THE OKLAHOMA WATER RESOURCES RESEARCH INSTITUTE

Final Technical Completion Report

B-029-OKLA (14-31-0001-4120)

EVAPOTRANSPIRATION REDUCTION BY FIELD GEOMETRY EFFECTS

By
John F. Stone, Professor
Department of Agronomy
Oklahoma State University

With Contributions by
G. N. McCauley
E. W. Chin Choy
H. E. Reeves

Submitted by
Oklahoma Agricultural Experiment Station
F. H. Baker, Director
November, 1976

The work upon which this report is based was supported by funds provided by the United States Department of the Interior, Office of Water Research and Technology, as authorized under the Water Resources Research Act of 1964 and by non-federal funds supplied by the Oklahoma Agricultural Experiment Station

ERRATA

Page, Paragraph, Line	Comment
2,1,third from end.	... signs of generating greater...
7,3,4.	... as long as the conditions do not change. When they do change...
10,last,3.	... conditions where ~~distinct~~ rows are...
18,2,1.	... balance equation is the Bowen ratio...
31,2,4.	... in Table 2.
67,1,fourth line from bottom.	... be tested for uniform.
76,1,9.	... demand. The measured ET ~~for both locations~~ in 1974 will be compared to the demand. The measured ET ~~at Goodwell~~ for 1973...
84,1,last sentence.	... periods. August 22 may bound...
86,1,7.	... from 20 to 30^{o}C. In period 2, the 45 cm treatment had the lowest ET at Goodwell while east-west treatments had the lowest ET at Ft. Cobb...
89,2,4.	... could have been extracted from...
89,3,4.	... two periods 142 cm rows had lower ET. In the other...

Table of Contents

ABSTRACT

Scope and methods of study: The objectives of this study were to identify the factors causing peanuts (Arachis hypogaea, L.) planted in narrow north-south rows to consume less water than other spacings and orientations, and to look for the effect of reduced water consumption with narrow north-south rows of grain sorghum (Sorghum bicolor, Moench). Two row-spacings, 45 and 142 cm, with grain sorghum where studied for the second objective in 1973 and 1974. Water content of the soil profile was determined by the neutron method and the deep drainage component from the profile was monitored with tensiometers. Evaporative losses over periods of a few days in length were then calculated. Meteorological conditions were monitored to correlate with the evaporative water loss during a period. Two row-spacings, 30 and 90 cm, combined with two orientations, north-south and east-west, with peanuts were studied for the principal objective in 1973 and 1974. Evapotranspiration was calculated to verify the previously observed treatment differences. Meteorological conditions were monitored in 1974 to correlate with evaporative water loss. Energy balance measurements were obtained during part of 1974 to characterize solar radiation and treatment differences related to net radiation, advective energy and latent heat of evaporation by the Bowen ratio. Wind profile measurements were obtained during part of 1974 to characterize aerodynamic transport coefficients.

Findings and Conclusions: In two years of study sorghum treatments of 45 cm and peanut treatments of 30 cm of north-south orientation had the lowest evapotranspiration in 5 of 7 periods of measurement. These treatments were always the lowest in evapotranspiration during periods

EVAPOTRANSPIRATION REDUCTION BY FIELD GEOMETRY EFFECTS

GENERAL PREMISE AND PERSONNEL

Previous studies at this station on reduction of nonproductive evapotranspiration gave strong evidence that north-south narrow-spaced rows of peanuts cause lower evapotranspiration (ET) in peanuts than wide rows or of wide or narrow rows running east-west (Stone, 1972). In one of the years of the study the reduction of ET was over 1 inch, an economically significant amount. The study did not identify the factors responsible for the reduction. The study also showed that the narrow rows increase peanut yields by 20 to 100 percent. Thus, it would be feasible to get the practice adopted by farmers. However, further information was needed to explain the water conservation effect so that it might be enhanced and made more certain.

The objectives of the present study were to identify the factors causing the reduced ET effects in peanuts and to look for the effect in grain sorghum, an important crop in the water limited Great Plains area.

The fact that north-south versus east-west oriented rows had different evapotranspiration levels suggested that aerodynamics and/or radiant energy could be involved. Row-spacing and row orientation could effect several components of the radiant energy. The light extinction coefficient could be changed by the row-spacing as it affects the leaf area index. Reflectivity could be greatly affected especially during the period when the soil surface is not completely shaded. Row orientation could greatly affect the extinction coefficient by the different alignments of the stems and leaves. These factors would in turn affect the net radiation. The aerodynamic involvement lesser evapotranspiration (ET) than wide rows or than east-west rows. The cause for this effect was investigated in this study. It was first considered that the effect might be related to wind, since prevailing wind in the growing season in Oklahoma is south. Secondly, the possibility of row direction related to sun angle was considered by including an energy budget study. To cover the possibility that the effect may extend to other crops, the water budget of a sorghum crop was studied also. All work with peanuts was performed at the Irrigation Research Station, Ft. Cobb, Oklahoma. The grain sorghum work was conducted at the Panhandle Research Station, Goodwell, Oklahoma.

The peanut study contained 4 treatments using north-south and east-west rows with spacings of 30 cm and 90 cm. The grain sorghum study had only north-south rows (due to space limitations) with spacings of 45 and 142 cm. The experiments were replicated three times in both the 1973 and 1974 growing season. Both experiments were irrigated. A furrow system was used at Goodwell and a sprinkler system was used at Ft. Cobb. Irrigations were made as deemed necessary at Goodwell. At Ft. Cobb irrigations were made on a 7-day schedule.

In both studies ET was estimated by a water budget method, using the neutron soil moisture probe and tensiometers, for periods of a few days to a week in length. General meteorological conditions were monitored during the study site except at Ft. Cobb in 1973. During two periods at Ft. Cobb in 1974 ET was estimated from the energy budget method using the Bowen ratio. The water-vapor gradient was measured with a sensor containing two lithum chloride cells separated 30 cm vertically. The temperature gradient was measured with a 24-junction copper-constantan thermopile. Both measuring devices were contained in a single self-aspirated system. In the same two periods other variables measured were water budget. In periods of moderate to high demand some of the treatments experienced periods of advective energy and LE depression. During the periods of moderate to high demand the north-south treatments had the lowest ET. The N 30 treatment experienced advective energy input and LE depression more than the other treatments. When the demand was moderate to high, the net radiation (Rn) for the treatments from high to low was N 90, N 30, E 90, and E 30. During periods of low demand only slight or no advected energy input was evident. When the demand was low ET was closely related to Rn. When the demand was low, Rn for the treatments from high to low was E 30, E 90, N 30, and N 90. In periods of low demand the wide treatments had the lowest ET.

In each of the last two periods of 1974, leaf resistance (r_s) measurements were made at Ft. Cobb. Leaf resistance is inversely proportional to ET. The r_s measurements supported the same treatment ET rankings in each period that was indicated by the water budget and energy budget measurements. Thus, the results of the three independent sets of measurements generally support the same treatment ET ranking, though most of the individual measurements did not convey great confidence. However, the general agreement of the independent measurement lends credence to the results.

Two types of ET periods were evident in this study. Natural ET periods determined by the meteorological conditions and defined ET periods determined by the investigator from convenience or experimental design. The treatment ET sequence remained fairly constant as long as the conditions change they do not stablize immediately. Therefore, two natural ET periods are separated by a transition-type natural ET period. Treatment ET differences for a day inside a natural ET period were more significant than a day in a transition-type natural ET period. The natural ET periods may be from one especially during days with low evaporative demand. In days with a high demand the ET is strongly influenced by periods of advective energy input and periods with high leaf transpiration resistance. These seem to be correlated with row-spacing and direction. In days of high evaporative demand the Rn in north-south rows was greater than in east-west. In days of low evaporative demand the east-west row plants had higher Rn. Estimates of aerodynamic roughness appeared higher in north-south rows. However, evidence of days with ET being controlled by turbulent transfer was too infrequent to give credence to this factor.

Since periods of water budget study in the field are between arbitrary irrigation dates, the study results may be confounded with prevailing natural periods of evaporative demand. Such periods may overlap measurement periods causing confused results. The results suggest that if a growing season contains many moderately high evaporative demand days (not extremely high or low) the north-south narrow rows will consume significantly less water than wide rows or than east-west rows. Seasons with a mixture of days with all sorts of demands will give a mixture of results with the integrated seasonal effect showing no differences between treatments. In addition, exploratory measurements on plant physiological responses suggest that the plant itself may exert some effect in regulating ET and that this is perhaps conditioned by the row-spacing and direction in which the plant exists.

Recapitulation

1. Periods of uniform evaporative demand several days in length existed in Oklahoma during the period of this study. Except for a time lag, these demand periods were coincidental at two research stations 200 miles apart.

REVIEW OF LITERATURE

Reports of peanut (*Arachis hypogaea* L.) row-spacing and directional orientation effects on evapotranspiration have not been found in the literature. Water use efficiency and actual water use are factors of great importance in both irrigated and dryland crop production. In a review of crop geometry factors relating to plant growth, Donald (1963) makes no mention of studies which relate plant population, density or row-spacing, or orientation effects on the amount of water used by any crop plants. Linvill and Dale (1975) reported no significant differences in water use relating to plant density of grain sorghum.

Yao and Shaw (1964a) Iowa found that corn in 21-inch row-spacing used less water than either 32 or 42-inch row-spacing. North-south versus east-west row orientations in combination with each of the row-spacings showed no significant difference in the water use of corn. They did indicate the relation of the row orientations to the prevailing wind direction. Such orientation could have an effect on water use. They employed the water budget method using the neutron probe to determine the water use but made no allowance for the deep drainage component of the soil water. The omission of the drainage term can lead to considerable error over the period of a season especially in an irrigated study such as the one conducted by Yao and Shaw (1964a). Downey (1971) reported that there was no significant difference in the water use of corn grown at the three densities of 24, 59 and 79 thousand plants per hectare in Australia. He used the water budget method to estimate the water use. The soil moisture content was monitored by periodic gravimetric sampling. The deep drainage component was estimated by following chloride distribution in the gravimetric cores.

peanuts (which form a low dense ground cover in which rows are distinct at 90 cm width). At any rate, the literature does seem to indicate that for many crops in rows narrow enough to completely shade the ground and thus reduce net radiation, ET can be less than the crop in wide rows. Studies of energy budget are discussed in a subsequent section.

Water effects should not be considered independently from yield effects. The survey of Donald (1963) showed several literature reports of north-south row orientation giving higher yield on several species. Allen (1974) developed a model which predicts that north-south rows should have the greatest light interception (provided rows are distinct).

Aerodynamics

The wind is the vehicle which carries away water vapor from a surface from which water has evaporated. As the wind blows across a rough surface such as a crop, friction causes a decrease in wind speed near the surface. This wind surface interaction results in a turbulent boundary layer dependent on wind speed, distance upwind (fetch), crop height, and surface roughness. The wind profile above a crop follows a linear relation with the natural log of the height of the wind measurement (Rose, 1966; Rosenberg, 1974 and Sellers, 1965). The equation which describes the relation between wind speed and height is:

$$u = \frac{1}{K} \left(\frac{\tau}{\rho}\right)^{\frac{1}{2}} \ln \frac{z}{z_o}$$

where
u = wind speed at height z
K = von Karman constant
τ = shear stress
ρ = air density
z_o = roughness parameter

This equation is valid for short crops (mown lawn grass) but must be modified for taller crops (alfalfa) to:

$$u = \frac{1}{K} \left(\frac{\tau}{\rho}\right)^{\frac{1}{2}} \ln \frac{z-d}{z_o}$$

ice, 0 to 0.1 cm for sand, 0.02 to 0.6 cm for water, 0.1 to 0.6 cm for snow, 0.6 to 4 cm for short grass and 4 to 10 cm for long grass. Tanner and Pelton (1960) reported that evapotranspiration increases as z_o increases, other things being equal. The closeness of the relation between z_o and evapotranspiration led to its presence in several evapotranspiration models (Rosenberg et al., 1968). But a good relation has not been found since most of these models do not give a very good estimate of evapotranspiration (Rosenbery et al., 1968; Suomi and Tanner, 1958; Tanner, 1960; Tanner and Pelton, 1960). The lack of success of these models does not detract from the view that z_o is related to evapotranspiration. King and Lettau as reported by Tanner and Pelton (1960) found that there is a log-log relation between crop height H and z_o. The exact relation, $\log z_o = 0.997 \log H - 0.883$, was the result of a compilation of z_o versus crop height data for several crops. The introduction of this equation did much to promote the theory that z_o is a geometric constant of the crop.

Consideration must also be given to location of the instruments above the crop when conducting an aerodynamic study. The instruments must be located near enough to the surface to be within the internal boundary layer. The boundary layer is the layer of air above the surface that exhibits the turbulent characteristics of the crop area of interest. The boundary layer is considered to extend to the height where the wind speed becomes 90 percent of the prevailing wind speed. The boundary layer is a function of the wind speed, crop height, roughness and fetch (Chang, 1968). Elliott (1958) gave strong evidence for a relation of the form $h = 0.75\ x^{0.8}\ z_o^{0.2}$ (h = height of boundary layer, x = fetch and z_o = roughness length, all in meters). He reports that this equation is valid for values of x as small as 3m. This equation is generally accepted to be valid for smooth surfaces (Chang, 1968; Lemon, 1963; Rosenberg, 1974). Care must also be taken not side of the equation (Ritchie, 1971 and Tanner and Pelton, 1960). This quantity is the least when the amount of radiation reaching the soil surface is the least. The amount of radiation reaching the soil surface decreases as the row-spacing decreases (Aubertin and Peters, 1961; Ritchie, 1971; Tanner et al., 1960 and Yao and Shaw, 1964b). Because it is small and hard to determine, G can be neglected with negligible error. With these omissions the equation is simplified to Rn = H + LE. The left side can be measured but neither term on the right can be measured directly.

The energy balance shows the direct relation between Rn and ET. Ritchie and Burnett (1971) have reported the possibility of reducing the soil evaporation component of ET by decreasing the row-spacing. By determining the net radiation at the soil surface under a crop canopy the amount of energy available for evaporation from the soil can be estimated. Yao and Shaw (1964b) working with corn in Iowa showed that the net radiation six inches above the soil surface decreased as the row-spacing decreased. Also, the net radiation measured above the crop canopy decreased as the row-spacing decreased. They attributed these effects to the difference in albedo between the soil and the crop surfaces. The ratio of the net radiation 6 inches above the soil to that above the crop also gives an indication of the amount of energy available for evaporation from the soil. They showed that this ratio decreased as the row-spacing decreased. By the closer spacing the soil net radiation decreases more rapidly than the net radiation above the crop. Aubertin and Peters (1961) in Illinois reported similar results with corn. They found as the row-spacing decreases the net radiation above the crop canopy decreases and the fraction of the radiation the crop absorbs increases. Tanner et al. (1960) in Wisconsin working with corn reported similar trends of net radiation as plant population increases from closer spacing. But they found no significant difference heat from the up fetch area to the ET of the crop area. These workers report the Bowen-energy balance equation gives very good estimates, within 5 percent, of the ET when figured on hourly averages as compared to estimates from lysimeters. The error of the estimates decreases as the length of the period increases. The estimate from the equation is very close over a period of a few days or more.

Sensible heat can make a sizable contribution to ET under some conditions. There are two general cases: a) heat transferred from the air to the crop and b) heat transferred from the crop to the air. The first case can occur when an irrigated field is located with a fetch of arrid land. The second case can occur when a dry field is located with a fetch of cooler irrigated cropland and sensible heat is transferred from the crop to the air. If neither of these conditions occur net radiation usually will be directly proportional to ET. In summary, reports in the literature generally agree that decreasing the row-spacing decreases the net radiation above the crop canopy. Relationship of row direction to net radiation is not so obvious.

Leaf Resistance

Transpiration is the loss of water from plant surfaces. Ritchie (1971) reports that transpiration accounts for the major portion of water loss for a crop when the soil surface is completely covered. The water vapor concentration inside the stomatal cavity is usually at or near saturation, unless the plant is severely wilted (Rosenberg, 1974). The water vapor inside the stomatal cavity diffuses to the leaf boundary layer through the stomate. The guard cells control the degree to which the stomates open in relation to the plant water status. As the stomates open and close the diffusion of water vapor is regulated. One way of expressing the regulated

PART I

Influence of Row-Spacing and Direction on Water Use and Energy Balance in Peanuts.

G. N. McCauley and J. F. Stone

This was the principal study of the research project. Since the preceding research on the row direction and spacing effects on evapotranspiration (ET) was conducted on peanuts the main thrust of this study was designed to explain the noted effects. Namely, this involved a lesser ET on peanuts grown in narrow, north-south rows compared to ET in wide rows or east-west rows of either direction. A study of aerodynamic parameters accompanied this study and is reported in Part II.

The purpose of this study was to determine the water budget and energy budget in peanuts grown in 4 treatments: 30 cm north-south rows, 90 cm north-south rows, 30 cm east-west rows and 90 cm east-west rows.

Materials and Methods

Field Layout

The study was conducted in 1973 and 1974. Peanuts were studied at the Caddo Peanut Research Station, Ft. Cobb, Oklahoma. The experimental site was situated on Cobb fine sandy loam and Meno fine sandy loam (See Fig. 1). These soils are classified as hapulstalfs. The Cobb fine sandy loam occurred in two phases: 1 to 3 percent slope and 3 to 5 percent slope severely eroded. The replications were oriented such that 2 replications were on Cobb fine sandy loam, and one on the Meno fine sandy loam (Gray and Stahnke, 1967).

In 1973 and 1974 there were 4 treatments with 3 replications per treatment. As indicated the treatments were 30 and 90 cm row-spacing of north-south

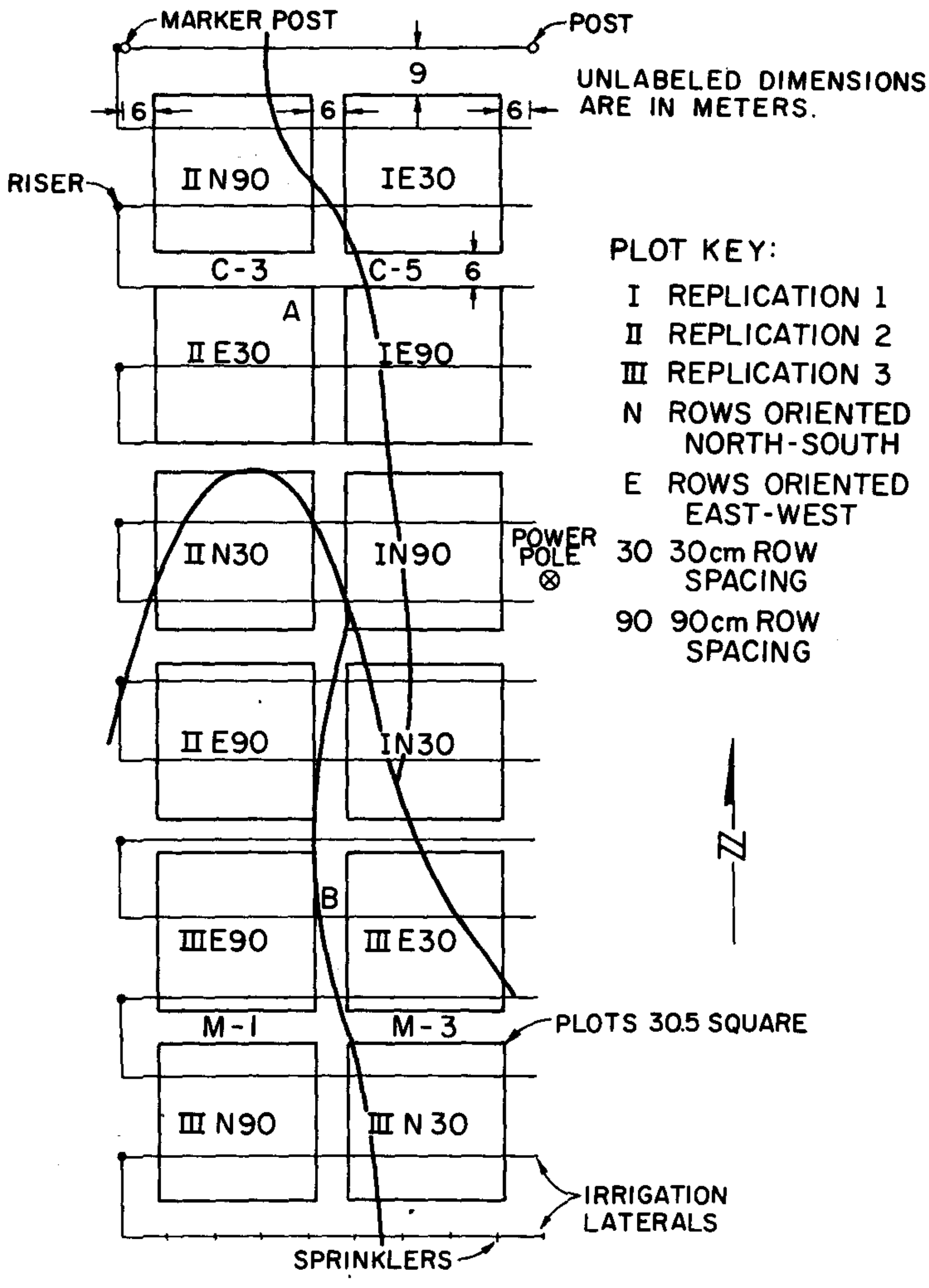

Fig. 1. Field layout of 1973 peanut study. Soil-type boundaries are indicated: C-Cobb, M-Meno. Numerals with soil type are maximum slope in degrees. (See Text).

Both the fungicide and insecticide were applied aerially. The fungicide was applied at approximately 14-day intervals. The insecticide was applied on request after visual inspection. Fertilizer was applied each year: 112 kg/ha of 10-30-10 in 1973 and 168 kg/ha of 8-32-16 in 1974. The fertilizer was broadcast applied and then incorporated into the soil by discing.

On October 9, 1973 and October 24, 1974 an area 4.9 m by 1.8 m in a representive area of each plot was hand harvested and the population was determined by counting the tap roots. The harvested peanuts were cleaned, dried and threshed for yield determination.

Water Budget

The water budget was designed to account for all the water leaving the soil profile whether it be through evapotranspiration or deep flux, either upward or downward. The difference in water content in the 120 cm soil profile between the beginning and end of a period was the primary component of ET.

Table 1. Irrigation schedule for peanuts at Ft. Cobb in 1973 and 1974

1973	1974
July 20	June 25
Aug. 1	July 8
Aug. 10	July 12
Aug. 17	July 19
Aug. 24	July 26
Aug. 31	Aug. 9
Sept. 7	Aug. 16
	Aug. 23

In order to correct this value for water flux at the 120 cm depth, the water flux across and accumulation in the 120 and 150 cm layer were used to estimate downward loss. Near the end of the season it was common to gain water from below the 120 cm depth. The described technique will account for gain as well as loss. The water content of the 120 cm profile was determined by the

In both years the tensiometers were reprimed whenever an air bubble appeared at the top of the tensiometer and always before each irrigation. An extra tensiometer was placed at 90 cm for use in case either the 120 or 150 cm tensiometers became inoperative. If a tensiometer became inoperative, the accumulation in and flux across the 120 to 150 cm layer values were estimated from the data before and after the period. This could be done with small error since tensiometers were rarely inoperative more than one day. Tensiometers were installed at these three depths in each plot because of a severe problem with rodents in previous studies at that location.

The evapotranspiration from each plot was estimated by the following equation:

$$ET = W - q - C + R$$

where

ET = evapotranspiration (loss positive)
W = water loss by neutron determination (loss positive)
q = flux across the 120 to 150 cm layer (downward positive)
C = change in water content of the 120 to 150 cm layer (sign same as q)
R = rainfall (positive)

The water loss w was determined from the difference in the soil water content as determined with the neutron probe after one irrigation and before the next irrigation or at selected times in between if deemed desirable. The access tubes were read at depths of 15, 30, 45, 60, 75, 90, 105, and 120 cm. The total soil water in the profile was calculated. By using the difference between the two probe readings the exact amount of irrigation water applied and that lost by evaporation or runoff need not be taken into account. Thus, use of the probe readings relates only to the moisture that was lost either by evapotranspiration or deep percolation from the 120 cm profile.

In 1973 all plots were instrumented on July 18 with a neutron access tube and three mercury manometer tensiometers at depths of 90, 120 and 150 cm. The access tubes were located approximately 4.5 m from the north end of the plots in the midway between rows near the east-west center of the plots in an area of ideal plant population. The tensiometers were located in approximately 40 cm intervals down the row to the south or west, depending on the row orientation, of the access tube also in the middle of the row. The 90 cm tensiometer was placed nearest the access tube. The manometers were located on the north edge of the plots.

In 1974 two neutron access tubes were installed in each plot to improve estimation of the soil moisture. The access tubes and tensiometers were installed on July 12 in much the same manner as in 1973. The added access tube was located 40 cm from the 150 cm tensiometer. Thus the two access tubes were about 1.5 m apart.

During both seasons the tensiometers were read daily between 8 and 9 a.m. except on weekends. The neutron tubes were read just before and after each irrigation.

Energy Budget

The energy budget study was conducted in 1974 during the days of August 21 and 22 and September 4, 5, 6, 11 and 12. The energy budget consisted of accounting for all the energy exchange over the crop canopy by the familiar equation:

$$Rn = H + LE$$

where

Rn = net radiation
H = sensible heat flux
L = latent heat of vaporization of water
E = evaporation flux density

As indicated earlier an assumption is generally made that the soil heat flux component usually accounts for less than three percent of the net radiation.

Thus the soil heat flux term can generally be neglected especially after the crop canopy shades the ground. Spanish peanuts have a high leaf area index (visually estimated at greater than 3.5). The ground became completely shaded early in August. Hence, the soil heat flux was not measured.

The net radiation was measured at a height 1.5 m above the soil surface. This height was at least 1 m above the crop surface in most plots. The average canopy height for each plot and the height of the net radiometer above the crop is shown in Table II.

The net radiometers used in the study were constructed in the laboratory and were similar to the minature net radiometer as described by Fritschen (1960, 1963, 1965) with the modification described by Idso (1970, 1971). Fritschen stated that the net radiometers described in his work should have a white ring on the surface. This design was to balance the response to long and short wave radiation. Idso pointed out an error in Fritschen's calculation which had lead to the decision of placing the white ring on the surfaces. Idso showed the response was balanced with completely black surfaces.

The net radiometers had 24 junction thermopiles, which lead to higher sensitivity than the Fritschen units. The net radiometers were calibrated in a box similar to that described by Fritschen (1960, 1963). Four Thornthwaite net radiometers (model MNR-601) were used to measure radiant flux inside the box. The Thornthwaite net radiometers had been individually factory-calibrated and were used as standards. This bypassed the need to compute the flux from temperature and emmisivity data. The net radiometers were evaluated for their response to both long and short wave radiation and were found to have less than 3% variation from the Thornthwaite net radiometers. A test for linear response was conducted by

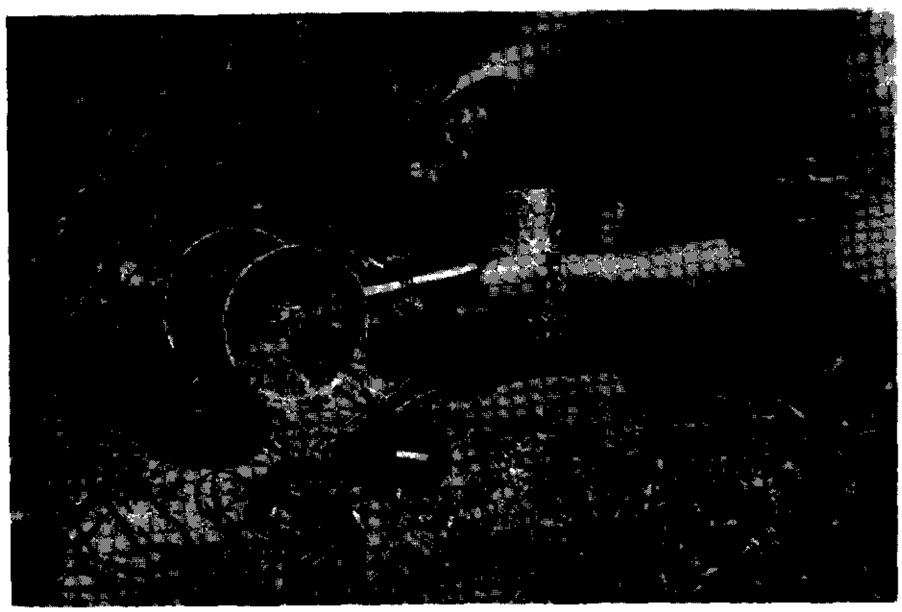

Fig. 3. Bowen ratio mast. Assembly in right hand is the lithium chloride vapor pressure sensor. Temperature differential sensor is in the large housing in the left hand where tube joins the cylinder (behind wrist watch). Wind aspirator is on the left. Read-out device is on the ground.

highest elevation outside the plot area within a reasonable distance. The wind direction was monitored. The plots were laid out and instrumented with the knowledge that the prevailing wind would be primarily southerly.

Leaf Resistance

Individual leaf diffusion resistance measurements were made in replication 2 of the experiment. The measurements were made at varied intervals through the day during the same periods that the energy budget study was conducted in 1974. The measurements were made in random order. The leaf resistance readings were made using a diffusive resistance meter with a tubular sensor as described by van Bavel et al. (1965), (Lambda Instrument Co. Model LI-60). The resistance meter was calibrated in the laboratory as described by Kanemasu et al. (1969).

Data Acquisition System

The aerodynamic characteristics and the energy balance are necessary components to gain insight into an evapotranspiration study. For either parameter to have any meaning the measurements must be measured effectively instantaneously over the entire study. This is to say that each of the components: net radiation, temperature, humidity at two heights, temperature gradient, solar radiation, 48 anemometers, temperature profile, and wind direction should be measured at the same time in all of the plots. This is a task that can only be approached and never completely achieved. The measurements during both the aerodynamic study and energy balance study were made with a 96 channel data acquisition system controlled by a minicomputer (Computer Automation, Incorporated, model Alpha 16). The acquired data were then recorded both on a cassette system (CAI) and printed out on a teleprinter (Teletype model ASR 33). This system was programmed to scan the instruments every ten minutes over the period of

The sequence of rank of the ET of the treatments was not as consistent over the 1974 season as in 1973. The N 30 treatment had the lowest ET only in period 3. This period had the highest overall ET rate of the four periods. In period 2 most of the treatments had their second highest rates of the season, although in period 2 the E 90 treatment had its lowest ET rate of the season. In period 1 the N 30 and E 30 treatments had their lowest ET rates of the season. In 1973 and 1974, except for period 3, E 30 had the highest ET rate of all the treatments. There was practically no difference between the narrow and wide spacing of east-west orientation in period 3. The ET rates were higher through most of the 1974 season than in 1973. This may have been because of the higher average soil water content over the 1974 season. With the higher average soil water content the plants were not under low soil water availability where the stomates would be expected to close. In 1974 the treatment ET differences for period 2 were significant at the 10% level. The treatment ET differences for the other three periods could be considered significant only at the 50% level.

The meteorological conditions during the periods in 1974 are listed in Table 4. The wind was southerly throughout the periods of ET calculations. Meteorological conditions suggest that period 1 had a fairly low evaporative demand. This is seen to be the period of lowest ET rate (Table 3). During this period the E 90 and N 30 treatments had the lowest ET. Period 4 also had a low demand. This period had the second lowest ET rate. But during this period the N 90 and E 90 treatments had the lowest ET. Period 2 had the second highest demand and ET rate of the season. In this period the E 90 and N 90 treatments had the lowest ET rate. Period 3 had the highest demand and ET rate of any of the periods. During this period the north-south oriented treatments of both row-spacing had the lowest ET.

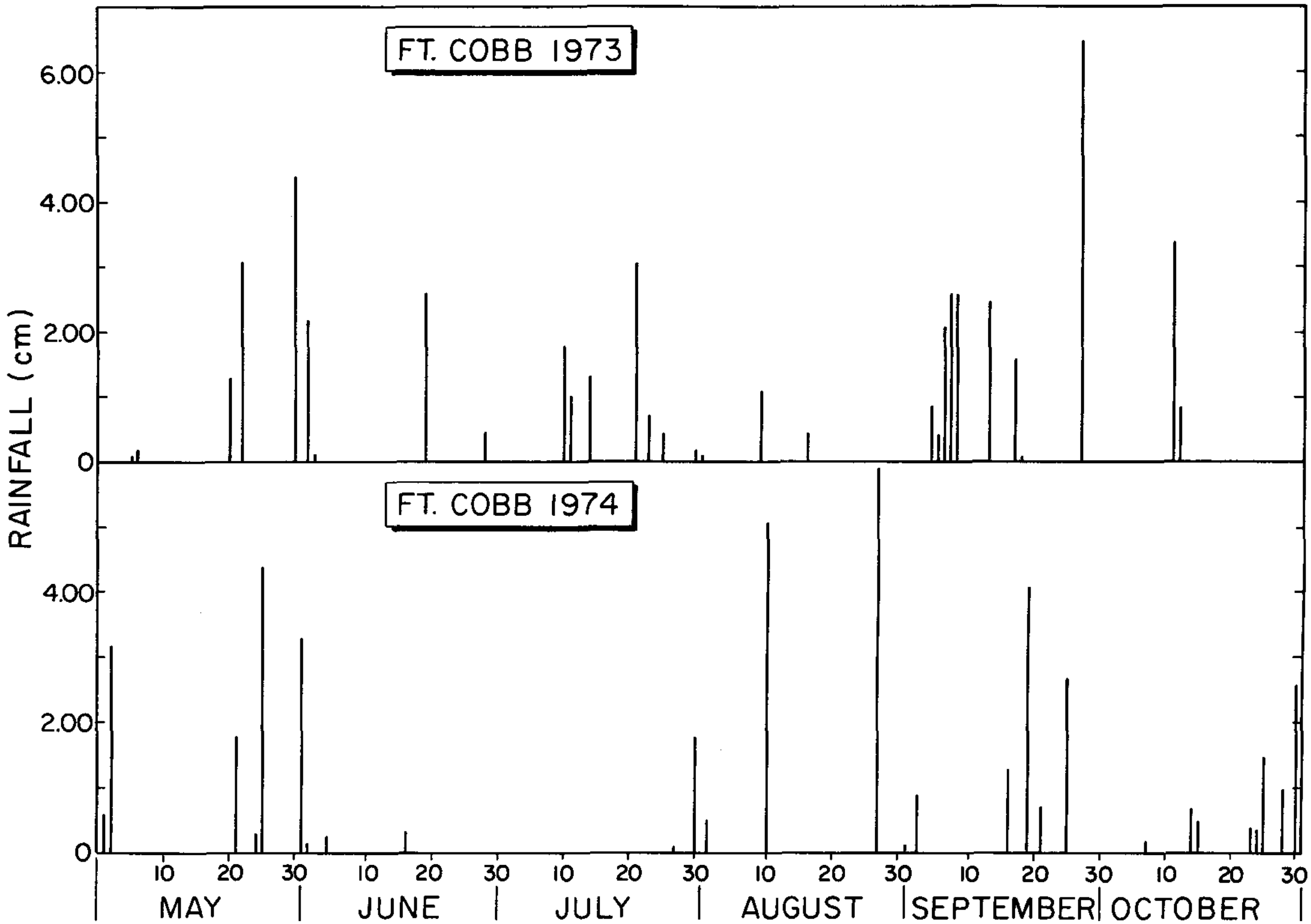

Fig. 5. Precipitation pattern, Ft. Cobb, Oklahoma, 1973 and 1974.

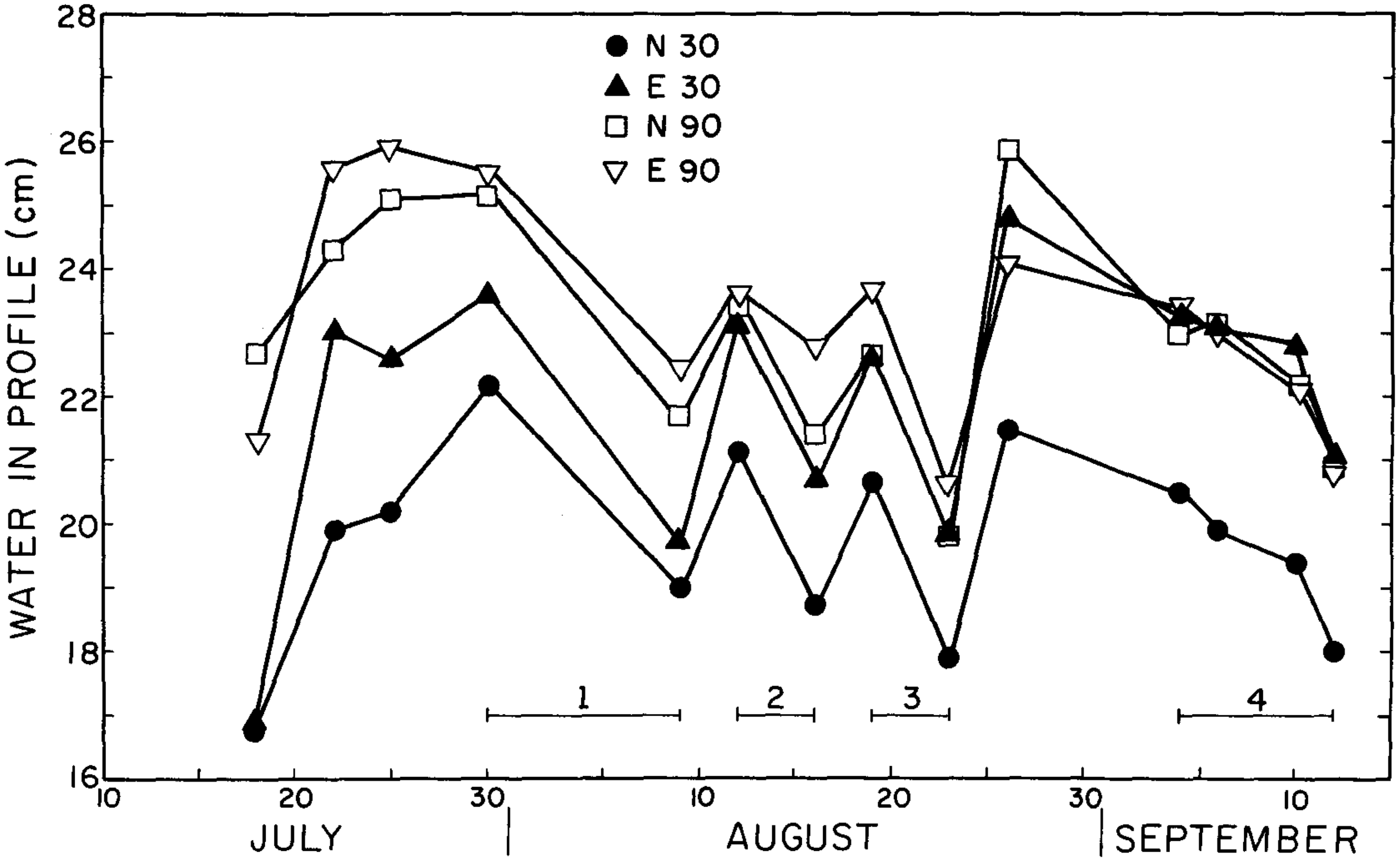

Fig. 6. Neutron determined soil water content in the 1974 growing season.

Table 4. Daily Meteorological, 1974, Caddo Peanut Research Station, Ft. Cobb, Oklahoma.

Date	Wind Direction	Wind Speed (km/hr)	Relative Humidity (%)	Maximum Temperature °C
July 30	S	13.2	57	29.4
31	S	11.4	60	31.1
Aug. 1	SE	11.8	72	30.0
2	SW	12.4	60	28.9
3	SW	10.5	59	25.0
4	SW	8.2	60	31.1
5	S	15.6	72	25.6
6	SW	10.9	81	22.2
7	S	9.5	67	28.9
8	S	15.2	69	31.1
9	S	23.3	69	32.8
12	S	12.6	65	31.1
13	SE	12.1	66	32.2
14	SE	18.5	67	31.1
15	S	19.1	61	32.8
16	S	16.2	57	33.9
19	S	13.6	48	33.3
20	S	19.1	51	33.9
21	S	16.6	55	33.3
22	SE	11.5	62	33.3
23	E	13.8	73	26.7
Sept. 4	SE	7.8	64	21.1
5	SE	10.0	65	23.9
6	SE	12.1	65	24.4
7	S	6.4	60	27.2
8	E	9.8	65	27.8
9	SE	12.9	71	27.8
10	SE	7.5	79	26.7
11	S	20.4	71	31.1
12	NE	23.8	77	22.8

Table 5. Evapotranspiration from the energy budget study and water budget study, 1974, Ft. Cobb, Oklahoma. Values are average ET for the time period indicated.

	ET, cm/da			
	N 30	E 30	N 90	E 90
Aug. 21	.66	.57	.62	.60
22	.51	.71	.59	.75
Average Rate	.59	.64	.61	.68
Water Budget (Aug. 12-23)	.60	.71	.59	.72
Sept. 4 (0.7 day)	.30	.33	.30	.32
5	.51	.62	.49	.45
6	.49	.51	.48	.49
11	.46	.47	.47	.44
12 (0.9 day)	.16	.17	.14	.16
Average Rate	.42	.46	.41	.40
Water Budget (Sept. 4-12)	.37	.44	.31	.32

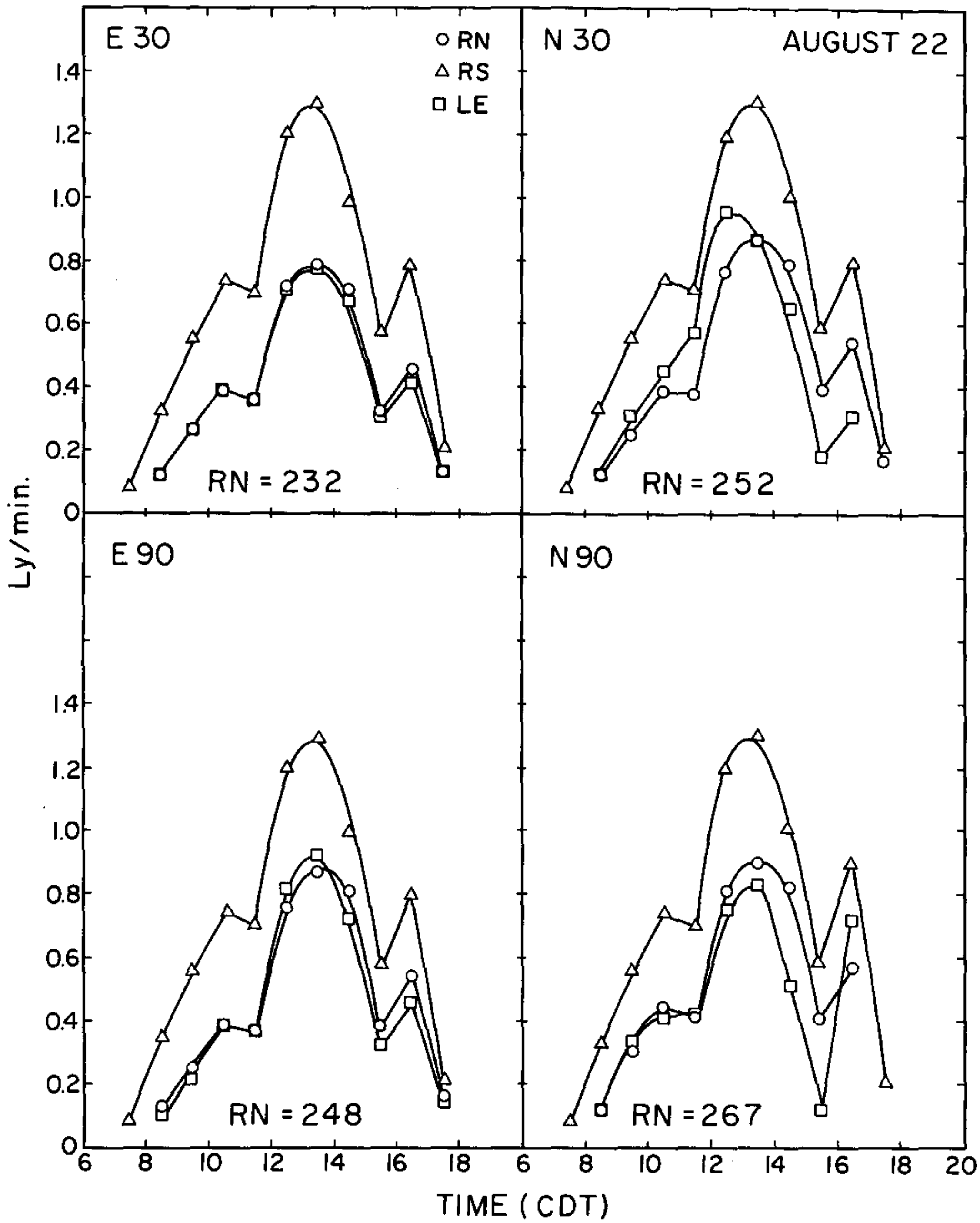

Fig. 8. Solar radiation Rs, net radiation Rn and latent heat of evaporation LE for August 22. Total Rn for the day is shown on each graph in Ly.

September 5, 11, and 12 are days of transition to different weather conditions and treatments effects from these transition days were significant only at the 14% level on September 11 and less than 50% on the other two days. In fact it is hard to determine what order of ranking was developing for some of these transition days.

Figure 9 illustrates the Rs, Rn and LE pattern for September 5. This was a very clear day as indicated by the smoothness of the Rs data. At 1030 a slight irregularity in Rn was indicated. This is probably not real because only the last three 10-minute readings of the hour were available owing to malfunctioning of equipment. The Rn for N 90 and E 30 were essentially the same while E 90 had the highest level of Rn. For the E 30 treatment LE followed Rn closely before 1230. From 1230 to 1615 there was a period of strong advective energy input. The post-advective depression occurred but not to the degree which might be predicted from the apparent severity of the advective conditions. LE for the N 30 treatment also followed Rn closely prior to 1130. From 1130 to 1245 mildly advective conditions existed in this treatment. The post-advective depression appeared to coincide with the midday depression, since the depression was more severe than would normally be attributed to the preceeding advective period. A stronger advection period occurred in the afternoon from 1430 to 1630. The post-advective depression as observed in the N 30 and E 30 treatments were not as dramatic as might be expected. The mildness of the late afternoon depression for both E 30 and N 30 could be due to the fact that they did occur late in the day when evaporative demand was low. LE for the N 90 treatment almost exactly followed the Rn prior to 1130 and after 1530. Between 1130 and 1530 the midday depression occurred. LE from the E 90 treatment fell below Rn prior to 1515 when a short period of advective condition existed. After 1545 LE again fell below Rn. The midday depression was quite apparent between 1230 and 1430.

On September 5, as on August 21, some of the treatments were subjected to various degrees of advection during different time periods of the day. On September 5, three of the four treatments experienced periods of advection of different intensities. Treatment E 90 had a strong LE depression centered at 1330. Following the LE depression there was a slight drop of Rn at 1430. This may have been due to the fact that peanuts, like other legumes under severe water stress, have a characteristic of folding their leaves. When the leaves are folded visual observation indicates the surface reflectance seems to increase. The increase in surface reflectance might cause a drop in Rn, although no such drop is evident in Fig. 9.

Figure 10 illustrates Rs, Rn and LE for September 6. This was another day with very clear sky conditions as can be seen from the Rs data. The E 30 treatment had the highest Rn for the day with little differences between the other three treatments. Only slight periods of LE depression occurred at various times of the day for the four treatments.

Figure 11 illustrates Rs, Rn and LE for September 11. On this day clear sky conditions existed. The N 30 treatment had the highest Rn while E 90 had the lowest. Rn values above N 90 and E 30 treatments were the same. Treatments E 30, E 90 and N 90 exhibited approximately the same relation between LE and Rn. LE fell slightly below Rn for the entire day. The largest depression of LE appeared with the E 90 treatment, while the E 30 and N 90 had approximately the same degree of depression during the day. LE for the N 30 treatment followed Rn closely prior to 1030. These were two periods where LE dropped considerably below Rn. These two periods occurred at 1230 and 1500. After the second period of LE depression, LE fell below Rn for the remainder of the day.

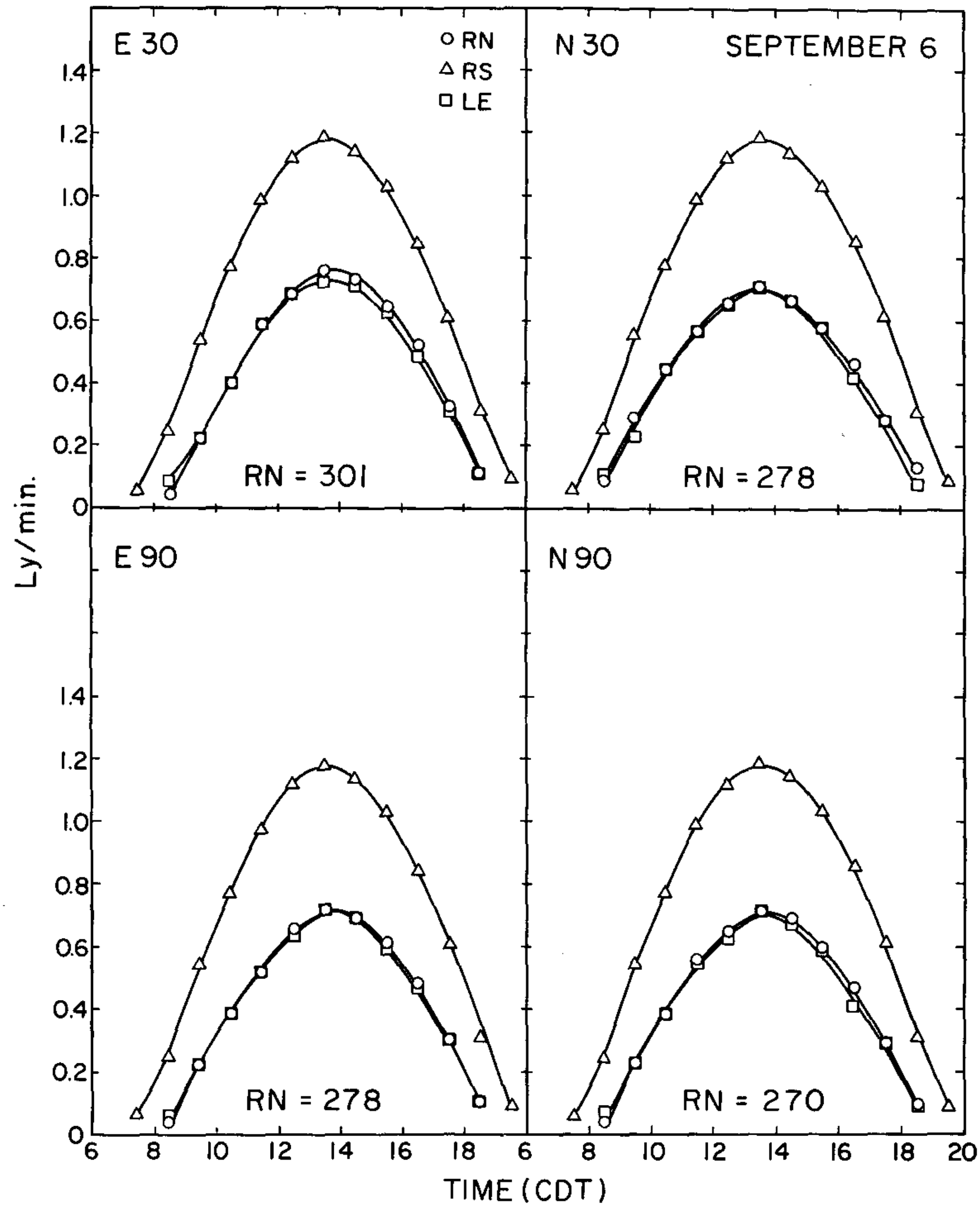

Fig. 10. Solar radiation Rs, net radiation Rn and latent heat of evaporation LE for September 6. Total Rn for the day is shown on each graph in Ly.

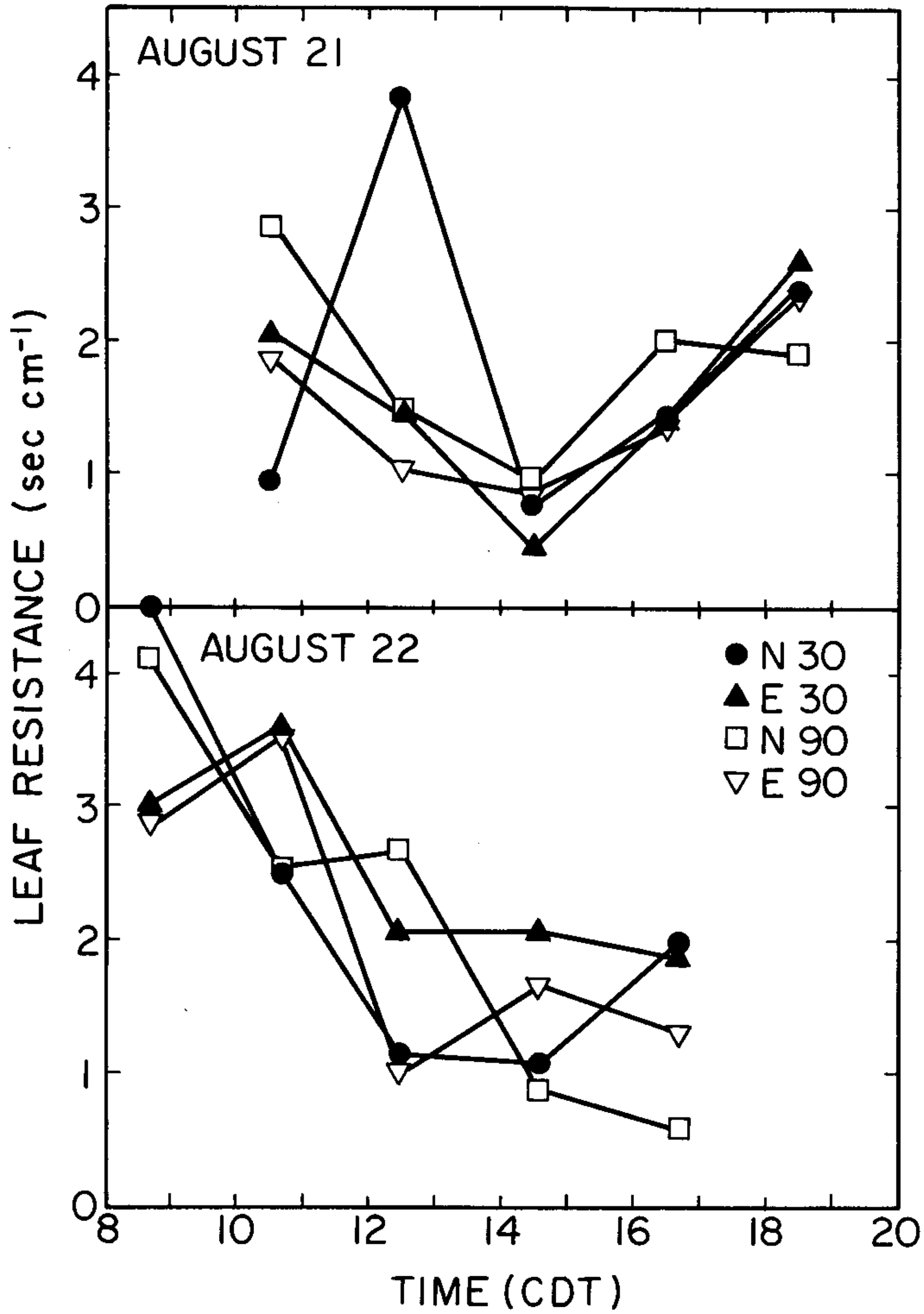

Fig. 12. Leaf resistance for Aug. 21 and Aug. 22.

Relocation of the replications in 1974 and chemical treatment of the horsenettle appears to be successful as no yield suppression from either drainage or weeds was readily apparent in the 1974 data. The yields in Table 6 show the same results reported in the literature (Chin Choy, 1972 and Stone, 1972) in that narrow rows produced the highest yields. There was a difference in yields between the treatments at the 2% level of significance in 1974.

Table 6. Yield of peanuts (cleaned, dried pods) in response to row orientation and spacing.

Treatment (row orientation and spacing)	Yield Kg/ha 1973	1974
N 30	3964	3032
E 30	2812	3185
N 90	3134	2558
E 90	2812	2101
LSD (.05)	681	411
Least Significant Difference (.05)		

Conclusions

The findings of this study must be related to the other studies and will be discussed in Part IV, Short Term Evapotranspiration Periods.

ground and still would be expected to have been well within the tubulent boundary.

The anemometers used in this study were constructed in the laboratory and were similar to the light beam interruption type described by Fritschen (1967). The main difference was that the light interruption device used in this study gave two pulses per revolution compared to one pulse in the device described by Ftitschen. The anemometers were calibrated in a wind tunnel equipped with a pitot tube for wind speed determination. The model used was of the form $W = a+bP$ where P is pulse rate and W is the wind speed. Data were fitted using the least squares method. First, second and third degree equations were tried but the best results were obtained with a first degree equation. Fifty-one anemometers were calibrated and all fit the same equation (R^2=0.967 and CV=0.08).

The output from the anemometers was fed into an electronic pulse counting circuit which in turn gave analog output. The circuit had a time constant of approximately 3.5 min. This made the sampling period about 7 min. Forty-eight of these circuits were built, one for each anemometer deployed in the field. These circuits were calibrated using a pulse generator, (Beckman model 9054) and digital voltmeter, (Non-Linear Systems model MX-2). Regression analysis using a least squares method was used to fit the data to a model of the form $P = a+bV+rV^2$ where V is output voltage and P is pulse rate. Individual circuit calibration equations were used to keep the error introduced from these circuits below 5%. Field data were digitized upon acquisition and were recorded with the previously described data acquisition system. Since the wind speed data of interest must be made during stable adiabatic conditions it was necessary to measure the air temperature profile along with the wind speed. This was done with

2 k ohm thermistors (Fenwal type GB32P6) mounted in 50 cm intervals between the heights of 0.5 m and 4 m above the ground. This mast was located near the center of the field. These thermistors were calibrated in the laboratory against a National Bureau of Standards secondary-standard thermometer that was scaled in increments of 0.1 C. Regression analysis using the least-squares method was used to fit the data to the model T = a-bV where V is voltage and T is temperature in centigrade. By using a separate equation for each thermistor, uncertainty could be held to $\pm$ 0.1 C, the precision of the secondary standard.

The data acquisition system was set to read the integrated output of the anemometers every 10 min. This was the closest repetition timing available which would insure non-overlapping time-averaged data, considering the 7 min. effective sample size of the integrators. Roughness length z_o was calculated by the method of Lettau as reported by Tanner and Pelton (1960). The method was adapted to handling by computer. The Lettau method iteratively finds a value for displacement length which minimizes the mean square error of a straight-line fit to a semi-log curve of the anemonmeter data. The program would first try all 4 anemometers on a mast and then eliminate any anemometer which did not conform. It would then proceed with three anemometers. If a suitable fit could not be obtained with three then the computation skipped that mast for that sample period. There were four treatments replicated three times and all plots were monitored (Fig. 2, Part I). All 48 anemometers were read in a 5 sec. scan period.

The program would also calculate Ri. Only z_o data with $-0.1 < Ri < 0.05$ were used to calculate mean z_o for a treatment. In a few cases, where only a few data were available and 4 anemometers were accepted by south rows which did not show in replication I. In fact, in this replication, the means for north-south were less than east-west. An analysis of variance showed the replication effect to be significant at the 5% level. The treatment effect was evidently completely disrupted by the replication I results and could be considered significant only at the 36% level, only slightly better than random. Replication I was the most sheltered from a south wind of all the replications. Note that the "hill" in the field (Fig. 14) is little more than a meter high and that the total length of the field was about 215 meters.

Since the coefficient of variation on individual treatment z_o values was small, representative individual curves represent the plots well and such are shown in Figs. 15, 16 and 17. Note that curves for the plots in Rep. I contain additional encircled points horizontally displaced for from the points joined by lines. The points connected by lines are the actual 10 min average for the period selected. The displaced points are the computer representation after curve fitting and displacement length determination. Most of the fitted data closely fit the actual data. Only Rep. I was so plotted since it contained points which involved the greatest statistical enhancement.

Consistently high wind speeds were noted in Rep. III (Fig. 17) and consistently low readings were noted in Rep. II (Fig. 16). This may be related to exposure, as illustrated in Fig. 14. The extremely low reading on the bottom anemometer on plot IIN90 (Fig. 16) would suggest proximity to the plant canopy. The only strong evidence of a top anemometer being above the boundary layer would be plot IIIE90 (Fig. 17), and this is questionable.

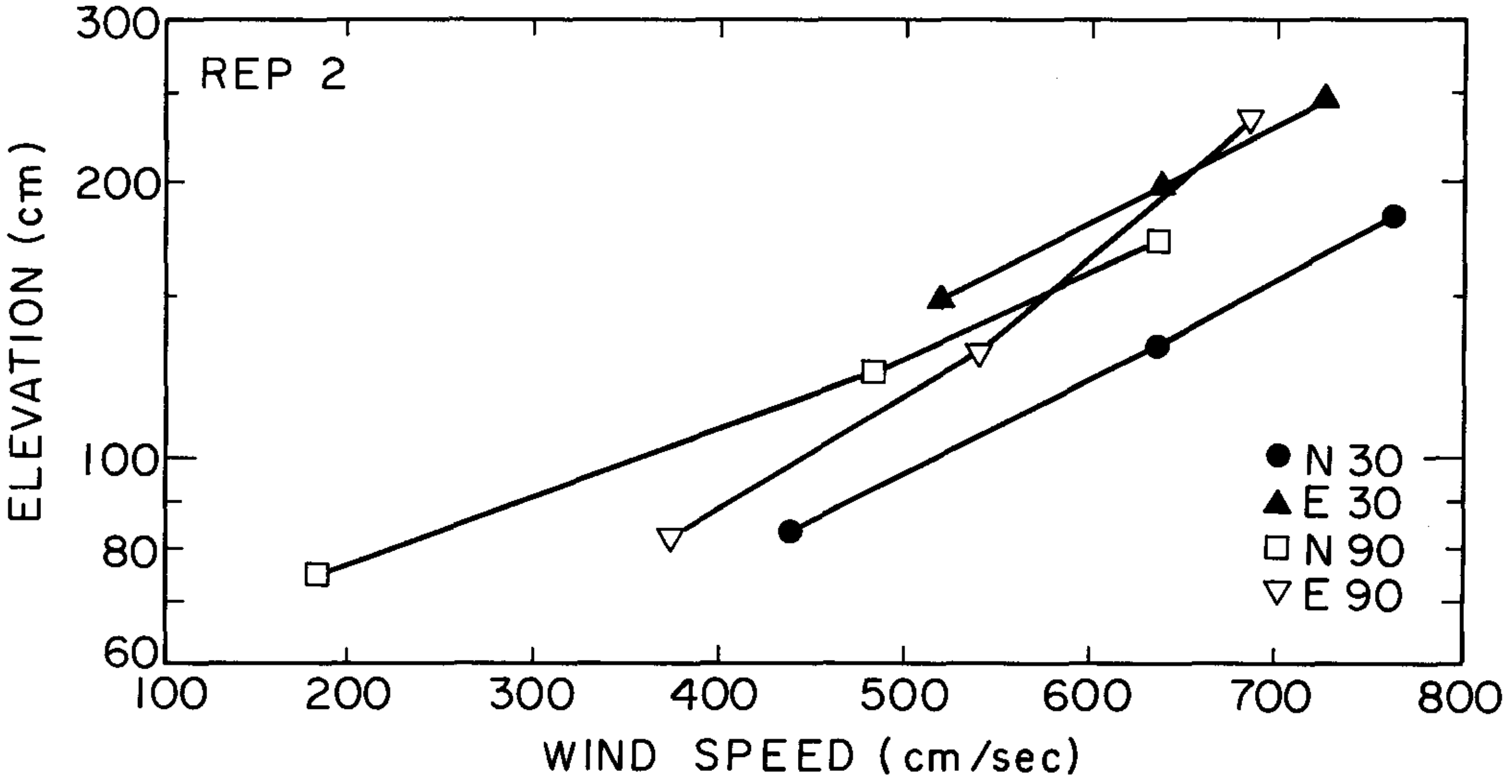

Fig. 16. Wind velocity profiles above plots in replication 2, Ft. Cobb. Data are for a single, time-averaged 10-min period.

In summary, there seems to have been a strong replication effect in the data. Replication effect may be related to exposure of the plots. At least one more anemometer per mast would be desirable, probably placed midway between the lower two anemometers. Additionally, a sixth one could well be added above the highest, at least 75 cm above. The entire mast could well be 20 cm higher above the plant canopy. The failure of Rep. I to show results similar to the other two probably invalidates the suggestions that north-south rows show different aerodynamic effects that east-west. However, it is interesting to note (Tables 4 and 5) that some indication of this possibility is shown on Aug. 21 and 22. Wind speed on Aug. 21 was 50% greater than on Aug. 22. North-south row plots showed the greater ET on Aug. 21 and east-west showed by the greater ET on Aug. 22. No such effect is obvious in the September data, despite two days (Sept. 11 and 12) with high wind speed. In addition, there was no evidence that narrow rows had different z_o from a wide rows. As suggested by Tanner (1964), all the anemometers should be tested uniform response and closely matched anemometers should be placed on each mast. Instrumenting each mast for sensing temperature gradient would probably result in improvement of estimate of Richardson number.

Water was applied as needed by furrow irrigation on approximately a 10-day schedule with each plot irrigated separately. The irrigation schedules are listed in Table 8. The amount of water at each application was monitored only to insure uniform application across the experiment.

In both years propazine herbicide was applied preplant at the recommended rate of 2.8 kg/ha. The weeds and any volunteer sorghum plants not controlled by the herbicide were controlled by hoeing. Preplant nitrogen fertilizer was applied at the rate of 280 kg/ha of elemental nitrogen.

Table 8. Irrigation Schedule, Goodwell Studies.

1973	1974
May 14-15	March 7
June 15-16	June 17-21
July 17-20	July 16-17
Aug. 15	
Sept. 5	

Plots were instrumented on July 5, 1973 and July 2 and 3, 1974, when the plants were about 30 cm high so that areas representive of the plant population could be selected. Two neutron access tubes were placed in each plot. The access tubes were located approximately 4.5 m from the north end of the plots. One tube was located near the east-west center of the plot. The other tube was located two beds to the west. Each tube was placed in the center of the bed. Two mercury-manometer tensiometers were placed in the same bed as the more easterly access tube in 40 cm intervals to the south of the access tube. The mercury manometers were located on the north border of the plots for ease of reading. The tensiometers were read daily between 8 and 9 a.m except weekends. Neutron readings were made before and after each irrigation and additionally at approximately three day intervals between irrigations. Installation and operation of neutron tubes and tensiometer was the same at Goodwell as at Ft. Cobb, Part I.

The ET from each plot was estimated by the following equation described in Part I:

$$ET = W-q-C+R$$

The water loss W was determined from the difference in the soil water content as determined with the neutron probe after one irrigation and before the next irrigation or at selected times in between these if deemed necessary. The access tubes were read at depths of 15, 30, 45, 60, 75, 90, 105, and 120 cm. The total soil water in the profile was calculated. By using the difference between the two probe readings the exact amount of irrigation water applied and that lost by evaporation or runoff during irrigation need not be taken into account. The use of the two probe readings relate only to the moisture that was lost either by ET or deep percolation from the 120 cm profile.

The flux across the 120 to 150 cm layer q was determined from the Darcy equation: as described in Part I.

$$q(\text{cm/day}) = -K(\text{cm/day}) \frac{\text{total head (150 cm depth)-total head (120 cm depth)}}{(150-120)\ \text{cm}}$$

Where K is the hydraulic conductivity. The total head gradient across the 120 to 150 cm layer was measured by the tensiometers at the two depths of 150 to 120 cm. The hydraulic conductivity K was given by: K(cm/day) = $3.069 \times 10^{-8} \exp(48.174\Theta)$ where Θ is the volumetric water content determined from the soil water pressure using the tensiometer data. These equations were determined from desorption studies previous to this study as described by Davidson et al. (1969). The soil-water pressure versus Θ relation was determined using undisturbed 7.6-cm diameter cores in the laboratory. The location A shown in Figure 18 was used to characterize the soil.

Allowance for water content change in the 120 to 150 cm layer was the same as in Part I. Rainfall R was measured at both research locations in 1973 and 1974.

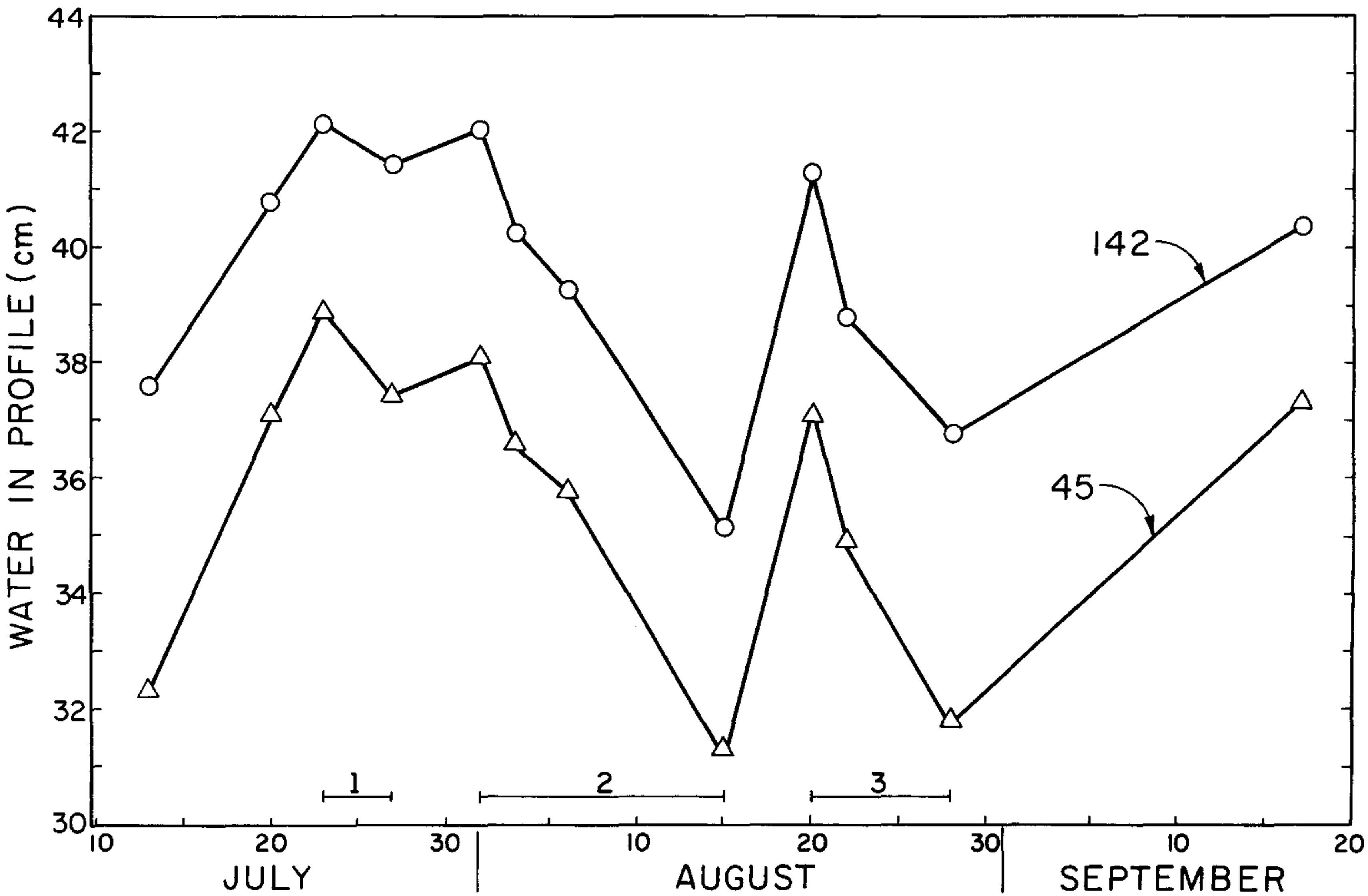

Fig. 19. Neutron determined soil water content in the 1973 growing season.

Table 9. Evapotranspiration (cm daily) from the water budget determination 1973 and 1974, Goodwell, Oklahoma.

Period		Row Spacings 142 cm	Row Spacings 45 cm	Ratio 45:142
		1973		
July 23-27	1	.26	.17	.67
Aug. 1-15	2	.24	.20	.83
Aug. 20-28	3	.16	.14	.86
		1974		
Aug. 2-5	1	.40	.59	1.49
Aug. 5-14	2	.63	.43	.68
Aug. 14-20	3	.49	.39	.80
Aug. 28-Sept. 4	4	.30	.41	1.37

Table 10. Selected Meteorological Data 1973 Panhandle Research Station Goodwell, Oklahoma.

Date	Maximum Temperature (^oC)	Pan Evaporation(cm)	Wind km/day	Cloud Cover
July 24	30	0.81	132.0	Clear
25	33.9	1.68	159.4	Cloudy
26	27.8	0.66	159.4	Cloudy
27	29.4	0.58	9.7	Clear
Aug. 2	27.8	0.71	59.7	Clear
3	27.8	0.66	46.7	Cloudy
4	30.6	0.84	109.5	Clear
5	30.6	0.74	104.7	Clear
6	33.3	1.19	199.6	Clear
7	32.8	1.52	119.1	P.Cloudy
8	31.7	0.71	66.0	P.Cloudy
9	30.6	0.56	20.9	P.Cloudy
10	31.7	1.45	74.1	P.Cloudy
11	31.7	0.74	67.6	Clear
12	33.9	0.58	61.2	Cloudy
13	33.3	0.99	53.1	P.Cloudy
14	27.2	0.84	59.6	Clear
15	33.3	0.74	66.0	Clear
21	33.9	1.09	91.8	Clear
22	35.6	1.35	228.6	Clear
23	38.3	1.75	259.2	Clear
24	35.6	0.71	128.8	Clear
25	40.0	1.50	172.3	Clear
26	38.3	0.81	252.8	Clear
27	34.4	1.27	201.3	Clear
28	33.3	1.24	212.5	Clear

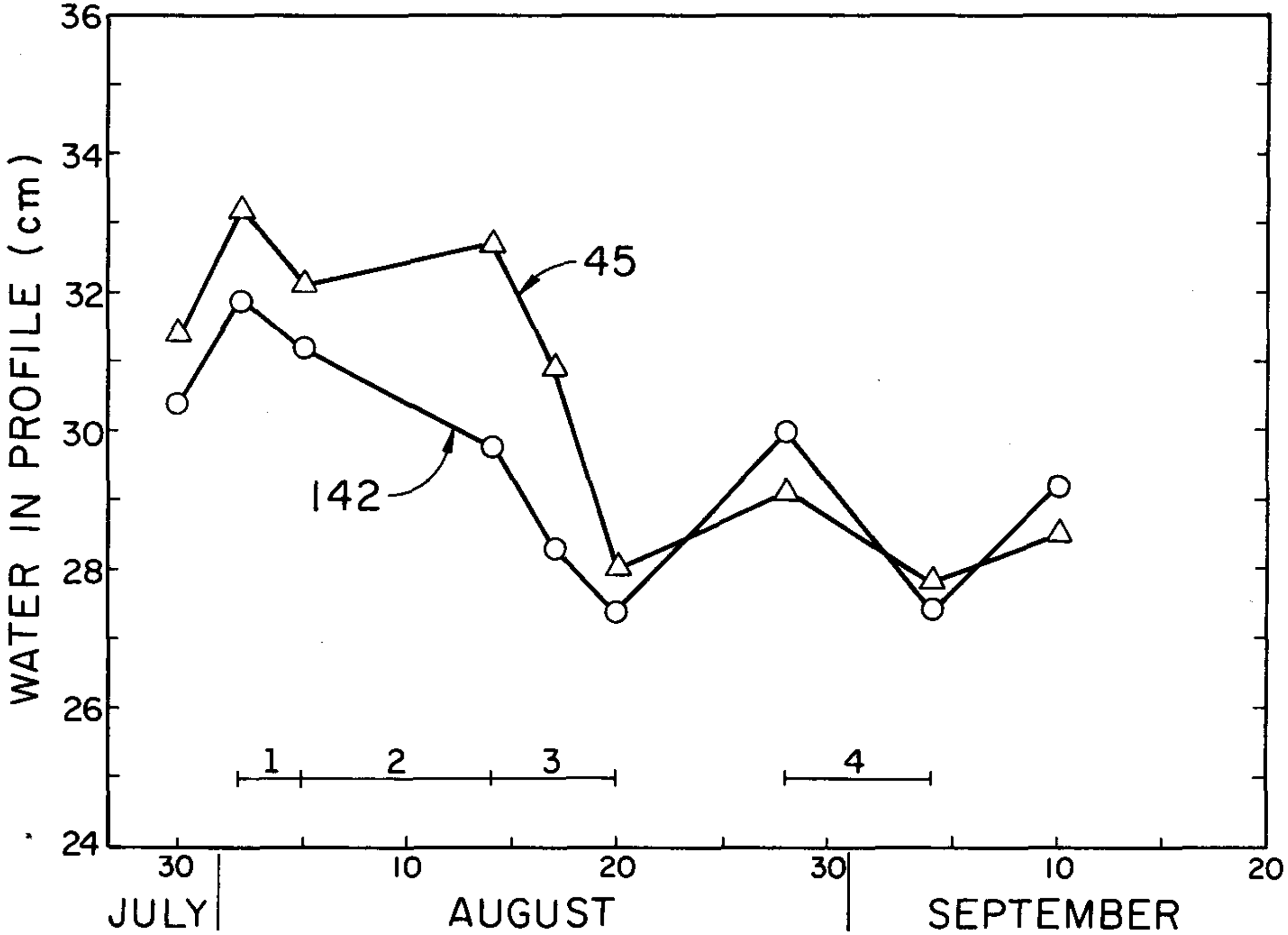

Fig. 21. Neutron determined soil water content in the 1974 growing season.

Table 11. Selected Meteorological Data 1974 Panhandle Research Station Goodwell, Oklahoma.

Date	Maximum Temperature(°C)	Pan Evaporation(cm)	Wind km/day	Cloud Cover
Aug. 3	31.7	.81	280	Cloudy
4	20.6	.33	158	Clear
5	26.7	.84	286	P.Cloudy
6	31.1	.99	185	Cloudy
7	23.3	.66	134	Cloudy
8	28.3	1.12	331	Clear
9	30.0	---	228	Clear
10	27.2	.69	143	Cloudy
11	27.8	1.24	148	Cloudy
12	28.3	.74	237	Cloudy
13	32.8	1.17	233	Cloudy
14	32.2	1.22	259	P.Cloudy
15	33.9	1.22	274	Clear
16	33.3	1.02	177	Clear
17	33.3	1.12	138	Clear
18	36.1	1.24	241	Clear
19	33.9	1.55	245	Clear
20	34.4	1.93	422	P.Cloudy
29	24.4	.48	106	P.Cloudy
30	28.3	.81	212	Clear
31	31.7	.91	257	Clear
Sept.1	28.3	.10	186	Cloudy
2	21.7	---	238	Cloudy
3	13.9	---	164	P.Cloudy
4	18.9	---	159	P.Cloudy

Conclusions

The results of this study are compared to Parts I and II in the next part.

The defined ET periods are set by convenience and experimental design, mainly the irrigation schedule. The natural ET periods and defined ET periods generally do not coincide, since the natural ET periods cannot be accurately determined except in retrospect. The possibility that a defined ET period will be contained within a natural ET period increases when stable meteorological conditions exist over a period of a week or more. The best agreement of the two types of periods occurred in period 3 of 1974 (Fig. 4, Table 4).

For the 1973 study, Tables 3 and 9 show that the same general ET treatment ET rankings for the defined ET periods existed for Ft. Cobb and Goodwell in that the ET rate was low in period 1, higher in period 2, and lower again in period 3. The Goodwell meteorological data have already been used to explain the ET treatment sequences. No comparison can be made of the natural ET periods for the two locations as no meteorological data were available for Ft. Cobb in 1973. But the dates for the three defined ET periods are not too far apart especially when the above mentioned time lag is considered.

Table 9 shows that the 45:142 ratio from the first and second defined ET periods in 1973 are similar to the second and third defined ET periods in 1974 at Goodwell. Table 10 and Table 11 reveal that the meteorological conditions for the first defined ET period in 1973 and second defined ET period in 1974 are similar. The daily maximum temperature ranged from 20 to 30°C and the sky conditions were generally clear. The same similarities exist for the meteorological conditions for the second period of 1973 and the third period of 1974. The daily maximum temperature ranged from 27 to 36°C and the sky was generally clear. The daily ET rate did not reflect that the same meteorological conditions existed but this has previously been attributed to the differences in soil water conditions.

about 33°C and clear skies) the treatment ET sequences were strongly influenced by advected energy and LE (latent energy flux) depression. Advected energy and LE depression occurred most frequently in the N 30 treatments. The N 30 treatment had the lowest ET on the days with advective energy and LE depression. In days with a high demand, the treatment net radiation (Rn) order was generally from high to low N 90, N 30, E 90 and E 30. In natural ET periods with a low demand (maximum temperature below 27°C and clear skies) the treatment ET sequence followed closely to treatment Rn. The order of treatment Rn from high to low was E 30, E 90, N 30 and N 90 (Table 13).

Table 13. Net radiation for days of high and low evaporative demand. Ft. Cobb. 1974. High demand data are averages of total Rn for Figs. 10, 11, and 14. Low demand data are from Figs. 12 and 13.

Demand	Average Total Rn (Ly/day)			
	E 30	N 30	E 90	N 90
High	267	292	278	295
Low	293	274	287	275

A clue to the reason for different ET rankings on different demand conditions may be seen in the Ft. Cobb data. August 21 and 22 had high evaporative demand (despite a cloudy conditions on August 22). Also, it appears that August 22 was transitional to the lesser demand period that followed (August 23-September 10) (Table 4). On August 21 the north rows had the greatest LE (Table 5) and on the August 22 the east rows had greatest LE. On September 11 the LE rankings were indistinct so no treatment showed predominance.

all treatments on September 11 (Fig. 13) could be due to the low water content of the soil profile (Fig. 6). Allowing for the evidences of advective energy removal for the N 30 treatment, the LE values for September 11 appear to be more proportional to the Rn, as pointed out in Part I.

Actually, the foregoing analysis is based upon rather cursory data, particularly the aerodynamics. It is obvious that had the defined ET periods coincided with the natural ET periods considerably more information could had been extracted from the study. In the future it will be desirable to study plant response to row-spacing and direction using the natural ET period concept as a base as much as possible and with more measurements of r_s, a better estimate of aerodynamic roughness, wind, and the energy budget.

The Goodwell results could be interpreted in a similar manner but no definite conclusion can be drawn without energy budget measurements. In two years of measurement only two periods had low demand conditions. In these two periods 140 cm rows had lower ET. The other five periods the meteorological conditions were close to normal with a moderate to high demand. In these five periods the 45 cm rows had the lowest ET.

CONCLUSIONS

1. Periods of uniform evaporative demand existed in Oklahoma during the period of this study. Except for a time lag, these demand periods were coincidental at two research stations 200 miles apart.
2. Evapotranspiration rankings between treatments of different row-spacing and direction appear to vary with the prevailing evaporative demand (involving solar radiation, wind velocity and direction and temperature).
3. In high evaporative demand periods, net radiation was highest in north-south-row plots. ET was not necessarily highest in these plots but was strongly influenced by stomatal closure conditions effects prevailing in the

LITERATURE CITED

1. Allen, L. H., Jr. 1974. Model of light penetration into a wide-row crop. Agron. J. 66:41-47.

2. Aubertin, G. M. and D. B. Peters. 1961. Net radiation determinations in a cornfield. Agron. J. 53:269-272.

3. Blum, A. 1970. Effect of plant density and growth duration on grain sorghum yield under limited water supply. Agron. J. 62:779-787.

4. Brown, Paul L. and W. D. Shrader. 1956. Yield, evapotranspiration, and water use efficiency of grain sorghum under difference cultural practices. Agron. J. 51:339-343.

5. Chang, Jen-Hu. 1968. Climate and Agriculture, and Ecological Survey. Aldin Pub. Co., Chicago.

6. Chin Choy, Edward W. 1972. The effects of plant population and geometry on yield and water utilization by peanuts (Arachis hypogaea L.). Unpub. Ph.D. thesis. Okla. State Univ., Stillwater, Oklahoma.

7. Chin Choy, E. W. and E. T. Kanemasu. 1974. Energy balance comparisons of wide and narrow row-spacing in sorghum. Agron. J. 66:98-100.

8. Crawford, T. V. 1965. Moisture transfer in free and forced convection. Quart. J. Royal Meteorol. Soc. 90:18-27.

9. Davidson, J. M., L. R. Stone, D. R. Neilsen and M. E. Larue. 1969. Field measurement and use of soil water properties. Water Resour. Res. 5:1313-1321.

10. Donald, C. M. 1963. Competition among crop and pasture plants. Advan. Agron. 15:1-18.

11. Doss, B. D. and D. L. Thurlow. 1974. Irrigation, row width and plant population in relation to growth characteristics of two sorghum varieties. Agron. J. 66:628-623.

12. Downey, Lloyd A. 1971. Water use by maize at three plant densities. Exp. Agr. 7:161-169.

13. Elliott, W. P. 1958. The growth of the atmospheric internal boundary layer. Trans. Amer. Geophys. Union 39:1048-1054.

14. Fritschen, L. J. 1960. Construction and calibration details of the thermal-transducer type net radiometers. Bull. Amer. Meteorol. Soc. 41:180-183.

15. Fritschen, L. J. 1963. Construction and evaluation of a miniature net radiometer. J. Appl. Meteorol. 2:165-172.

32. Rosenberg, N. J. 1974. Microclimate: The Biological Environment. John Wiley and Son's, New York. 315 pp.

33. _____, H. E. Hart and K. W. Brown. 1968. Evapotranspiration, Review of Research. Neb. Exp. Sta. Publ. MP 20.

34. Sellers, W. D. 1965. Physical Climatology, The Univ. Chicago Press, Chicago.

35. Stanhill, G. 1969. A simple instrument for the field measurement of turbulent diffusion flux. J. Appl. Meteorol. 8:509-513.

36. Stone, J. F. 1972. Plant population effects on the efficient use of water: water uptake characteristics. Technical Completion Report to Office of Water Resources Research U.S. Dept. of Interior. Matching Grant Project B-012-OKLA.

37. Suomi, B. E. and C. B. Tanner. 1958. Evapotranspiration estimates from heat-budget measurements over a field crop. Trans. Amer. Geophys. Union. 39:298-304.

38. Szeicz, G., G. Endrodi and S. Tajchman. 1969. Aerodynamic and surface factors in evaporation. Water Resour. Res. 5:380-394.

39. Tanner, C. B. 1960. Energy balance approach to evapotranspiration estimates by the approximate energy balance method of Penman. Soil Sci. Soc. Amer. Proc. 24:1-9.

40. _____. 1965. Basic instrumentation and measurement of plant environment and micrometeorology. Soils Bull. No., 6 Dept. Soil Science, University of Wisconsin, Madison, Wisconsin.

41. _____ and W. L. Pelton. 1960. Potential evapotranspiration estimates by the approximate energy balance method of Penman. J. Geophys. Res. 65:3391-3413.

42. _____, A. E. Peterson and J. R. Love. 1960. Radiant energy exchange in a cornfield. Agron. J. 54:207-212.

43. Taylor, P. A. 1969. On wind and shear stress profile above a change in surface roughness. Quart. J. Royal Meteorol. Soc. 95:77-91.

44. Van Bavel, C. H. M., F. S. Nakayama, W. L. Ehrler. 1965. Measuring transpiration resistance of leaves. Plant Physiol. 40:535-540.

45. Webb, E. K. 1970. Profile relationships: the log-linear range, and extension to strong stability. Quart. J. Royal Meteorol. Soc. 96:67-90.

46. Yao, Augustine Y. M. and R. H. Shaw. 1964a. Effect of plant population and planting pattern of corn on water use and yield. Agron. J. 56:147-152.

47. _____ and R. H. Shaw. 1964b. Effect of plant population and planting pattern of corn on the distribution of net radiation. Agron. J. 56:165-169.