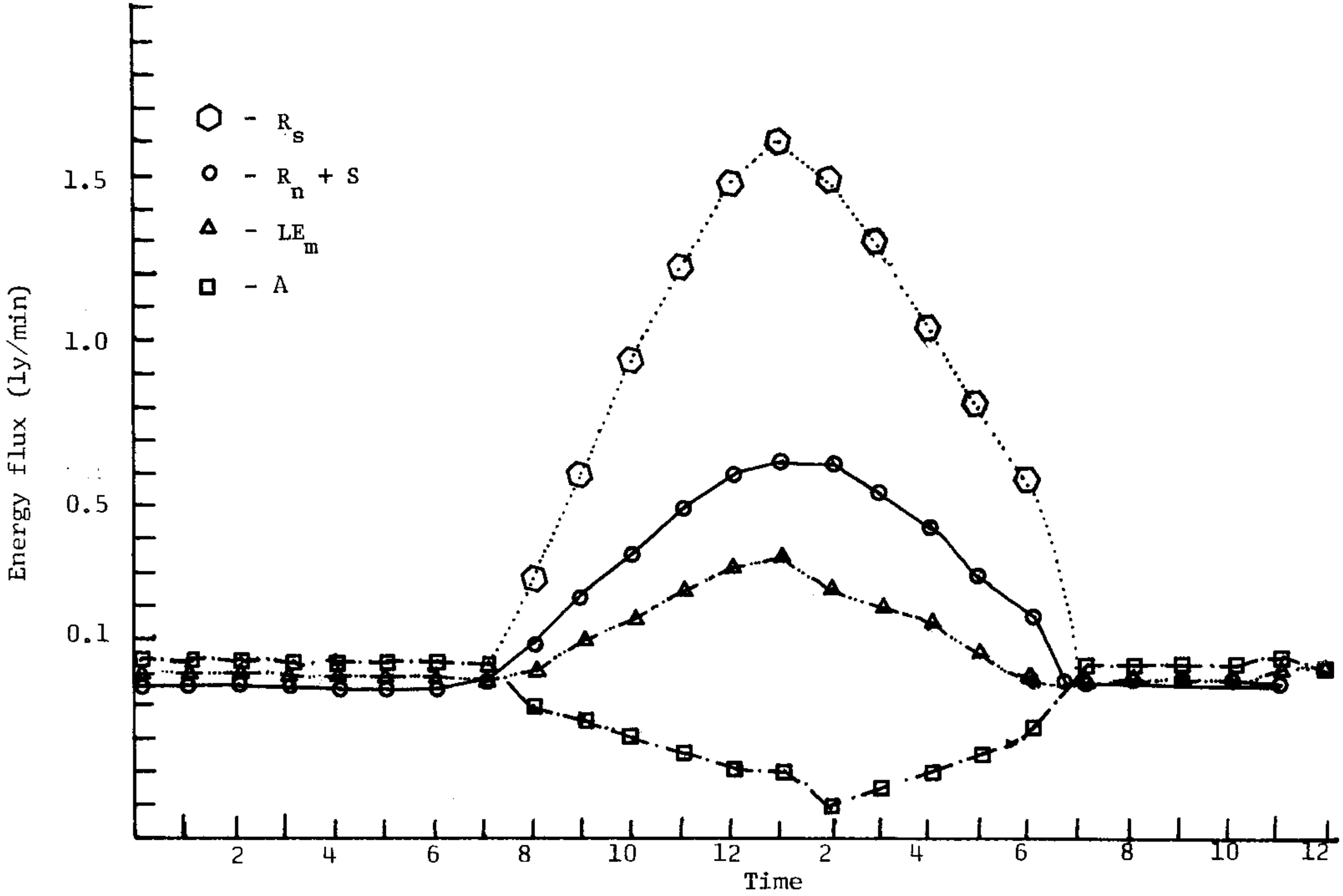

Figure 15. Energy balance time components for cotton on September 4, 1969.

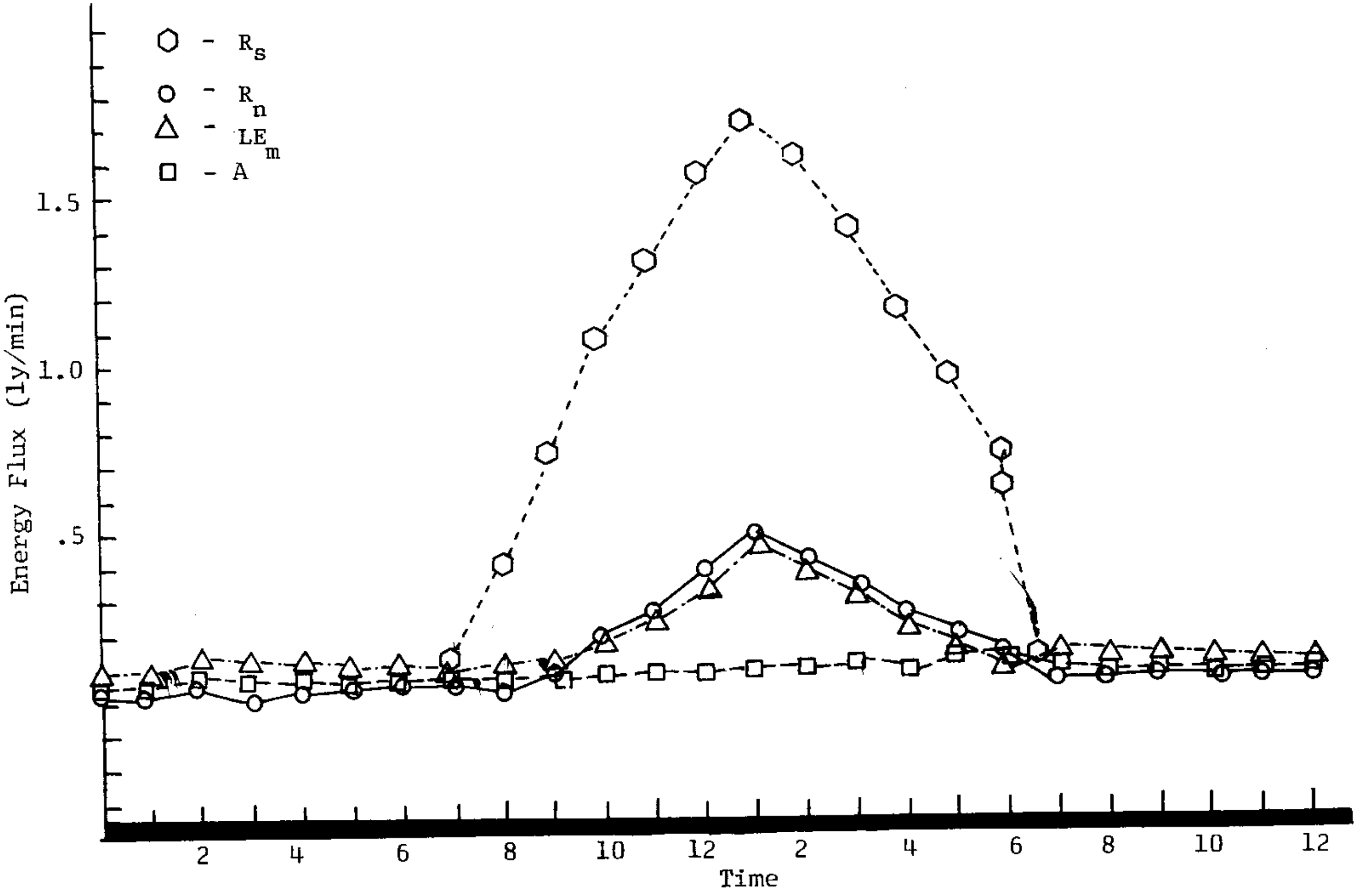

Figure 16. Energy budget components for bare soil in cotton canopy on September 4, 1969.

Table 3. Energy Balance of Bare Soil Surface, Cotton and Bare Soil Within Cotton Canopy (langley/day).

Day	Surface	Rs	R_n+S	LE	A
August 28	Bare Soil	486	315	-393	78
	Cotton		320	-280	-40
	Bare Soil in Cotton		108	-123	15
August 29	Bare Soil	416	236	-265	29
	Cotton		297	-310	13
	Bare Soil in Cotton		98	-115	17
August 30	Bare Soil	502	312	-293	-19
	Cotton		360	-430	70
	Bare Soil in Cotton		104	-123	19
August 31	Bare Soil	480	315	-216	-99
	Cotton		341	-393	52
	Bare Soil in Cotton		101	-109	8
September 1	Bare Soil	430	268	-218	-50
	Cotton		236	-275	39
	Bare Soil in Cotton		103	-98	-5
September 2	Bare Soil	512	311	-189	-122
	Cotton		361	-423	62
	Bare Soil in Cotton		107	-118	11
September 3	Bare Soil	602	362	-161	-201
	Cotton		423	-518	95
	Bare Soil in Cotton		87	-103	15
September 4	Bare Soil	688	383	-108	-275
	Cotton		438	-534	96
	Bare Soil in Cotton		56	-78	12

Calculated sensible heat values (A) for cotton were higher during September a few days after the rain than they were immediately after the rain. This indicates that advection became more of a parameter in the evapotranspiration of the cotton

The evaporation from the small lysimeters remained at a relatively low rate for the period (Figures 13, 16, and Table 3). The evaporation rate is apparently related to the net radiation and is little affected by the advected energy as is the evapotranspiration from the crop.

These results are comparable to those of other workers. Van Bavel (28) showed that advection was a major parameter in evaporation from bare soil immediately after irrigation in Arizona. The bare soil in this study contributed to the advective energy from the second day after the rain. Hanks (12) mentioned that the "constant stage" of evaporation lasted for only a short period following moisture additions. Cropped areas tend to transpire water at a high rate depending on the amount of water available and the climatic conditions. As previously indicated, advective energy appeared to be a major parameter in evapotranspiration of the cotton. Apparently, most of this energy was used in transpiration since the evaporation from the small lysimeters could be related closely to the net radiation. Also, as indicated in Figure 17, the wind velocity within the canopy was very low which would decrease the possibility that advective energy was a factor in evaporation from the soil within the crop canopy.

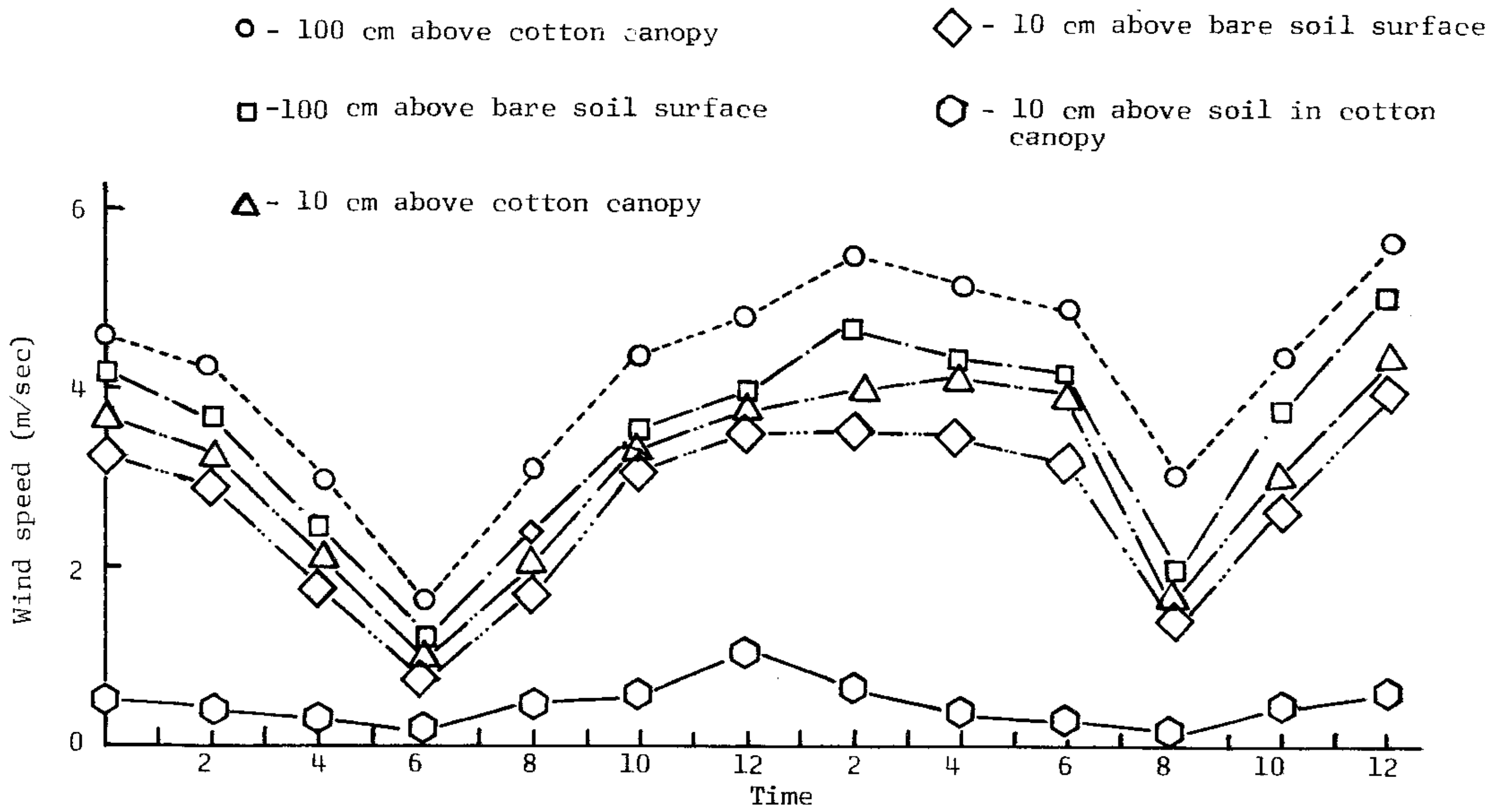

Figure 17. Wind speed at selected locations over bare soil and cotton canopy on September 4, 1969.

Figure 18 shows that the moisture content of the 0-3 surface layer decreased much faster in the bare soil surface than in the crop canopy. It thus appears that evaporation from the soil surface within the crop canopy, is directly related to the net radiation for the long period of time following moisture additions. Following this period, evaporation losses are related to the moisture content of the soil surface.

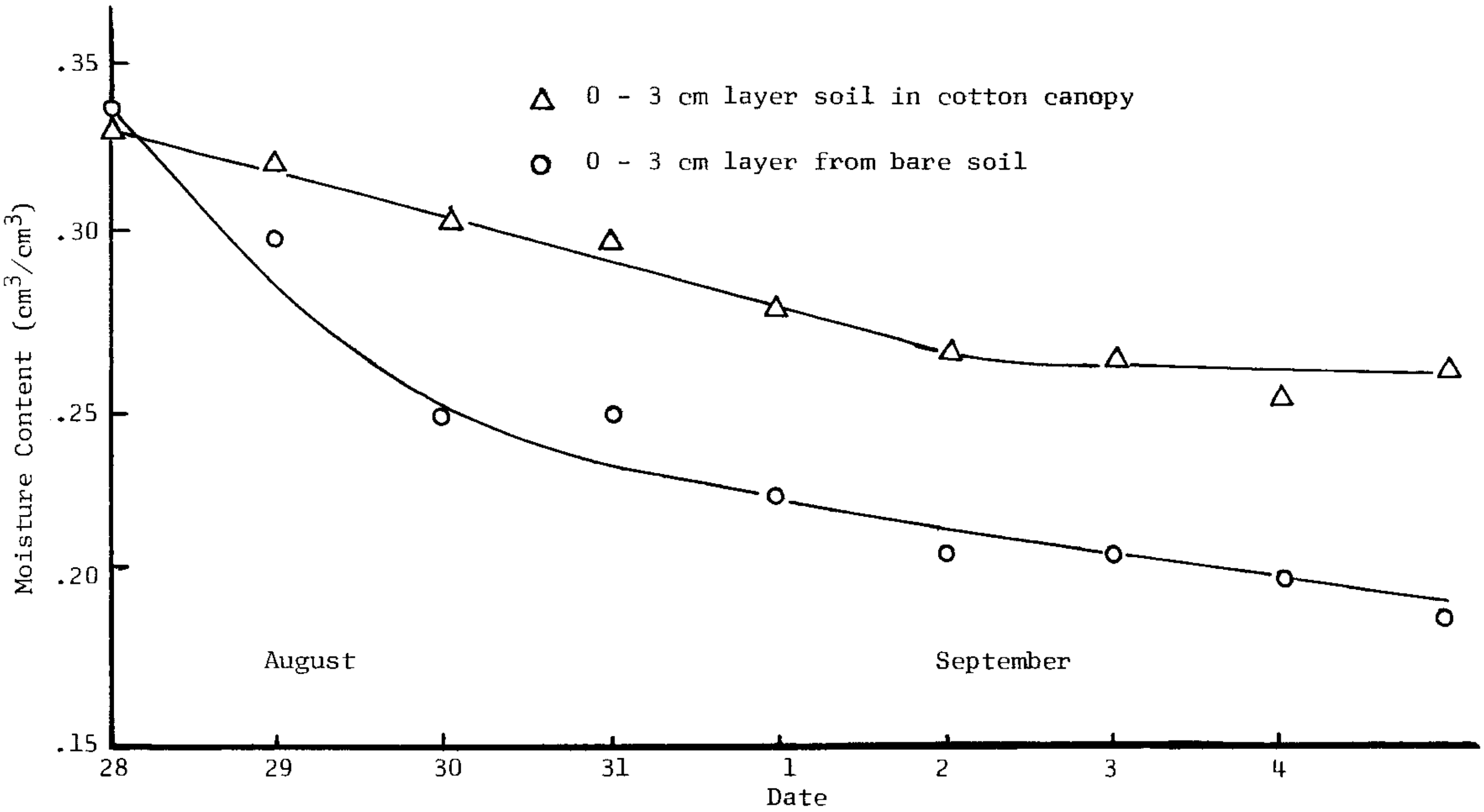

Figure 18. Moisture content of soil surface in bare soil in open and in cotton canopy in 1969.

C. Hydraulic Conductivity Studies

As previously mentioned, the so called constant high rate stage of soil water evaporation lasts for only a short period of time in areas that have high evaporative conditions such as the Great Plains. Since van Bavel's combination concept (29) and the Bowen Ratio (9) (10) only apply to well watered surfaces, it is not possible to use them to predict evaporation during the falling and low rate stages of drying. Much work is yet to be done in the development of models for predicting evaporation in the latter stages of drying. Information concerning the hydraulic conductivity of field soils _in situ_ would aid in the development of such models. It was therefore decided to determine the conductivity of the Olton loam soil of these studies.

1. Lysimeter studies

Methods and Materials

The large lysimeters previously described in Chapter I were used in the study. Since the lysimeters contained intact soil cores, information concerning the hydraulic conductivity obtained from the lysimeters should be applicable to the surrounding soil. Furthermore, information concerning the relationship between evaporation and hydraulic conductivity could also be obtained.

The study was undertaken following rainfall of 3.32 cm during the night of June 12, 1969. Following the rain, a vacuum was applied to the bottom of the lysimeters to remove any excess water that might have been conducted through the profile. Moisture tension measured with mercury tensiometers and moisture content was measured with calibrated neutron and gamma probes.

The major changes in soil water contents and pressure occurred in the 0-30 cm soil layer (Figures 19-23). Since both pressure and content data were available from the 15 and 30 cm depths, it was decided to use Darcy's law to calculate the capillary conductivity of this layer. The average amount of water that moved in this layer between measurements was determined by obtaining the difference between sums of the water contents for the two depths multiplying by the depth of the layer (15 cm) and dividing by the number of days. These values represented the daily mean flux values, q (x). The values for potential gradient ($^{d\phi}/dx$) were obtained for tensiometer readings (cm) averaged over the specified time interval. With these values, it was possible to calculate the capillary conductivity [K (cm/day)] from Darcy's law:

$$q = -K \frac{d\phi}{dx}$$

Results and Discussion

Figures 19-22 show the soil-water content distribution curves following rains in June. The shaded area represents the change in water content while the unshaded areas show the decrease in water content. There was still a major increase in the horizons above 30 cm after 24 hours even though evaporation was occurring. Furthermore, there was an increase at 90 cm after

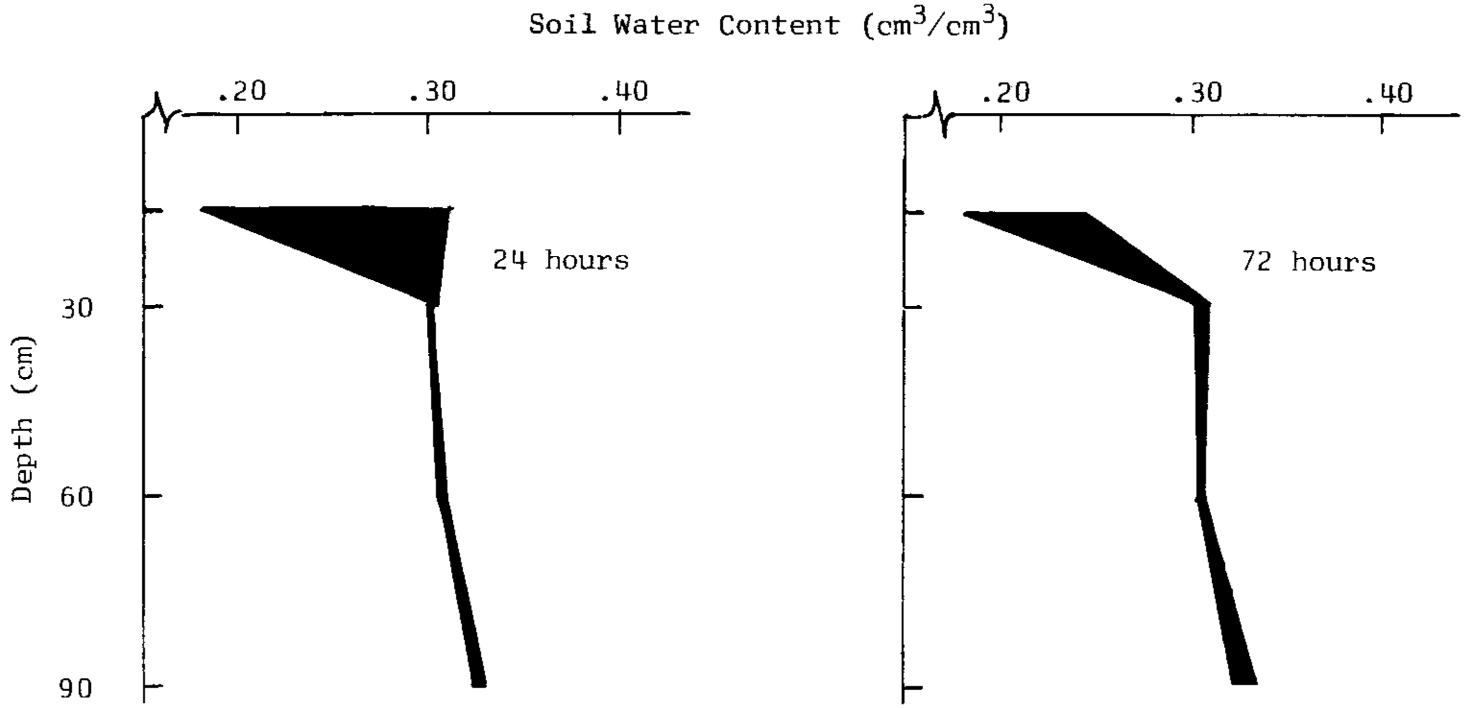

Figure 19. Soil water content versus soil depth measured following rainfall at the 30, 60, and 70 cm depths (shaded area represents the change in water content).

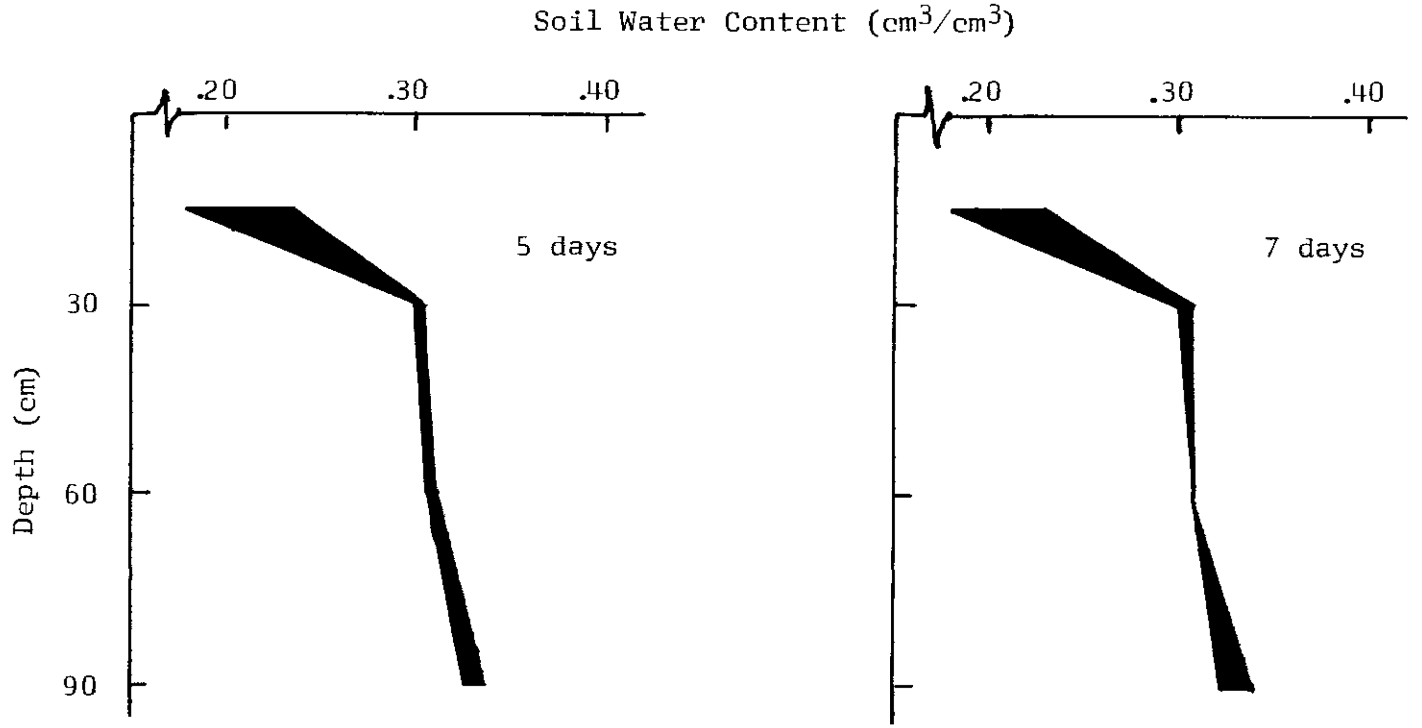

Figure 20 - Soil water content versus soil depth measured following rainfall at the 30, 60, and 90 cm depth (shaded area represents the change in water content).

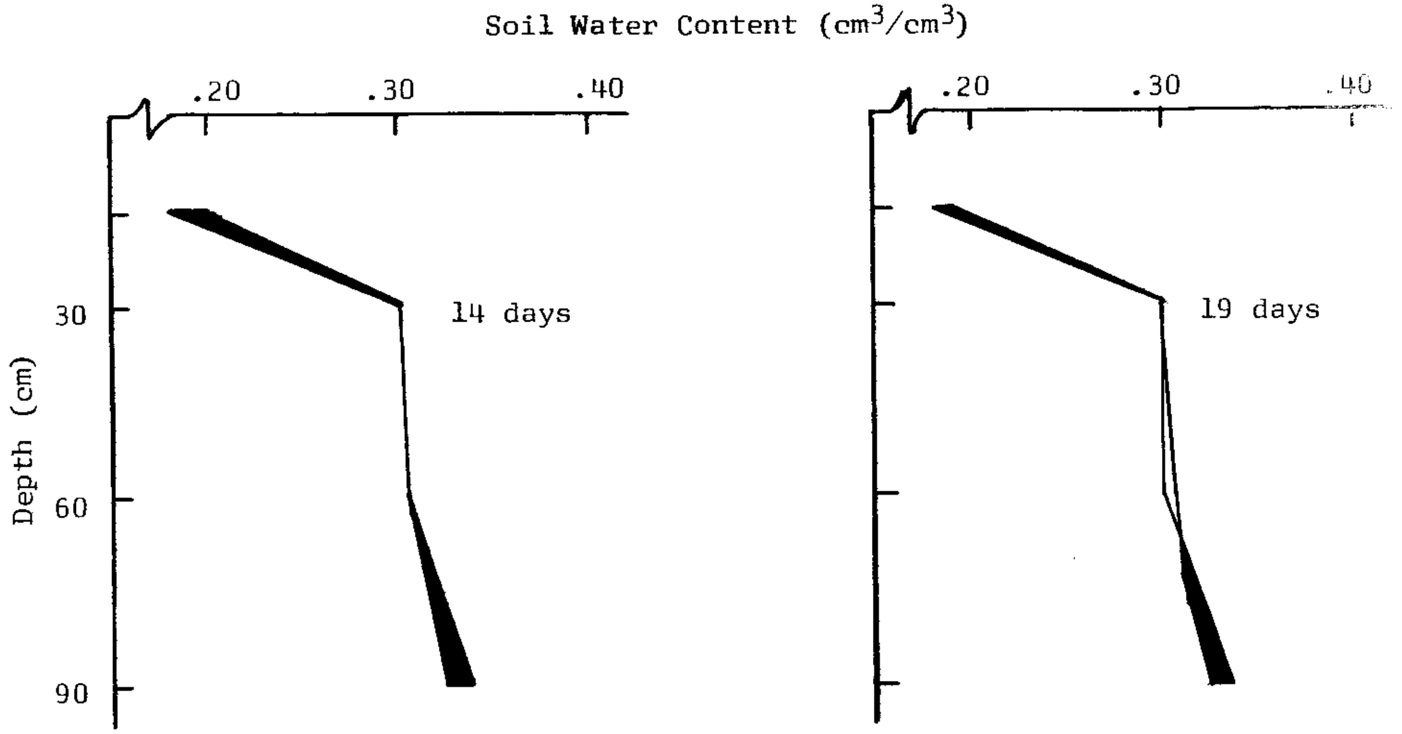

Figure **21** - Soil water content versus soil depth measured following rainfall and the 30, 60, and 90 cm depths (shaded area represents the change in water content).

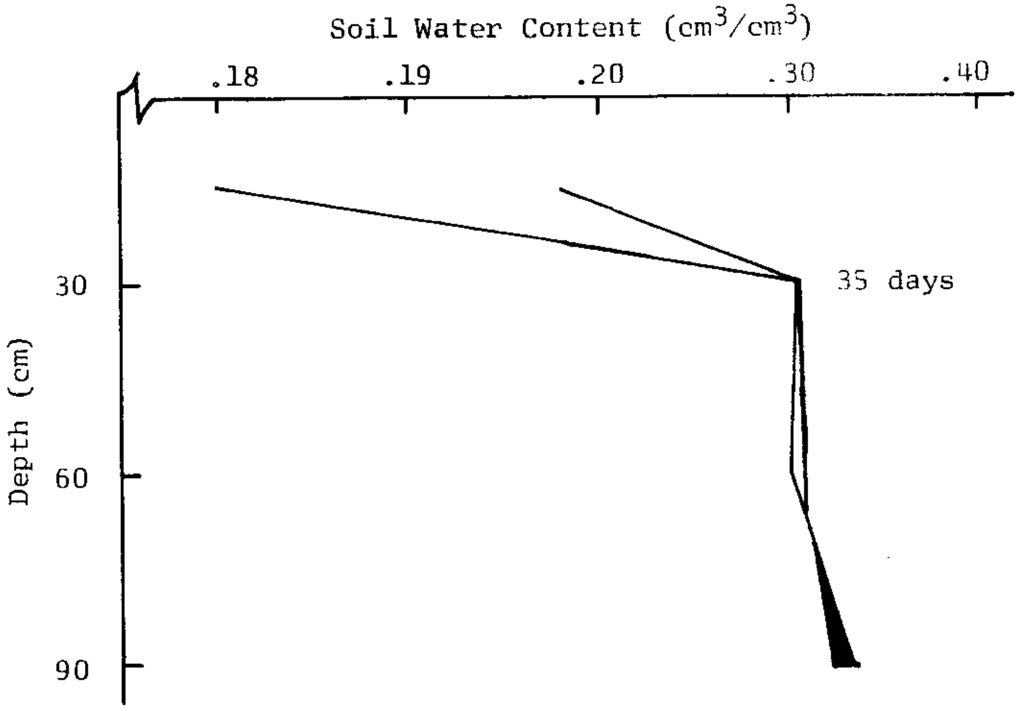

Figure 22. Soil-water content versus soil depth measured following rainfall at 30, 60, and 90 cm depth (shaded area represents the gain; light areas indicate loss in water content).

72 hours without much change at 30 and 60 cm.

There was little change between three and five days. However, at the end of seven days, there was an increase at 90 cm indicating a movement of the water downward. At the end of 14 days, all depths had decreased in content except the 90 cm depth. With the exception of the 15 cm depth, little change in water content occurred between 14 and 19 days. The 15 cm depth contained less water than it had prior to the rain. When the 35 day period was over, the 15 cm depth had even less water. Considering the overall period, there was a loss at 15 cm, little change at 30 to 60 cm, and a slight gain in water content at 90 cm.

The changes in soil-water pressure are indicated in Figure 23. The data were taken in the late evening at the same time each day so as to minimize the temperature effects on the tension readings. It can be seen that the major change in pressure took place at the 15 cm depth. The showers on days 4, 5, and 9 apparently slowed the rate of tension increase during these days. In no case was there a decrease in tension from the rainfall at 90 cm. The tension at 15 cm was higher 35 days after the rain than it was before the rain.

Due to the small changes in content and tension at the 30, 60, and 90 cm depths, it was not possible to calculate any conductivity values below 30 cm. However, since there were major changes in content and tension between 15 and 30 cm, it

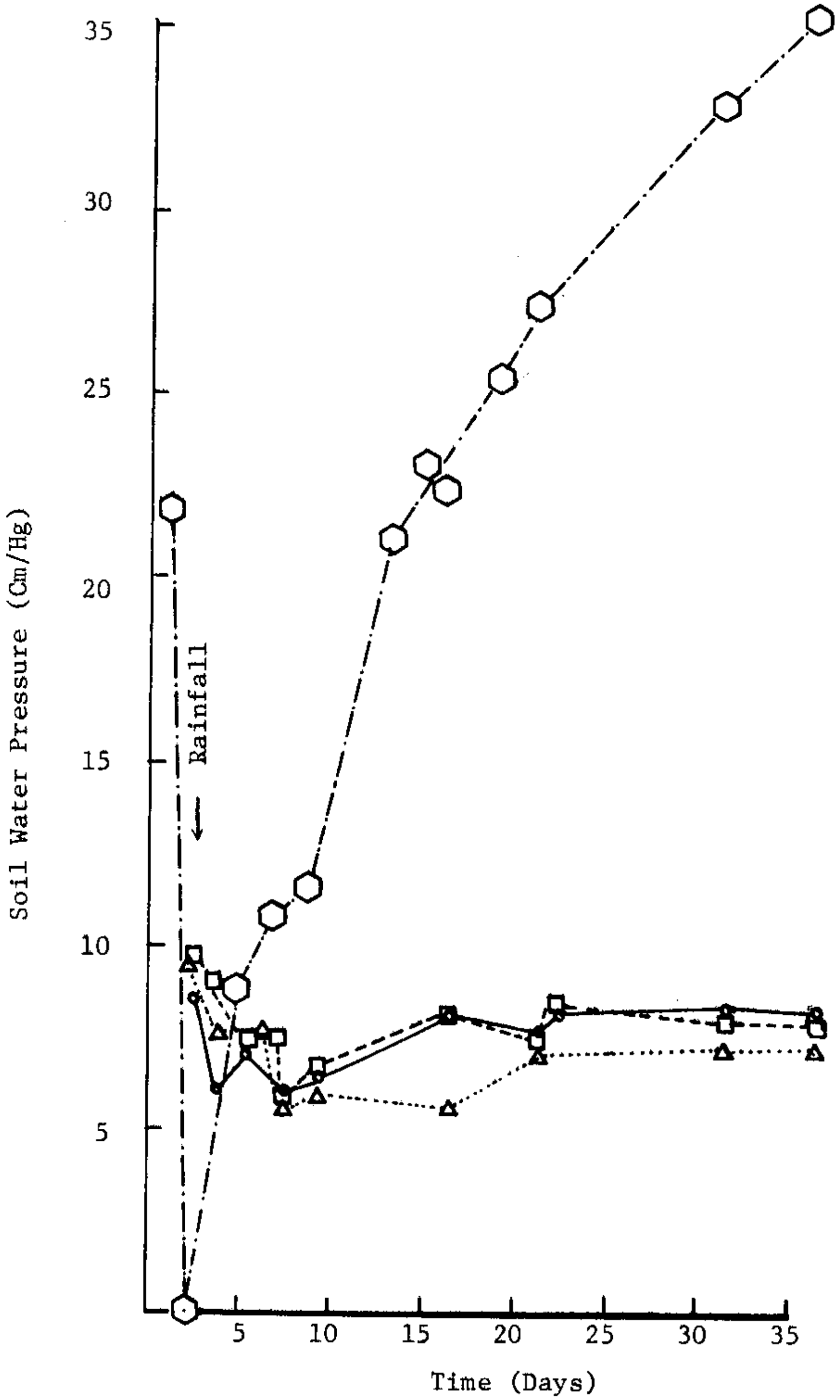

Figure 23. Soil-water pressure changes following rainfall.

it was possible to calculate some conductivity values for this area using Darcey's law. The results are indicated in Figures 24-25. Figure 24 shows the values as a function of soil-water pressure while Figure 25 shows the values as a function of soil-water content.

It is notable that major changes occur in conductivity with only small changes in tension and content. The conductivity decreases 100 fold with only 150 cm H_20 increase in water pressure. A 100 fold decrease in conductivity was noted with only a .014 - .015 cm^3/cm^3 decrease in water content.

From the practical standpoint, this major change in conductivity over a short tension and content range has several implications. From the standpoint of evaporative losses, the soil acts as its own evaporation suppressant. The low conductivity will prevent evaporation losses and since it occurrs at a relatively low tension, the water in the soil profile will be at a tension range considered readily available for crop growth. However, the crops grown on the soil must develop rather extensive root systems because the soil will not readily conduct water to the root systems, or the crops must be irrigated frequently to keep the soil-water tension low. It is entirely possible that fast growing crops will become stressed with plenty of moisture in the lower soil horizons. Due to the low capillary conductivity at low soil-water pressures and contents, it is probable that the crops could transpire the water in the surface

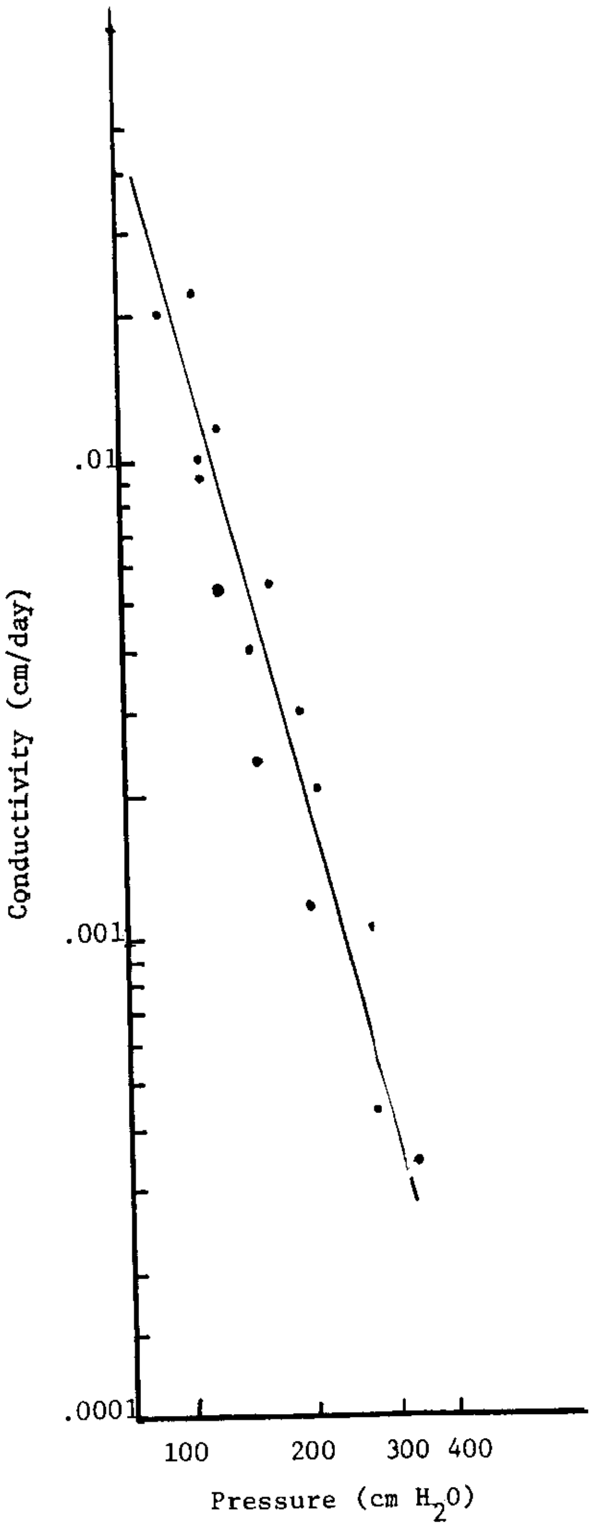

Figure 24. Relationship between soil-water pressure and conductivity of Olton loam soil.

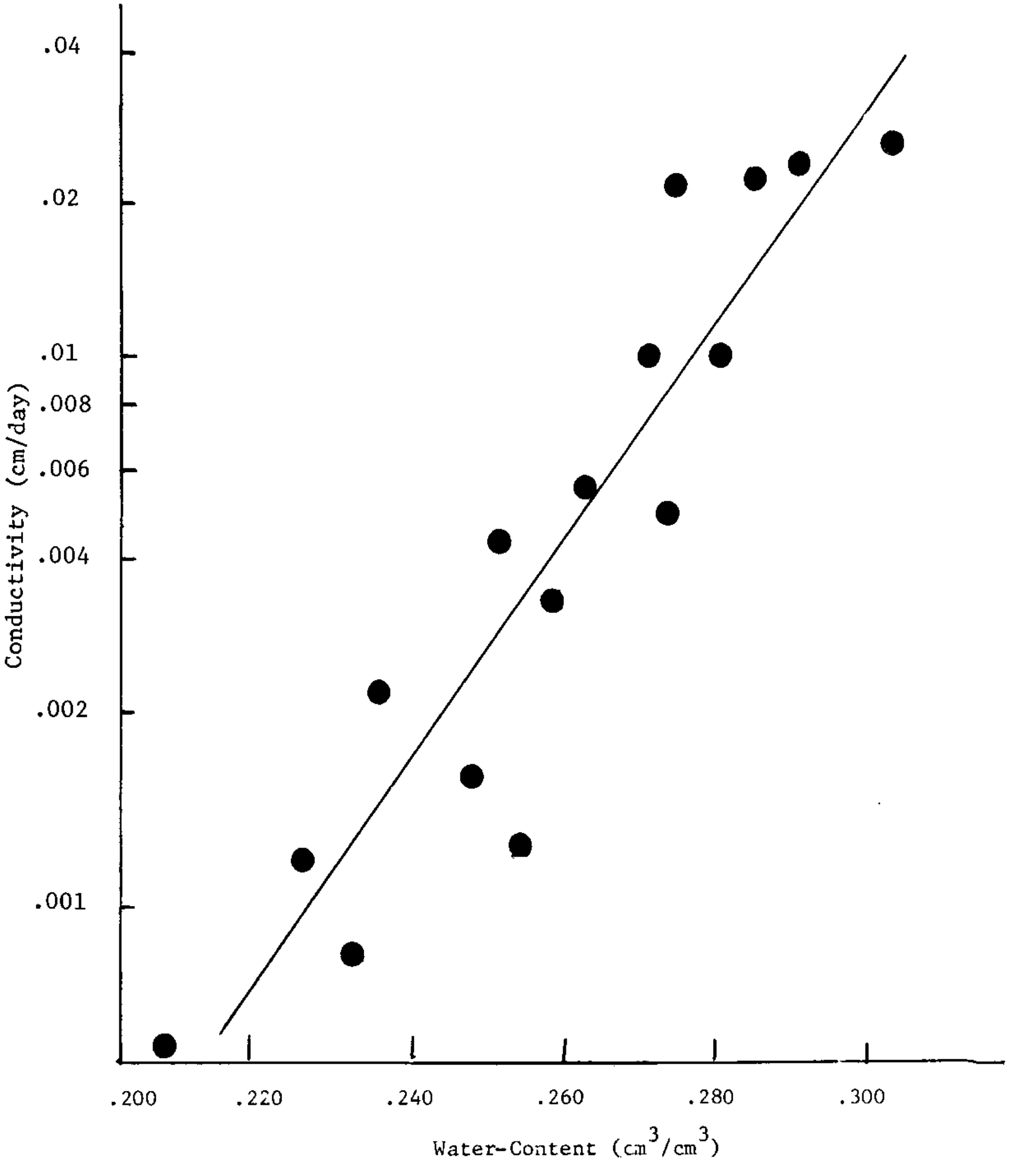

Figure 25. Relationship between soil-water content and conductivity of an Olton loam soil.

horizons and become stressed before they had an opportunity to develop a root system to utilize the water in the lower horizons of the soil.

Soil moisture content data were available from the 0-15 cm layer. It was thought that this data might be used along with the relationship obtained between conductivity and soil moisture content (Figure 25) to get an idea of the conductivity of the surface layer at different evaporation rates. However, as indicated in Table 1, there is a major difference in texture and structure between the layer from which the relationship was obtained and the surface layer. Therefore, it was not possible to investigate this relationship.

2. Conductivity studies in adjacent ateas

Materials and Methods

To obtain additional information on water movement in the Olton loam soil, it was decided to conduct a study to determine the hydraulic conductivity at different moisture contents and soil-water pressures in an area adjacent to the lysimeters. It was necessary to grow weeds on the area to get the moisture content low enough for the studies.

Four 8 x 8 meter square plots were used for the study. The plots were isolated from each other by metal barriers about 30 cm high to prevent surface runoff of the applied water. An area of 6 x 6 meters square in the middle of each plot was chosen for analyzing soil-water movement. The plots were divided arbitrarily into four equal subplots and each subplot provided with an acess tube, eight tensiometers, and eight thermocouples. Tensiometers were located at equal distances on the circumference of a circle having a radius of 1.0 meter. An access tube was at the center of each circle. The tensiometers and the thermocouples were placed at random at the following depths: 15, 30, 45, 60, 75, 90, 120, and 150 cm, and the access tubes to 250 cm in each subplot. Thermocouples at each depth were about 10 cm away from the tensiometer bulbs.

A shelter was constructed over three plots to protect them from rain. The fourth plot remained free from shelter and its moisture, received from precipitation, was recorded by a rain gauge. Evaporation was determined from lysimeters.

Two applications of 5-10 cm of water were made to the plots to study the hydraulic conductivity. Soil-water content, soil-water suction and soil temperature was measured at each depth before addition of water. The above measurements were made by a neutron moisture meter, tensiometers and thermocouples, respectively. The measurements were continued until the movement of water ceased.

The hydraulic conductivity *in situ* will be determined by using the equation developed by Rose, Stern, and Drummond (19). This equation for a given volume of vegetation-free soil may be written:

$$K_z = \frac{\int_{t_1}^{t_2} \left[P + I - E - \left(\int_0^z \frac{\partial \theta}{\partial t} \, dz \right) \right] dt}{\left[\frac{\partial h}{\partial z} + 1 \right]_z T} \quad \text{cm/sec}$$

where:

K_z = an average hydraulic conductivity over the time interval $T = t_2 - t_1$ (sec) between measurements of successive profiles,

P = rate of precipitation (cm/sec),

I = rate of irrigation application (cm/sec),

E = evaporation rate (cm/sec),

θ = volumetric water content (cm^3/cm^3),

t_1, t_2 = times of observations of conductive profiles (sec),

z = depth, positive downward, measured from the soil surface ($z = 0$) in cm.

This equation will be used for the determination of hydraulic conductivity of the uncovered plot. The terms P and E in the equation will be obtained from rain gauges and lysimeter data, respectively. The term I will be regarded as zero.

The data from the covered plots will be subjected to the method proposed by Childs and Collis - George (6) for calculating hydraulic conductivity from pore size distribution data. These data can be reduced from moisture characteristic curves obtained on disturbed or undisturbed samples, or from simultaneous measurements of soil-water content and soil-water pressure.

The equation they used may be written:

$$K = 1.884 \times 10^4 \; E^p \; n^{-2} \; \left[h_1^{-2} + 3h_2^{-2} + 5h_3^{-2} + \text{------}(2n-1) \right] h_n^{-2}$$

cm/min,

where:

K = the hydraulic conductivity at temperature 27°C, (cm/min),

h = the pressure potential (mb),

E = the water-filled porosity (cm^3/cm^3),

n = the number of pore classes up to the water content of interest and P is a constant, 2 or 4/3.

The data on the soil moisture contents and soil-water pressure obtained in the field will be used for calculating the hydraulic conductivity of the soil.

Results

Studies to determine the hydraulic conductivity using the model developed by Rose, Stern, and Drummond (19) have not been completed. All of the data has been procured, but the analyses are not complete. Figures 26-32 show the soil-water content versus the soil-water pressure curves obtained.

As indicated from the hydraulic conductivity studies using Darcey's law, the capillary conductivity of the subsoil of the Olton loam is low. It was necessary to grow weeds on the plot to get the soil moisture low enough for the study. Even then the soil-water pressure content changes occur over a very narrow range (Figures 26-31).

Figure 32 shows the soil-water pressure changes that occurred in one plot over a 390 hour period. It can be seen that there was little change in pressure 120 cm and below.

On the other hand, there was little change in soil-water content at 90 and 120 cm (Figure 33). This indicates that at the 90 cm depth major changes in soil tension can occur with little change in water content. At 150 cm however, major changes in content can occur with little change in soil-water pressure (Figures 32 and 33).

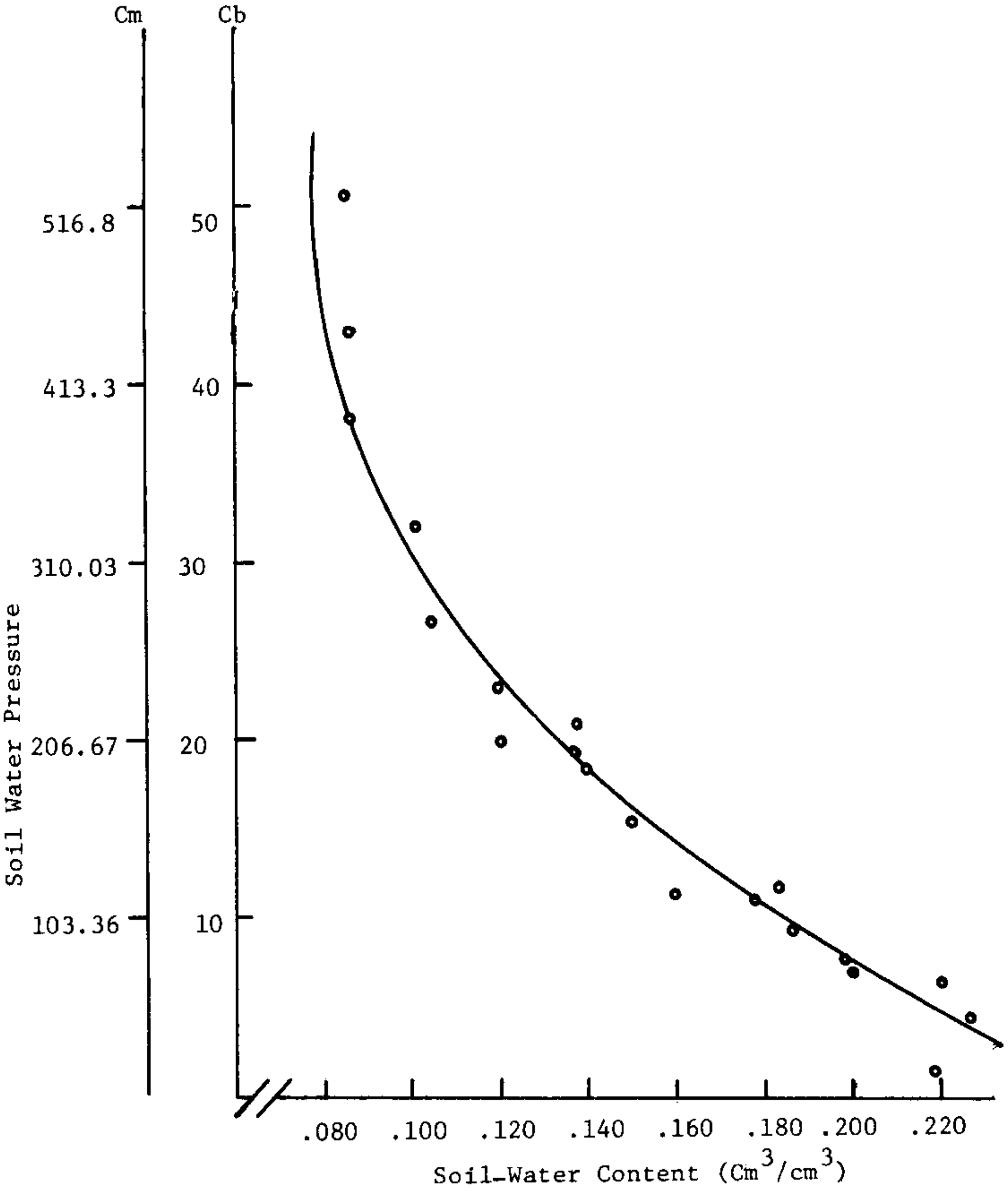

Figure 26. Soil-water content versus soil-water pressure measured at 15 cm depth.

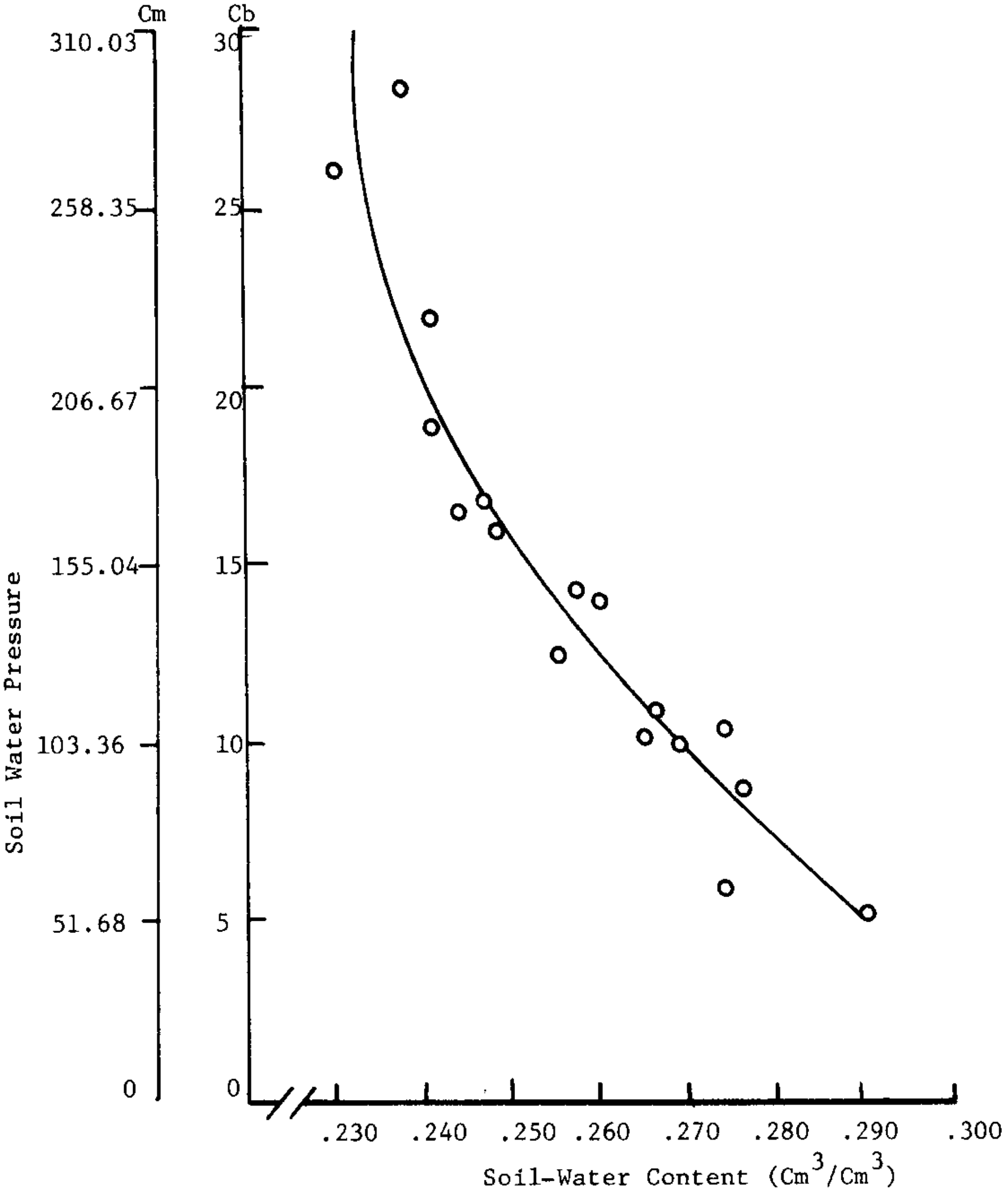

Figure 27. Soil-water content versus soil-water pressure measured at 30 cm depth.

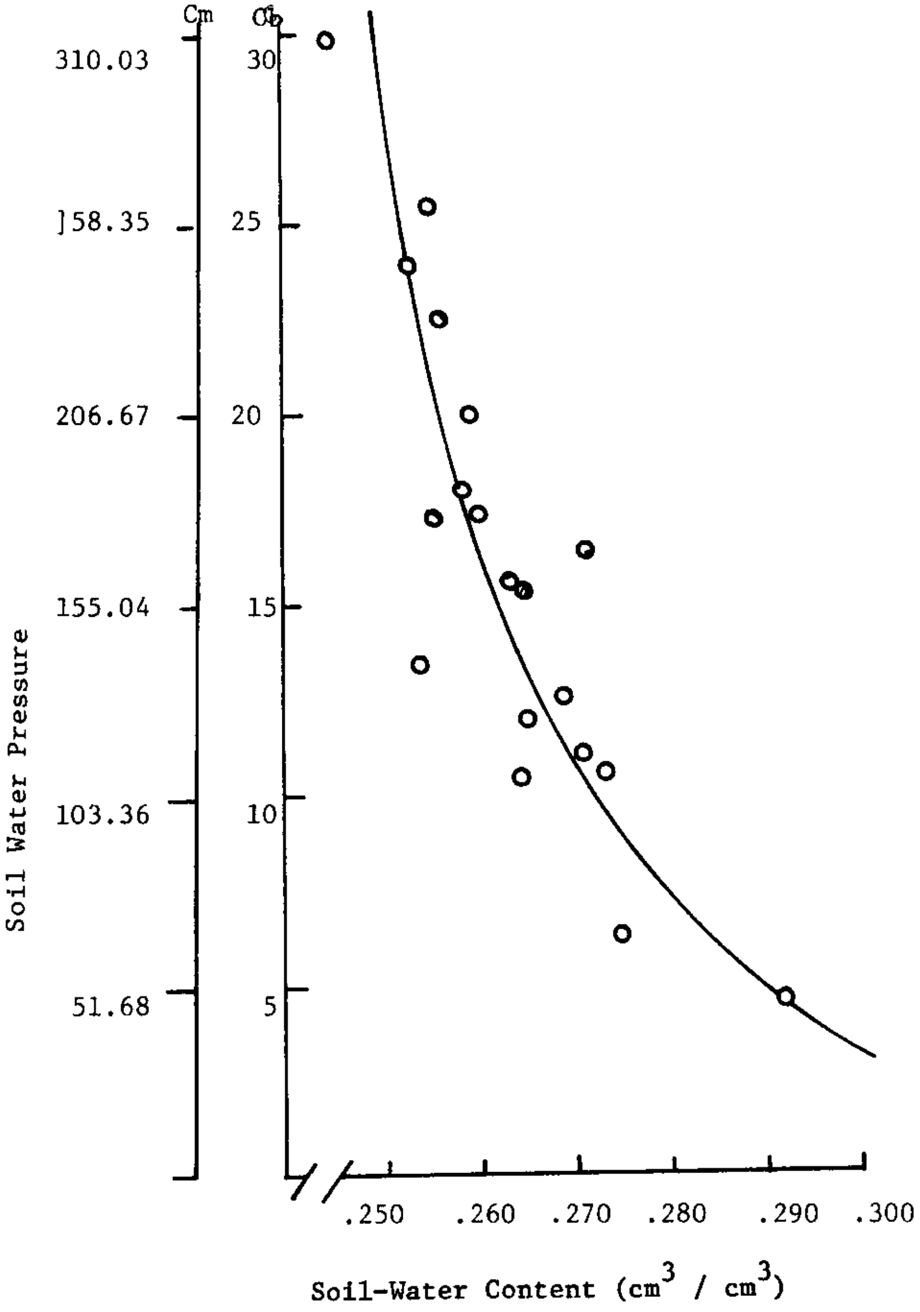

Figure 28. Soil-water content versus soil-water pressure measured at 45 cm depth.

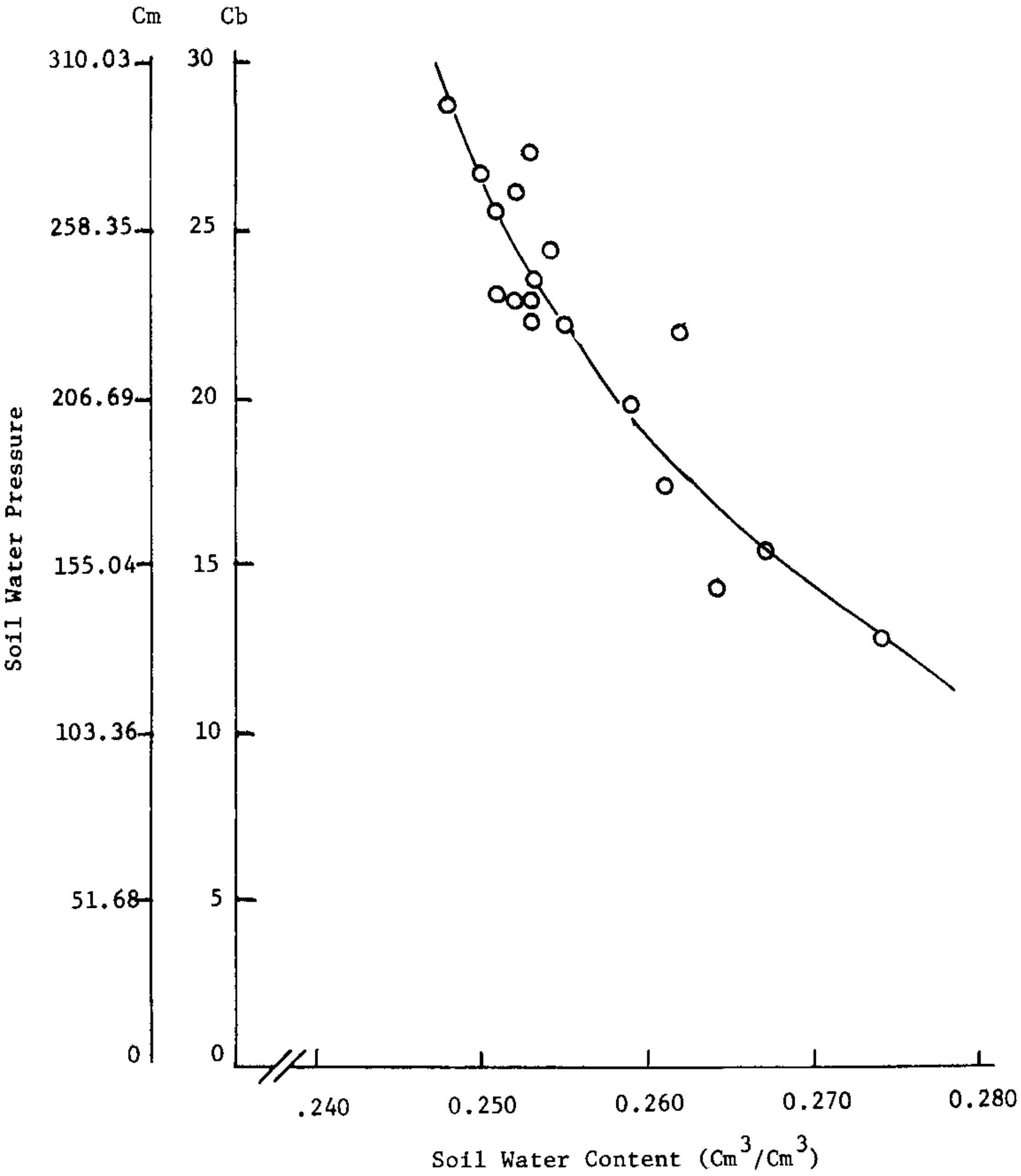

Figure 29. Soil water content versus soil water pressure measured at 60 cm depth.

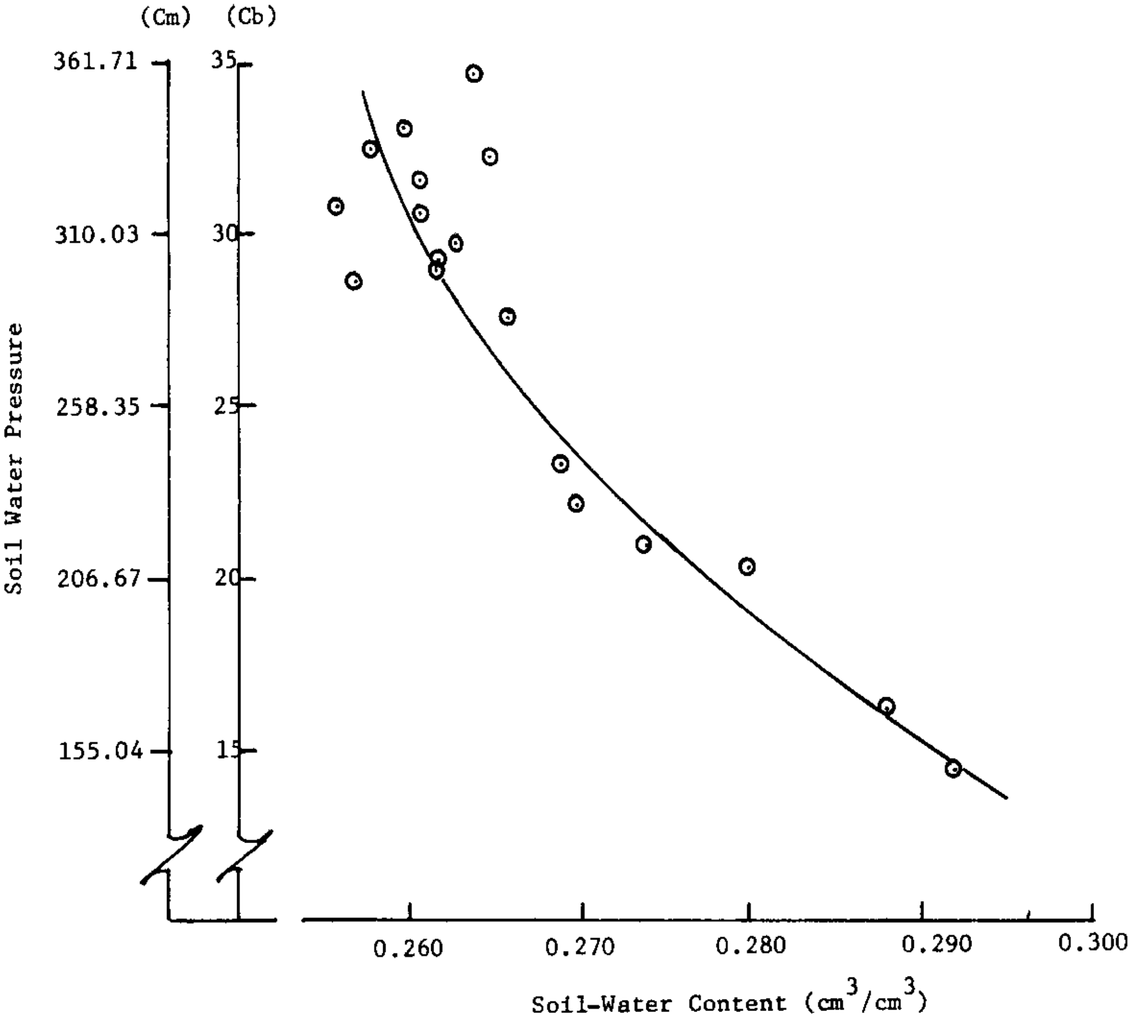

Figure 30. Soil-water content versus soil-water pressure measured at 75 cm depth.

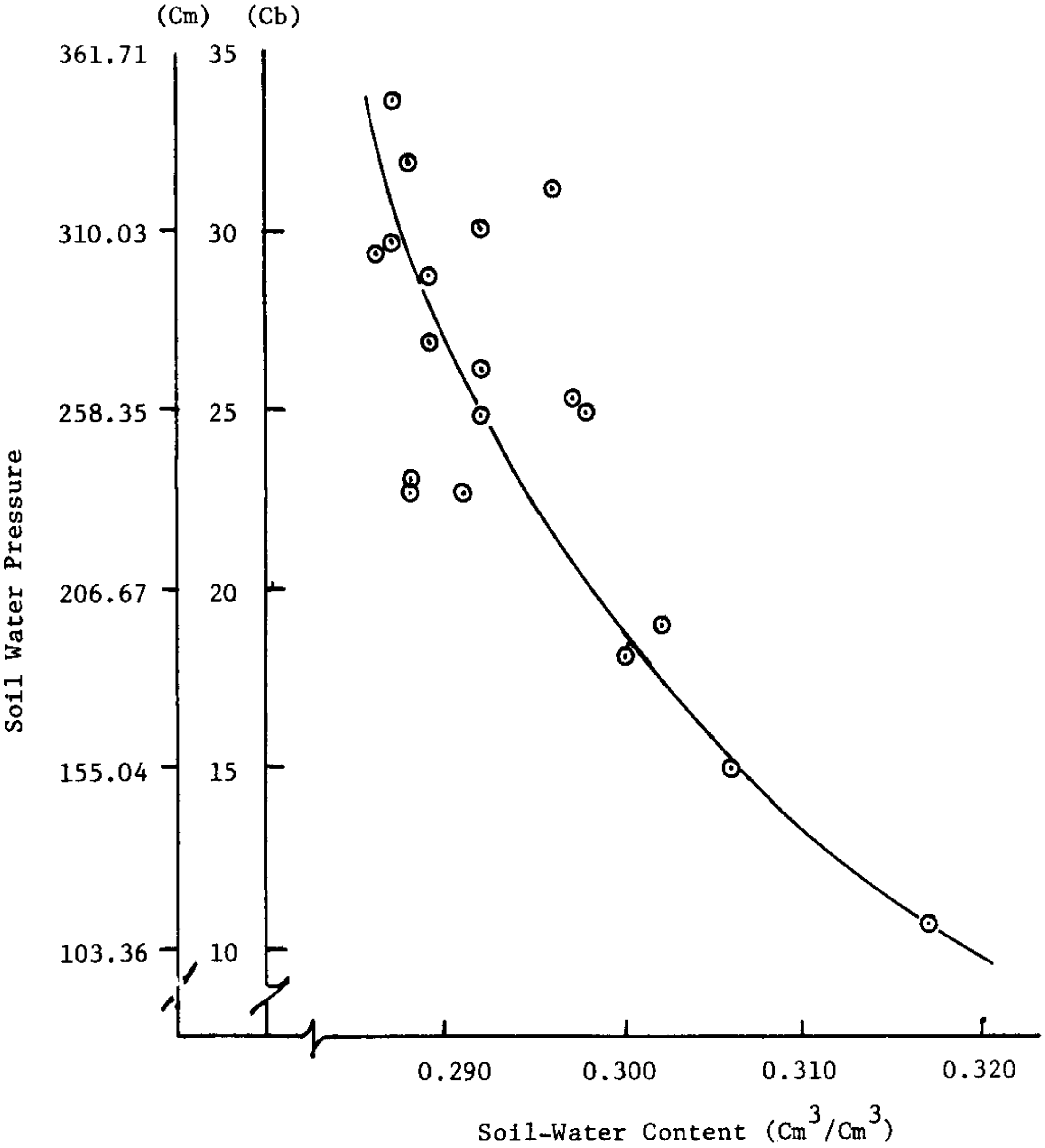

Figure 31. Soil-water content versus soil-water pressure measured at 90 cm depth.

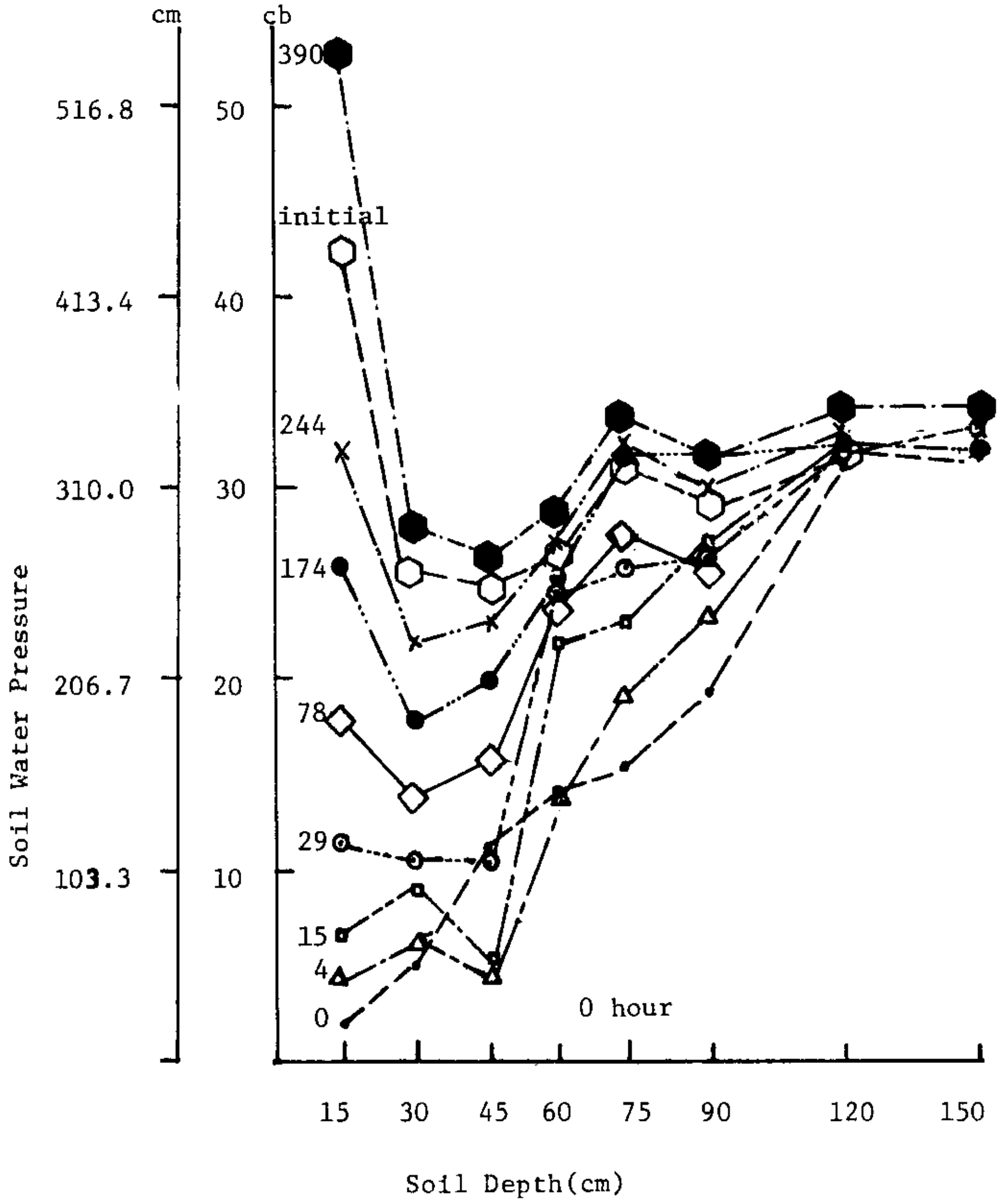

Figure 32. Soil-water tension versus soil depth measured at the commencement of drainage after the first water application. Zero hour designates the pressures measured immediately after the infiltration was over. All times are in hours.

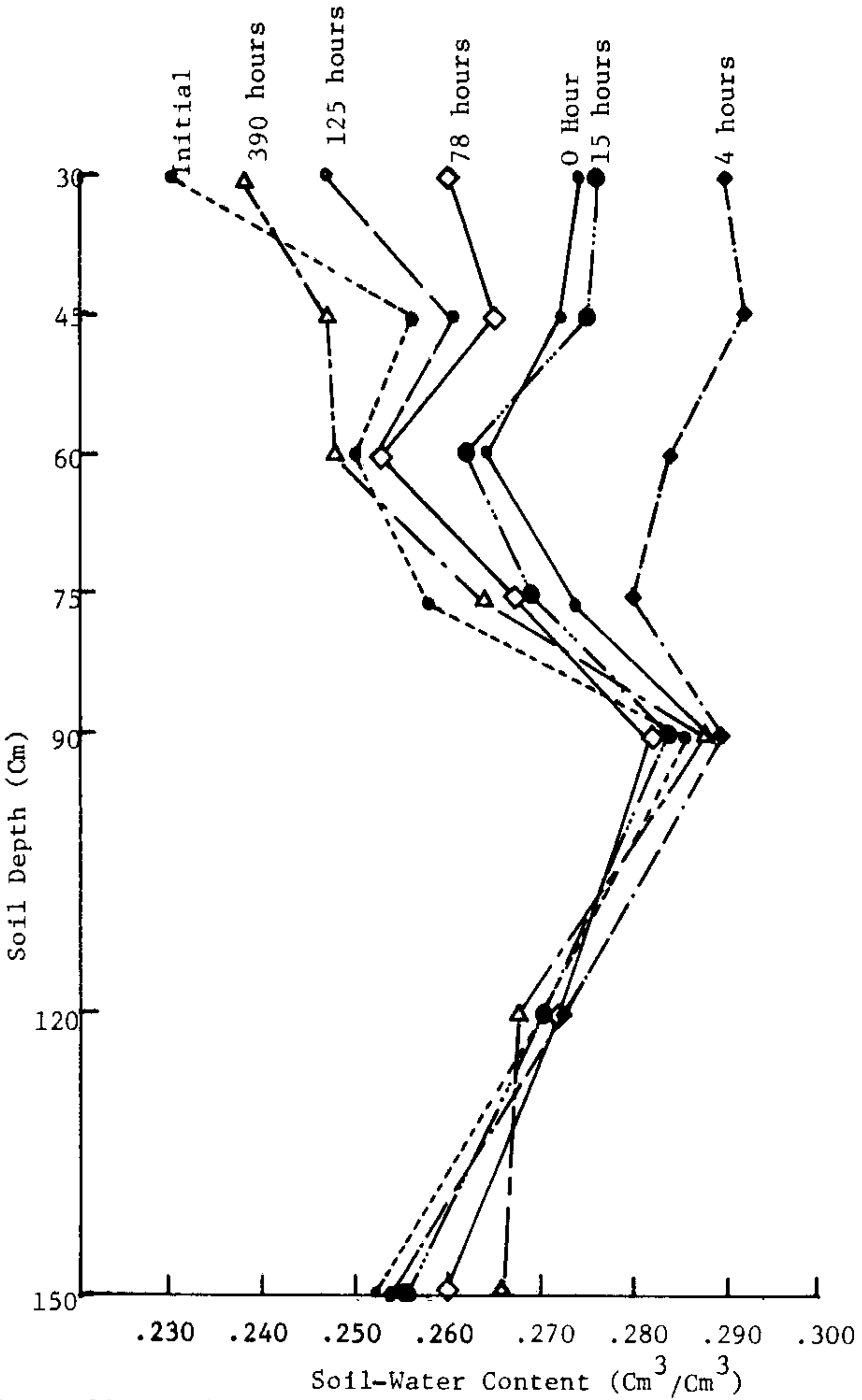

Figure 33. Soil water content versus soil depth at the commencement of drainage after the first water application. Zero hour designates the water content measured immediately after the infiltration was over.

These data represent only one experiment on one plot. There were a total of two experiments each on four different plots. As indicated earlier, these data are yet to be analyzed using the model by Rose, Stern and Drummond (19).

D. Effects of Crude Oil on Evaporation, Soil-Water Pressure, and Soil-Water Content

In greenhouse studies by Wendt and Runkles (32), it was found that crude oil was an effective soil water evaporation suppressant. To determine if the material would have any potential as an evaporation suppressant under field conditions, a study was undertaken using four of the lysimeters previously described in Chapter I. Soil-water tension at 15, 30, 60, and 90 cm was measured daily except on weekends. Although evaporation was measured hourly, only daily evaporation rates are reported. Soil moisture content measurements were made with a neutron probe at the beginning and end of the study. Crude oil was applied to two of the lysimeters at the rate of 300 gallons per acre following an irrigation on the lysimeters and the lysimeter area on May 5-6. Two other lysimeters in the area were untreated. Rainfall on the lysimeters on May 14 terminated the study.

Results

The tension-depth curves obtained during the study are indicated in Figures 34 and 35. The curves in Figure 34 are typical of those found in evaporation from a bare soil. There was some redistribution of the soil water the first four days due to movement within the profile. However, after this period the tension at 60 to 90 cm became relatively stable while the tension at 15 and 30 cm continued to change in response to the evaporative potential. Rainfall of .05 fell on May 13 so there was little change in the tension. However, on May 14 there was a major change in tension prior to the

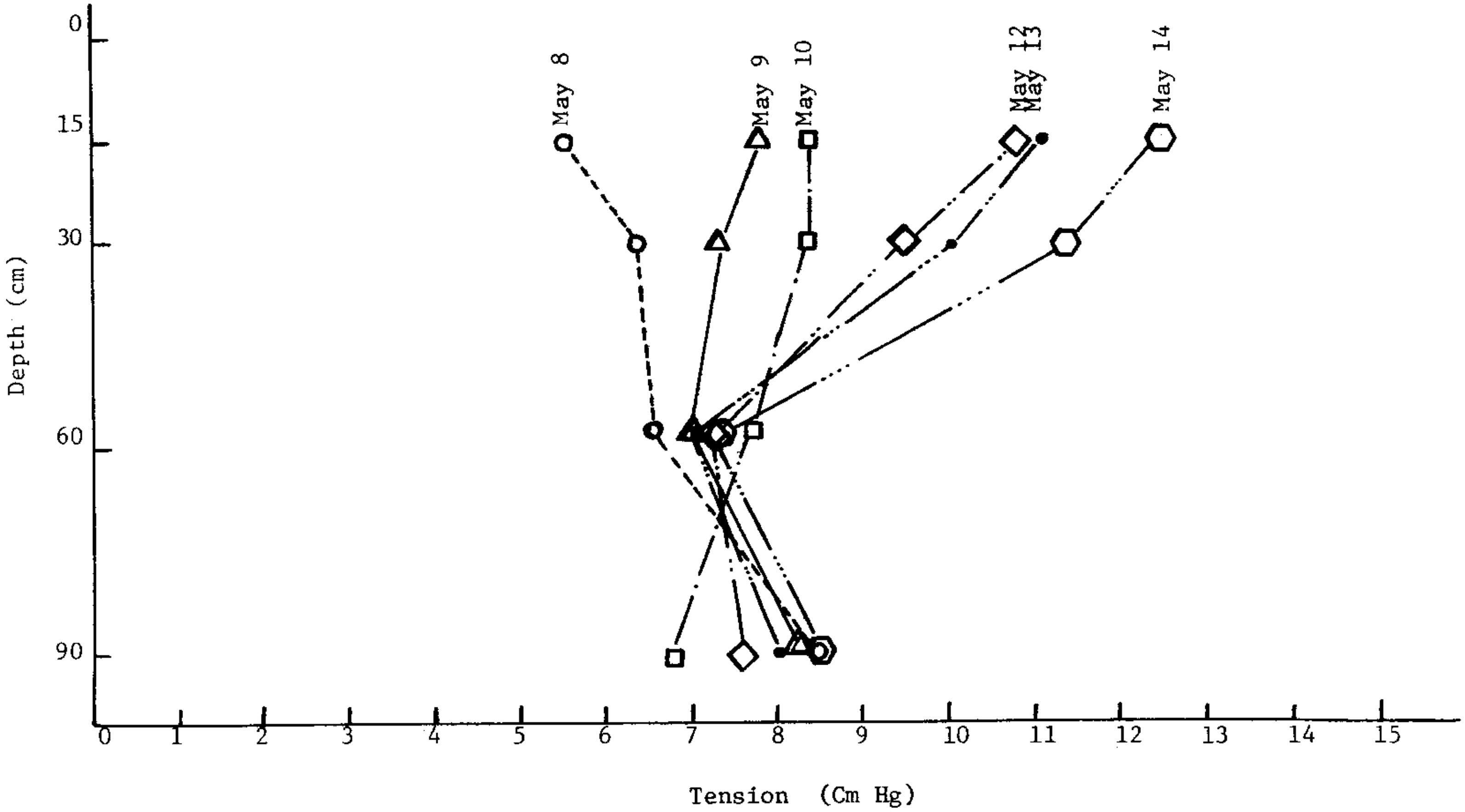

Figure 34. Tension - Depth curves of untreated Olton loam soil in lysimeters.

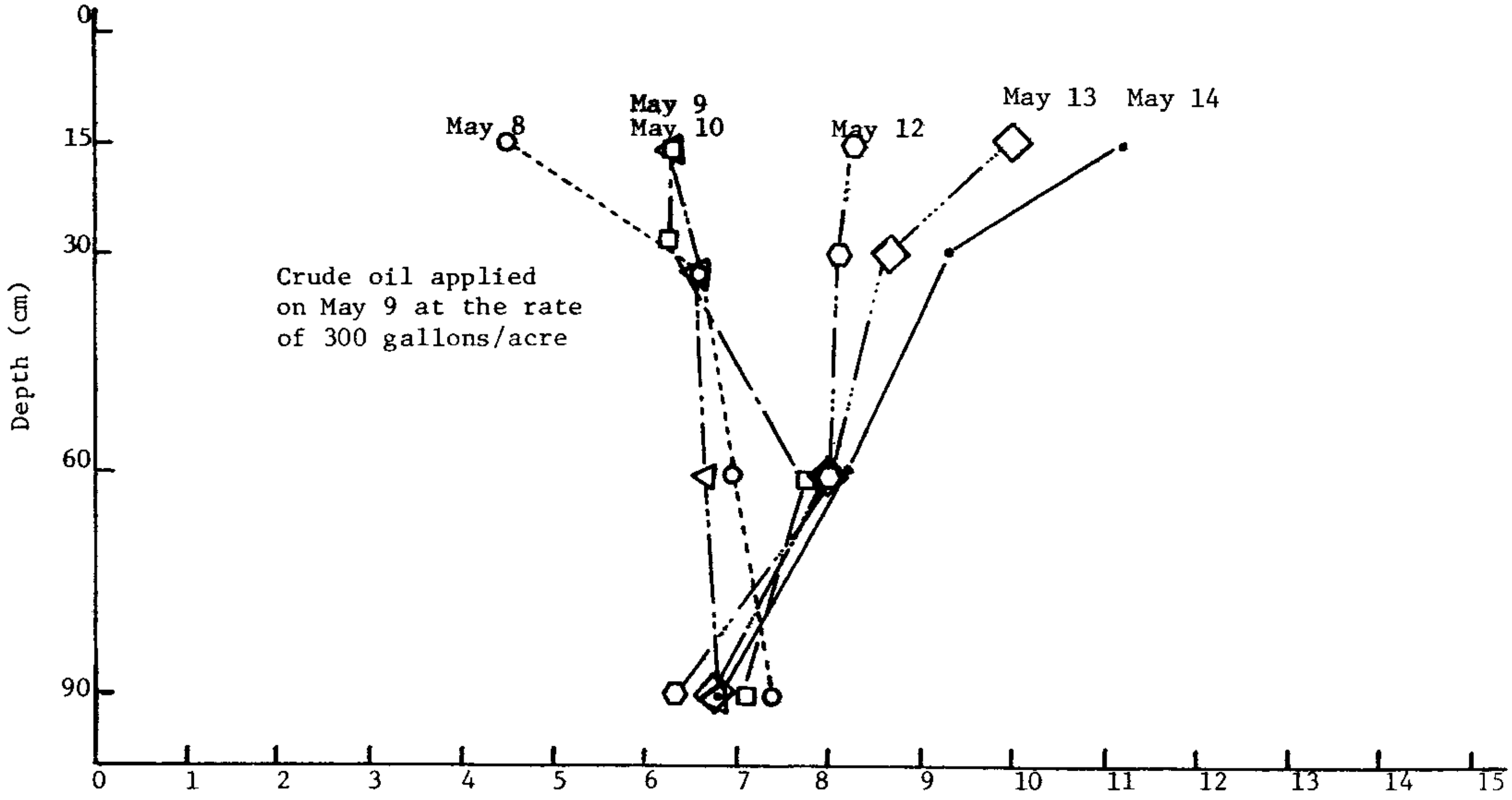

Figure 35. Tension - Depth curves of crude oil treated Olton loam soil in lysimeters.

rains which fell the night of May 14. May 10 was also cloudy and the tension change was not as great as on May 9.

It can be seen that major differences existed between the tension curves of the untreated lysimeters (Figure 34) and the crude oil treated lysimeters (Figure 35). There was some redistribution of the soil moisture following treatment with crude oil on May 9 as indicated by the decrease in soil-water pressure at the 60 cm depth. Little loss due to evaporation occurred until May 10 from the crude oil treated lysimeter (Figure 36). At no depth was the tension greater than 8 cm Hg prior to May 12 in the crude oil treated lysimeters while the untreated lysimeters exceeded 8 cm Hg cm May 10. At the end of the period, the soil-water pressure was less than 7 cm Hg at 90 cm in the crude oil treated lysimeters while it was greater than 7 cm Hg in the untreated lysimeters.

As previously mentioned, there was some variation in the evaporation from the lysimeters (Figure 36). In the untreated lysimeters, the cumulative evaporation followed the usual pattern of being high (May 10-12) then decreasing. Cumulative evaporation from the crude oil treated lysimeters was low the first day (May 10) following treatment then increased. This follows closely the results that have been found in greenhouse experiments. Evaporation rates are low immediately following a crude oil application then increase when the oil film reacts with the soil.

The crude oil treated lysimeters had a higher moisture content

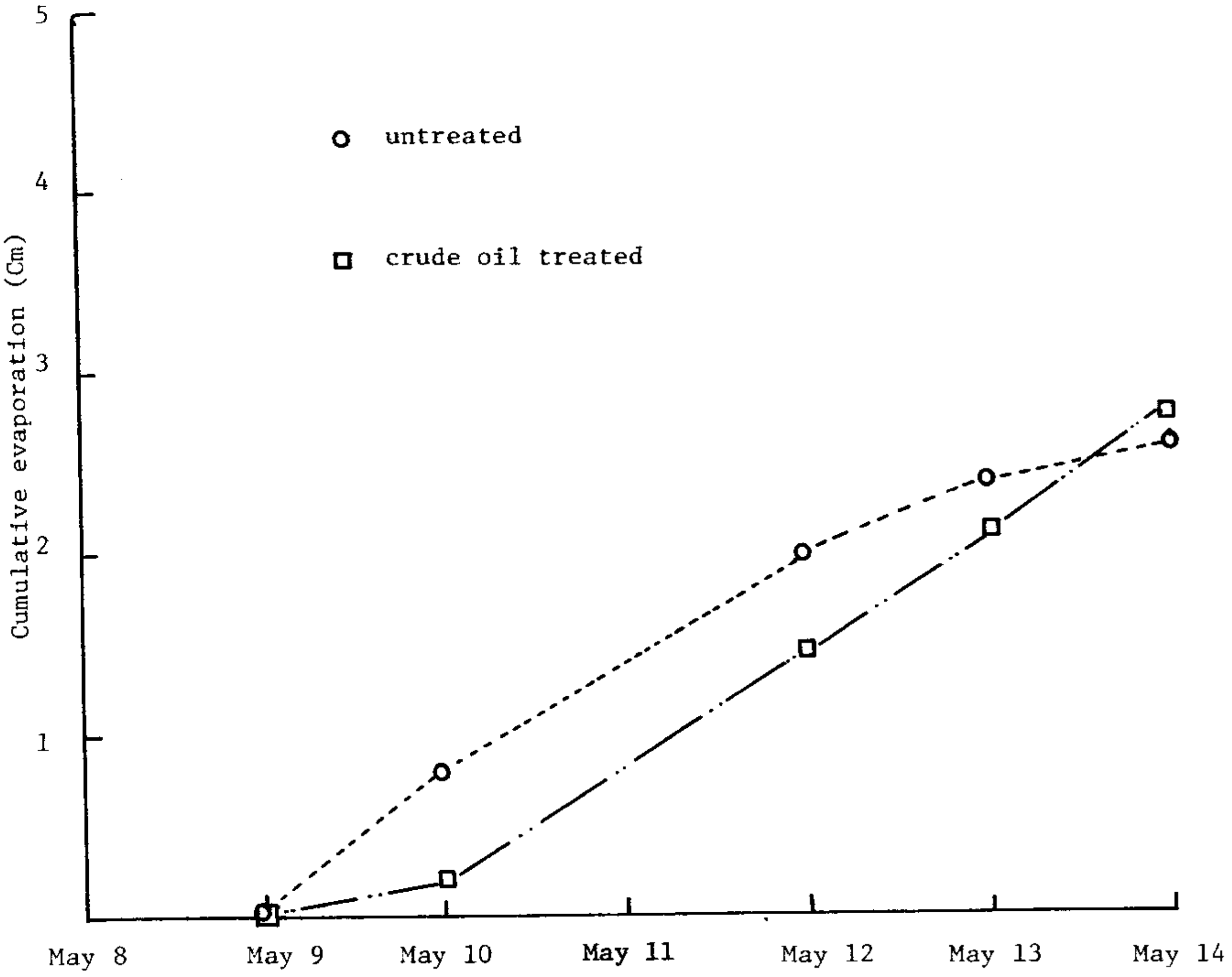

Figure 36. Evaporation from crude oil treated and untreated Olton Loam in lysimeters.

in the 15 and 30 cm depths than the untreated lysimeters in the end of the period of measurement (Figure 37). This was probably due to the initial suppression by the crude oil. However, the untreated lysimeters had a higher moisture content at 60 cm than the treated lysimeters. It may be possible that the initial lower drying rate in the treated lysimeters enabled capillary continuity to be maintained longer and allowed more water to be removed at the 60 cm depth.

It thus appears that crude oil will suppress evaporation under field conditions the first few days after water is applied. Much work is yet to be done on the influence the treatments have on soil water in the profile over long periods of time and techniques of application to determine if the suppressant has any practical value.

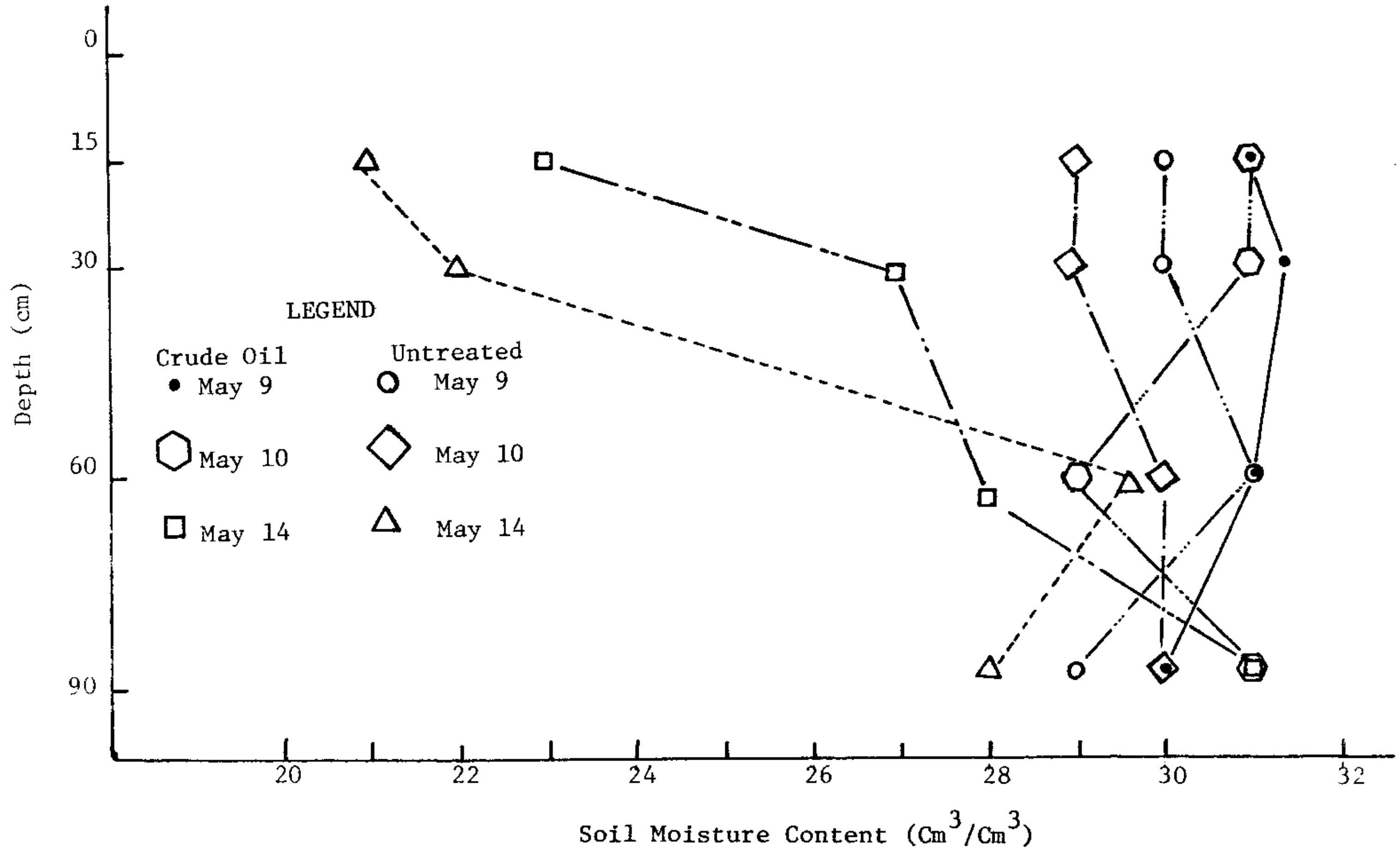

Figure 37. Soil moisture content - Depth curves of crude oil treated and untreated Olton loam soil in lysimeters.

E. Measurement of Diurnal Changes in Soil-Water Content

Diurnal changes in soil water have been observed by many workers. The fact that temperature gradients were known to influence the movement of soil moisture has been known for many years (4). That temperature gradients could cause vapor flux has been observed by numerous workers including Taylor (26) and Cary (5). More recently, Rose (20) (21) has shown that considerable vapor flux occurs diurnally in a field soil when the temperature gradient up to 10°C cm existed in the 0-15 cm soil layer. His work showed significant downward vapor flux during the day resulting in significant decreases in the moisture content in the 0-4 cm layer of soil. Studies to determine if such changes in water content occur at lower depths have not been conducted. Such studies would require a tremendous amount of labor to procure gravimetric soil samples at lower depths. Since the High Plains area is subjected to the conditions described by Rose, it was deemed desirable to investigate the possibility that such changes in content occurred in the area. In order to determine the water content at lower depths without gravimetric sampling, a system to take and record hourly neutron probe readings at 30 cm increments down to 240 cm was designed. The preliminary results obtained from using this system follow.

Methods and Materials

A machine has been constructed by Mr. John Chalupa and Mr. O. H. Newton of the USWB, Department of Commerce, which moves a neutron probe through the soil profile and stops at selected levels. Activation of the scaler is by a timer controlled solenoid which deactivates the system following a complete sequence of recordings. A motor turns a shaft which lowers the neutron probe to the 15 cm depth. The probe remains at this depth five minutes which is considered to be a "warm up" period. After five minutes, the probe is moved down to the 30 cm depth for a counting period of five minutes. Thereafter, the probe is moved down the hole in 30 cm increments for a five minute counting period, until the 240 cm depth is reached. Following the counting period at the 240 cm depth, the probe is returned to the surface.

A solenoid pushes the reset button on the scaler at the end of each five minute counting period to provide a zero reference. The output of the scaler is measured by photo cells placed over the 0 of the 100, 1,000, and 10,000 counting tubes. The output of the photocells is fed into an event recorder. The counts are thus determined by reading the "events" from the recorder from each counting tube. The machine is completely adjustable with respect to counting time interval and depth of measurements.

To obtain preliminary data with the system, it was located in a cleared area in a wheat field near the site of the meteorological instruments of the USWB. Soil temperature was measured with a thermocouple recorder.

Results and Discussion

In the preliminary studies, the machine was set to take neutron probe readings every four hours. Figures 38-39 show the moisture

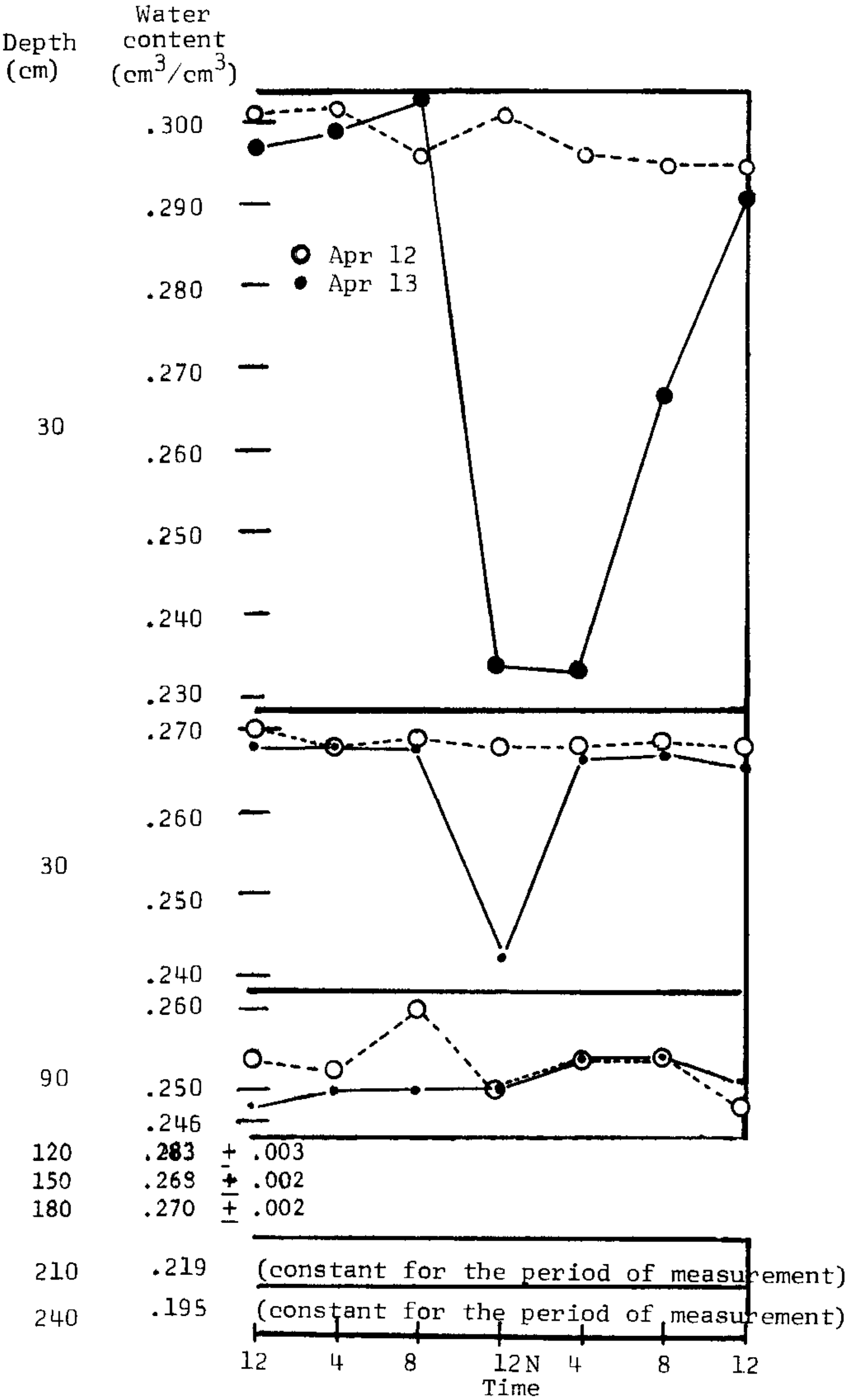

Figure 38. Diurnal changes in soil-moisture content as measured with a neutron probe on April 12-13.

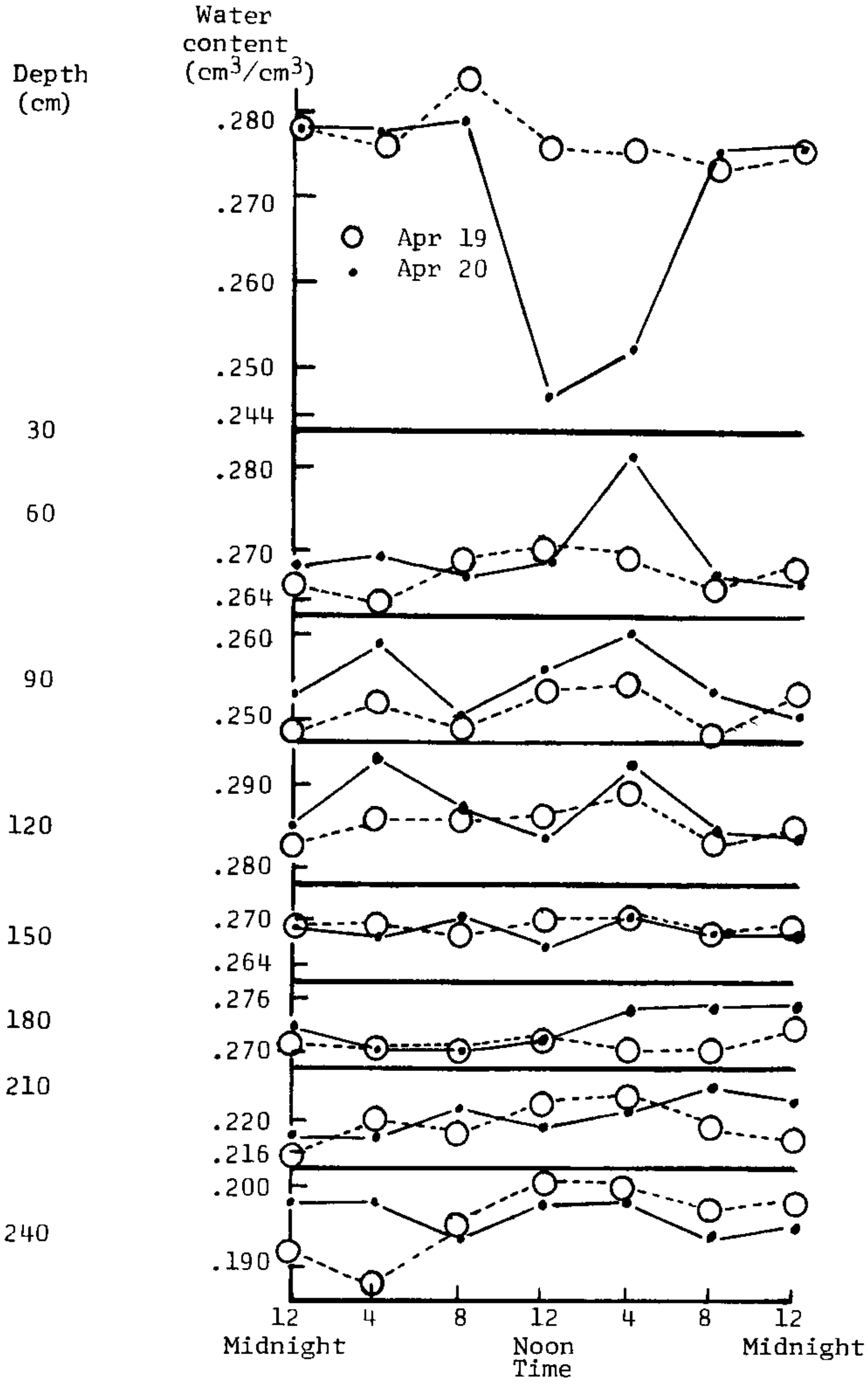

Figure 39. - Diurnal changes in soil moisture content as measured with a neutron probe on April 19-20.

content data and Figure 40 shows temperature profiles obtained on April 12-13 and 19-20. No reliable soil temperature data were obtained from depths less than 10 cm, so only the 10 cm, 30 cm, and air temperatures are plotted.

On April 12 and 19 the soil water contents were relatively constant (Figures 38-39). Both days were cloudy and the temperature fluctuations were not large (Figure 40). The moisture content decreased significantly on April 13 and April 20. The soil temperature fluctuation at the 10 cm depth was greater than 11°C on the two dates which is similar to the temperature fluctuations reported by Rose (20) at 13 cm.

The content fluctuated more on April 13 than on April 20. The moisture content was higher (.020 cm^3/cm^3) on April 13 than on April 19 indicating more water available for vapor transfer on the earlier date.

There might be some question concerning temperature effects on instrumentation since the probe was brought to the top of the hole following the readings. However, the strip charts from the event recorder show that the counting rate of the scaler was constant during the period of measurement at the 30 cm depth where the changes in content occurred. Furthermore, air temperature fluctuations occurred at night and the moisture content remained relatively constant during the night.

Since this was merely a preliminary study to see if the instrument would work, the correlation curve for the neutron probe

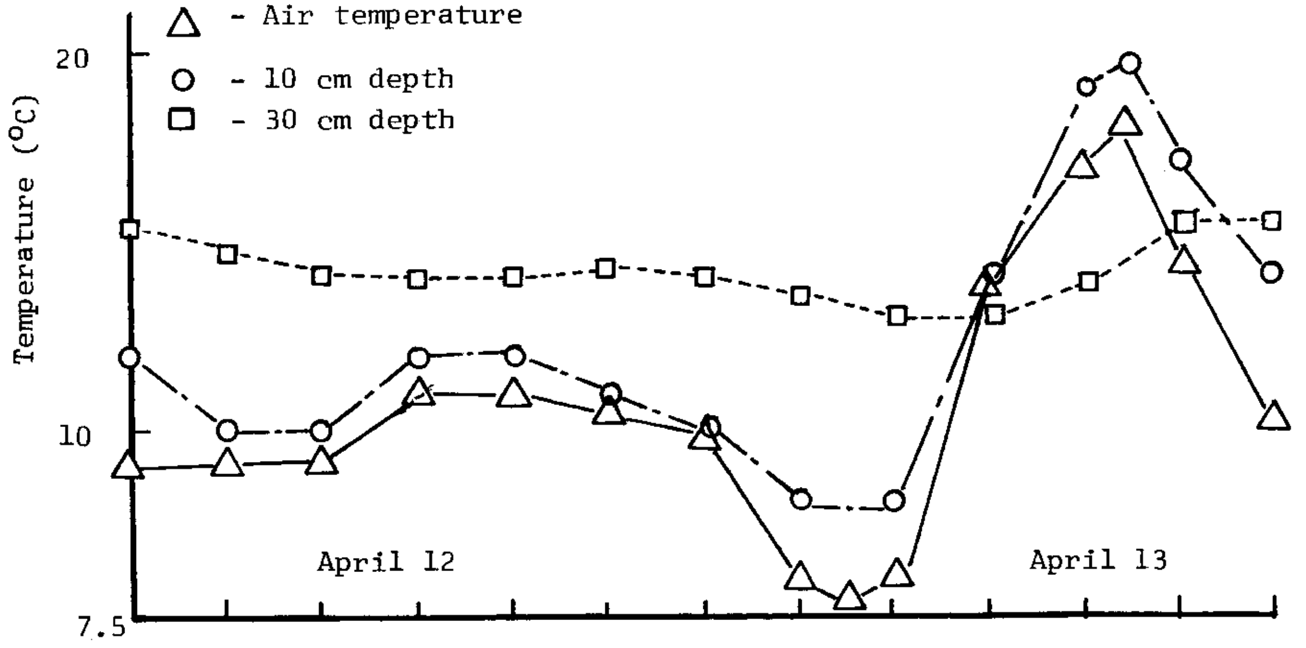

Figure 40. Diurnal time temperature changes on April 12-14 and April 19-20.

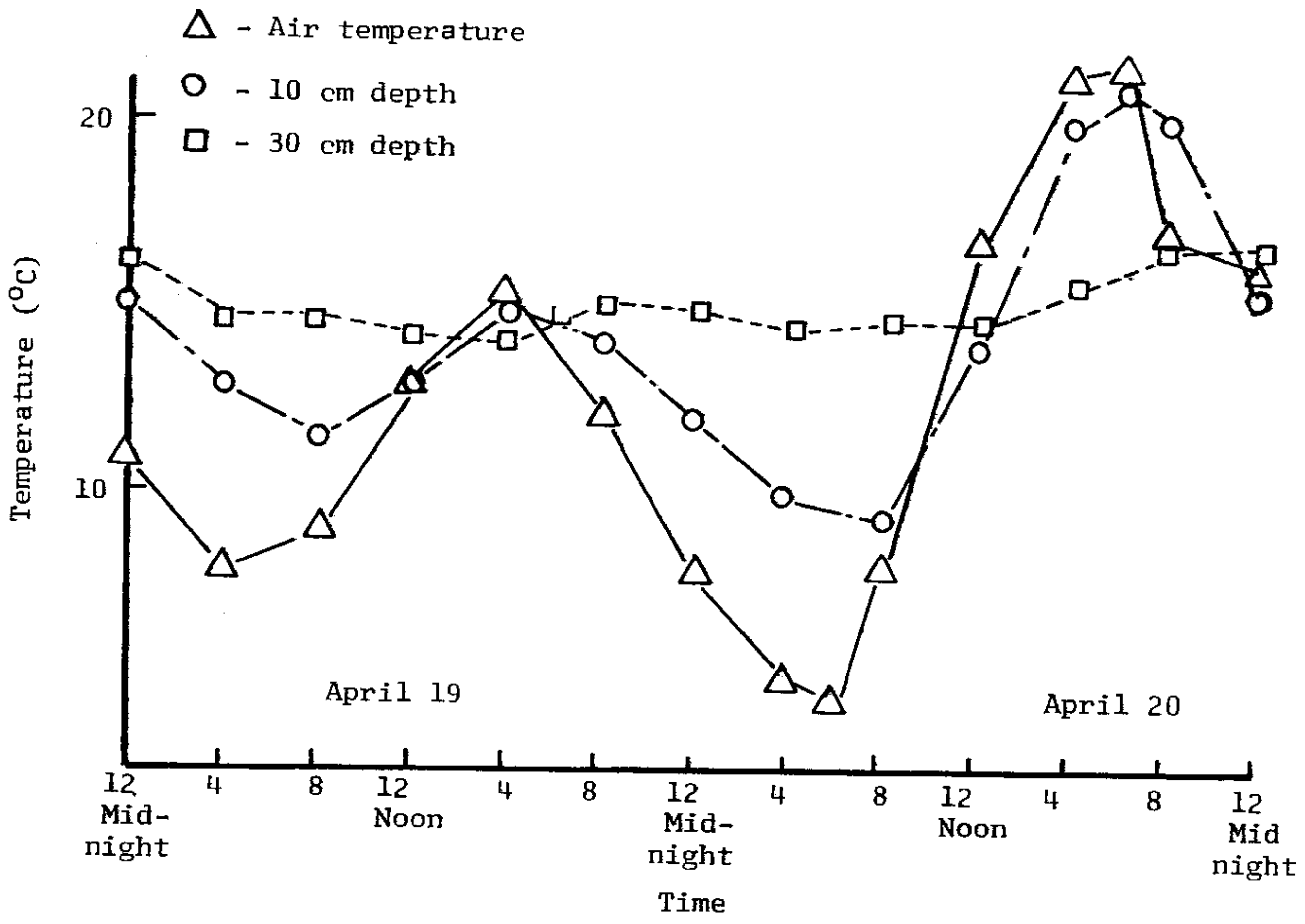

Figure 40 (continued). Diurnal time temperature changes on April 12-13 and April 19-20.

was based on data from another site. Therefore, the curves in Figures 38-39 are qualitative in nature. However, the moisture content data strongly suggest that the diurnal temperature in the High Plains area may cause a major change in the soil moisture content of the upper 30 cm of soil. The water vapor transport to the lower regions of the soil with subsequent decreases in soil moisture content and pressure could be a factor in causing stress in young crop seedlings grown in the area, and could explain some of the increased yield responses obtained when young seedlings are irrigated early even though the lower horizons of the soil profile have a high moisture content.

The data also suggest that the large diurnal temperature fluctuations may be a factor in suppressing soil-water evaporation. Those techniques which would aid in creating wide diurnal temperature differences in soil temperature (such as black soil surfaces) might be an aid in suppressing evaporation.

Although these data are preliminary, it does appear that the versatile apparatus designed by the personnel of the USWB can be used to detect diurnal changes in soil-water content and can be an invaluable aid in obtaining data concerning soil-water movement.

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