ROW SPACING AND ORIENTATION EFFECTS
ON EVAPOTRANSPIRATION

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CHAPTER I

INTRODUCTION

Water has become the limiting factor of agronomic production in many parts of the world. Water may be limited from either depletion of the resource or stress limited production or both.

Preliminary studies with peanuts at the Oklahoma Agricultural Experiment stations dating back to 1960 have shown that the water use could be reduced by proper selection of a row spacing and row orientation. These early studies narrowed the treatments to four, north-south and east-west oriented rows combined with 30 and 90 cm spacing. The results indicated that 30 cm north-south rows showed the lowest water use rate.

The fact that north-south versus east-west oriented rows had different evapotranspiration levels indicated that aerodynamics and/or radiant energy could be involved. Row spacing and row orientation could effect several components of the radiant energy. The 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. These factors would be reflected in the net radiation. The aerodynamic involvement is not quite as obvious until it is considered that the summer wind in western Oklahoma is predominately from the south. Row spacing and row orientation can affect the surface roughness which would influence the aerodynamic transport coefficient. Complex interaction between these factors could also exist.

The crops utilized in this experiment were grain sorghum (Sorghum bicolor, Moench) and peanuts (Arachis hypogaea, L.). Peanuts were used because they were the crop used in the preliminary studies where the effect was first observed. Grain sorghum was added to the experiment to see if the same effect of row spacing on water use could be observed with a different crop. Another reason for the selection of grain sorghum was its economic importance in the state and the results that a meaningful soil-plant-water relation study might produce.

The experiment was conducted at two locations. The peanut portion of the study was conducted at the Caddo Peanut Research Station near Ft. Cobb, Oklahoma. This location was selected because it was one of the sites of the preliminary studies. The Panhandle Research Station near Goodwell, Oklahoma was selected as the second experimental site for several reasons. Firstly, grain sorghum is an important crop in the Panhandle. Secondly, the same general meteorological conditions such as clear skys, high temperature, low summer rainfall and hot dry south wind prevail at both locations. Finally the low summer rainfall and availability of furrow irrigation are ideal for an evapotranspiration study.

The purpose of this study was to attempt to isolate row spacing and row orientation related treatment differences which could cause the previously observed differences in evapotranspiration. The study was designed to measure the evaporative water loss over periods of a few days in length. Meteorological measurements made during these same periods were designed to provide data with which to correlate differences in treatment effects and hopefully isolate causal mechanisms. Energy balance measurements made during part of the periods at Ft. Cobb were designed to characterize solar radiation and treatment differences related to net radiation, advective energy and latent heat of evaporation. Wind profile measurements made during part of the periods at Ft. Cobb were designed to determine roughness length and zero plane displacement for the treatments.

CHAPTER II

REVIEW OF LITERATURE

Since the amount of research related to peanuts and grain sorghum is limited in the literature, some relevant studies with corn will be reported. Corn and peanuts are not similar morphologically but corn results may be applicable to grain sorghum. Other than the preliminary research conducted in Oklahoma, no previous work was found in the literature on the influence of row spacing and orientation on the water use of peanuts.

Water Use

Yao and Shaw (45) in Iowa found that corn in 21-inch row spacing used less water than either 32 or 42-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 woil 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.

Downey (10) 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.

Blum (2) working with 12 populations of grain sorghum, reported that plant density had a definite effect on water use. The higher population had the lowest water use. He also noted that the early maturing sorghum varieties were much better competitors at the high plant densities. The early maturing varieties gave a higher water use efficiency. Brown and Shrader (4) reported that under dry land conditions in Kansas in dry years wide rows gave higher yields in dry years, but as moisture conditions improved, narrow spacing and higher plant population gave higher yields. Chin Choy and Kanemasu (7) found that grain sorghum in Kansas used 10 percent more water in wide rows (92 cm) than in narrow rows (46 cm). Their study was conducted on two large plots each equipped with a lysimeter for evapotranspiration estimates. The population down the row in both plots was held constant so that the population of the narrow-row plot would be double that of the wide-row plot on an area basis. The row orientation of both plots was north-south, the direction of the prevailing wind. Ritchie and Burnett (27) state that decreasing the row spacing to increase plant population should be very effective in increasing water use efficiency. Their conclusion was drawn from a compilation of work with grain sorghum and cotton in Texas. They introduced the term "threshold leaf area index (LAI)" which they define as the minimum LAI where the plant evaporation potential evaporation ratio becomes 0.9 and soil evaporation is small. In their experiment this threshold LAI was 2.7 for each of the two crops they investigated. When the LAI is below the threshold and soil moisture conditions are adequate, they found the plant evaporation-potential evaporation ratio to be characterized by -0.21 + 0.70 LAI. Above 2.7 LAI very little radiation can penetrate the canopy and soil evaporation becomes very small.

The only references found to water use of peanuts were reports by Chin Choy (6) and Stone (33). Chin Choy found that of four treatments in 12 and 36-inch spacing oriented north-south and east-west, the 12-inch rows oriented north-south used less water than any of the other treatments. Stone reports that there was a spacing effect but orientation seems to be the major factor. Twelve-inch rows with north-south orientation used the least water while 36-inch rows of north-south orientation generally used the most water.

Aerodynamics

The wind is the vehicle which carries away the moisture 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 boundary layer dependant 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 (28, 29, 31). 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:

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

where d is the zero plane displacement. No indication could be found in the literature as to whether peanuts should be classified as a tall crop or a short crop. Work has been done with other crops to estimate d for a given crop height. Stanhill (32) fitted an expression giving d as a function of crop height. The resulting equation is $\log d = 0.979 \log H - 0.154$ where H is the crop height. This equation was the result of a review of data published in the literature for a wide range of crops. Several equations have been developed with only slight variations in the constant (23, 42), but this equation is the one most generally accepted. For these equations to be valid the conditions in the atmosphere near the crop surface must be neutral. Neutral atmospheric conditions have been generally defined as a decrease in temperature with altitude of at least 1°C/100m (28). A better parameter to determine whether neutral conditions exist is the Richardson Number (29). Richardson's Number is expressed by the relation

$$Ri = \left[g\left(\frac{dT}{dz}\right)\right]\left[T\left(\frac{du}{dz}\right)\right]^{-1}$$

Where T is the absolute temperature. Generally, neutral conditions are considered to exist if $|Ri| \leq 0.03$ (36). When approaching zero from the positive side, neutral conditions are considered to exist for slightly larger values of Ri generally in the range of 0.05 (8, 11). While other workers report that neutral conditions exist up to 0.2 to 0.25 (5, 44).

The aerodynamic roughness parameter z_0 has been the subject of considerable research and debate. The roughness parameter is generally considered to be a function of the crop height and crop flexibility but may be considered a constant over a fairly wide range of wind speeds (5, 32, 41). Some typical values of z_0 (5) are 0 cm-ice, 0 to 0.1 cm-sand, 0.02 to 0.6 cm-water, 0.1 to 0.6 cm-snow, 0.6 to 4 cm-short grass and 4 to 10 cm-long grass. Tanner and Pelton (38) reported that evapotranspiration increases as z_0 increases, other things being equal. The closeness of the relation between z_0 and evapotranspiration led to its presence in several evapotranspiration models (30). But a good relation has not been found as most of these models do not give a very good estimate of evapotranspiration (30, 34, 37, 38). The lack of success of these models does not detract from the view that z_0 is closely related to evapotranspiration. King and Lettau as reported by Tanner and Pelton found that there is a log-log relation between crop height and z_0. The exact relation, $\log z_0 = 0.997 \log H - 0.883$, was the result of a compilation of z_0 versus crop height data for several crops. The introduction of this equation did much to promote the theory that z_0 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 should 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 (5). Elliott (11) has proposed a relation of the form $h = 0.75\ x^{0.8}$ (h = height of boundary layer and x = fetch). He reports that this equation is valid for values of x as small as 3 m. This equation is generally accepted to be valid (5, 23, 29). Care must also be taken not to locate an anemometer too near the surface as local turbulance can cause error. A general rule of thumb is to place the bottom instrument at $5\ z_o$ (41). Between these two locations the aerodynamic profile will follow the semi-log law under neutral conditions. This is not to say that all instantaneous readings taken with the above mentioned precautions will fit the semi-log law. But a series of such readings averaged across time will comply with the semi-log law. The desired length of time to be averaged across is controversial. Reports in the literature range from 5 minutes to several hours (23, 28).

Energy Budget

The energy balance at a given level above a crop can be represented (28, 38):

$$Rn = G + H + LE + M$$

where

Rn = net radiation
G = soil heat flux
H = sensible heat flux
L = latent heat of vaporiation of water
E = evaporation flux density
M = miscellaneous heat flux density terms

The miscellaneous term is generally recognized to contribute less than 1 percent to the relation (28, 38). For this reason the miscellaneous term which contains several components that are difficult to estimate is generally dropped from the equation. The soil heat flux term contributes from 3 to 5 percent to the total of the left-hand side of the equation (26, 38). 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 (1, 26, 39, 46). Because it is small and hard to determine, it can be neglected without too much 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 estimated directly.

From the above equation can be seem the direct relation between Rn and evapotranspiration. Ritchie and Burnett (27) have reported the possibility of reducing the soil evaporation component of evapotranspiration 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 (46) 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 of the soil and the crop surface. Corn planted in north-south rows also lowered the net radiation when compared with east-west oriented rows of the same spacing. The ratio of the net radiation six inches above the soil to that above the crop will also give 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 (1) 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 absorbed by the crop increases. Tanner et al. (39) in Wisconsin working with corn reported similar trends of net radiation as plant population increases from closer spacing. But they found no significant difference between north-south and east-west rows. Comparing their results to that of Yao and Shaw there seems to be a location effect. The difference in angle of the sun between the two locations has a large effect on the albedo. Ritchie (26) working with grain sorghum and cotton in Texas reports a decrease in the net radiation as the row spacing decreases. He attributes the lower net radiation to the wide variation in the albedo ranging from 0.055 over bare soils to 0.123 with almost complete ground cover. Chin Choy and Kanemasu (7) working with grain sorghum in Kansas verify this effect of row spacing on net radiation. They report the ratio of net radiation below the crop to the net radiation above the crop to vary from 0.6 with 0.92 m spacing to 0.26 with 0.46 m spacing.

One popular solution to the energy balance equation is from the Bowen ratio (3). The Bowen ratio (β) is illustrated by the following relation:

$$\beta = \frac{H}{LE} = \frac{\rho\ Cp\ Kh}{L\ \ Kw}\ \left(\frac{\partial\ T/\partial z}{\partial\ e/\partial z}\right)$$

Where ρ = air density
Cp = specific heat of moist air at constant pressure
L = latent heat of vaporization
Kh = transport constant for heat
Kw = transport constant for water vapor
T = temperature
e = water vapor pressure

Generally Kh and Kw are assumed to be equal. This is not actually true but the assumption can be made with minimal error during the times of interest (28, 34, 37). This simplifies the solution of the equation to a task that can be accomplished with minimal equipment. With the shapes of the moisture profile and vertical temperature being approximately the same the equation can be further simplified by $(\partial T/\partial z)/(\partial e/\partial z) = \Delta T/\Delta e$. Another substitution that can be made is ρ Cp/L = γ, where γ= psychrometric constant. The resulting equation after the simplifications is $\beta = \gamma(\Delta T/\Delta e)$. This equation is fairly easy to work with and solve. Combining the Bowen ratio and the energy balance equations yields an equation where all of the components can be measured. The results of this combination is $E = Rn/L(1+\beta)$. This equation gives a good estimate of the evapotranspiration from a crop (14, 17, 34, 37), except when β approaches -1. This usually occurrs only near sunrise and sunset (37). These are times of very little interest to estimate daily evapotranspiration. A look at the sensible heat flux can also be realized from this equation. This gives an insight into the contribution of heat from the up fetch area to the evapotranspiration of the crop area. Most workers (14, 17, 34, 37) report the Bowen-energy balance equation gives very good estimates, within 5 percent, of the evapotranspiration 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 evapotranspiration 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 hot dry air from the fetch is blown across the field. 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 will be directly proportional to evapotranspiration. In summary, reports in the literature agree that decreasing the row spacing decreases the net radiation above the crop canopy. Generally it is stated in the literature rows of north-south orientation result in lower net radiation. This is true except in the extreme northern part of the United States. By decreasing row spacing and using north-south orientation, the amount of energy available for evapotranspiration can be reduced.

Leaf Resistance

Transpiration is the loss of water from a crop. Ritchie (26) 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 severly wilted (29). The water vapor inside the stomatal cavity diffuses to the leaf boundary layer through the stomate. The guard cells control the degree 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 diffusion is by the stomate resistance (r_s). The stomatal resistance can be measured by a humidity sensor in an enclosed cell placed over the leaf. Kanemasu et al. (22) and Van Bavel et al. (43) describe an instrument and method of measuring stomatal resistance. The stomatal resistance has been used in several evapotranspiration models (29). Stomate resistance is inversely proportioned to evapotranspiration. Some insight of crop evapotranspiration may be obtained by monitoring the stomatal resistance.

CHAPTER III

MATERIALS AND METHODS

Field Layout

The study was conducted in 1973 and 1974, at two locations. Peanuts were studied at the Caddo Peanut Research Station, Ft. Cobb, Oklahoma. Grain Sorghum was studied at the Panhandle Research Station, Goodwell, Oklahoma.

Ft. Cobb

The experimental site was situated on Cobb fine sandy loam and Meno fine sandy loam. The Cobb fine sandy loam occurred in two phases: 1 to 3 percent slope and 3 to 5 percent slope severly eroded. The replications were oriented such that 2 replications were on Cobb fine sandy loam, and one on the Meno fine sandy loam.

In 1973 and 1974 there were 4 treatments with 3 replications per treatment. The treatments were 30 and 90 cm row spacing of north-south and east-west row orientation. In both years the treatments within replications were randomly assigned. Figure 1 shows the field layout for 1973. Figure 2 shows the field layout for 1974. In 1974 replication 1 was shifted 10 m to south while replication 2 and 3 were shifted 13 m to the south. This was done to put natural drainage through the alley ways. In both years the plots were 30.5 m square and were planted with a six-row Planet Jr. Planter with Comet variety, medium size seeds.

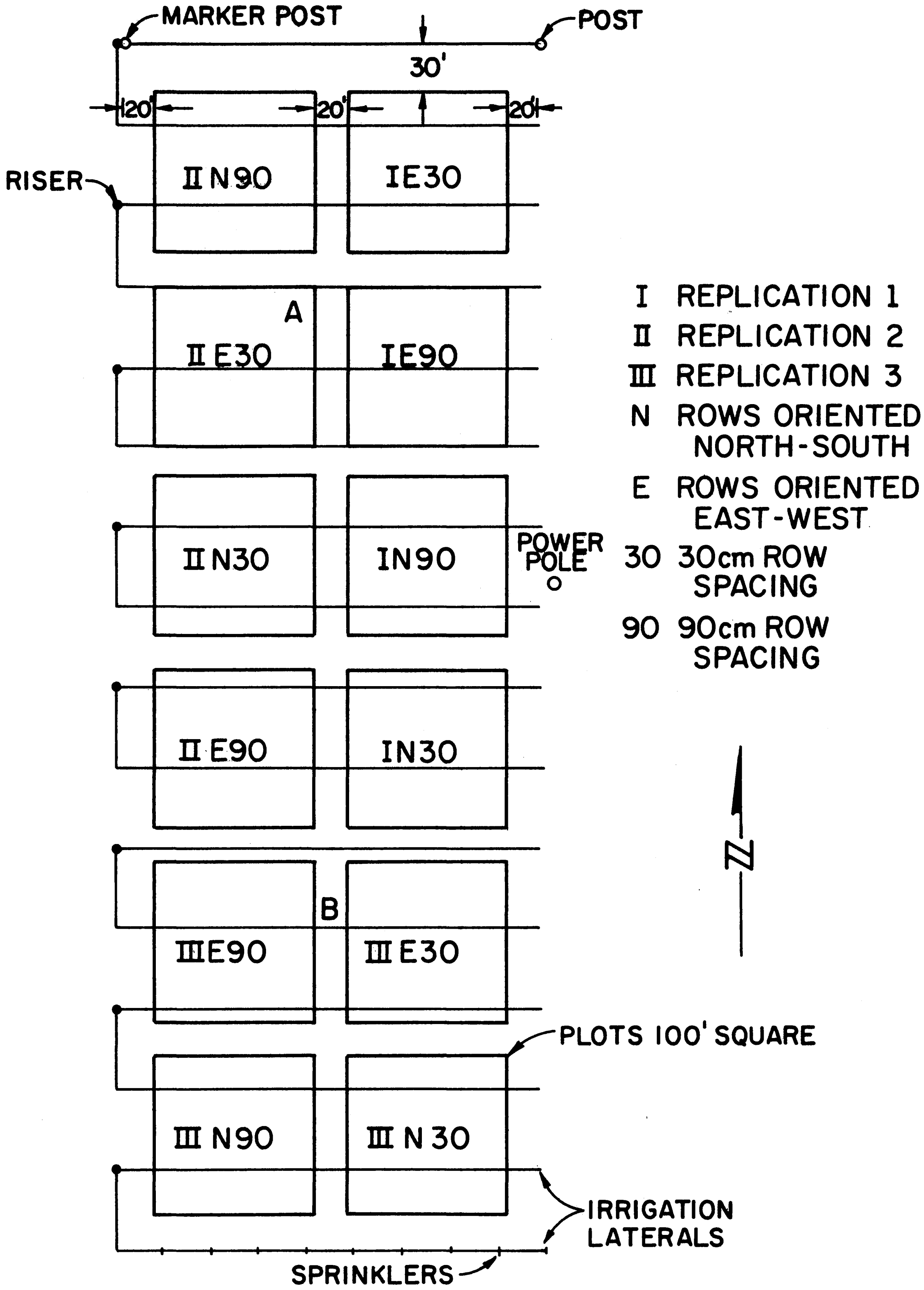

Figure 1. Field layout of 1973 peanut study.

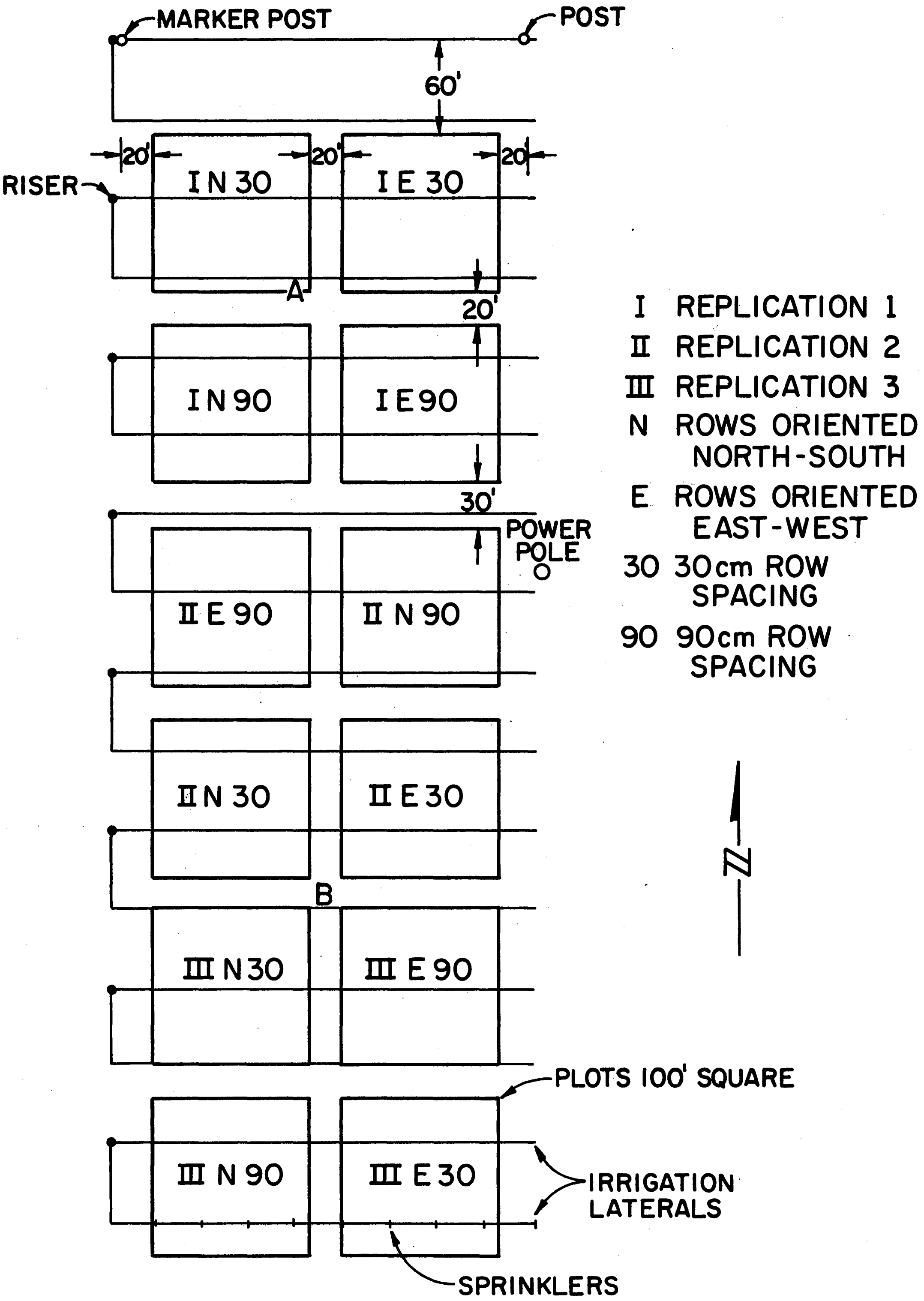

Figure 2. Field layout of 1974 peanut study.

The planter was set for 30 cm spacing between planter openers for the 30 cm row plots while the 90 cm rows were obtained by using the second and fifth openers. By this method the plant population down the row was held constant.

During 1973 and 1974 the plots were irrigated by a solid-set sprinkler irrigation system as diagrammed in Figures 1 and 2. The amount of water applied at each irrigation was not measured but water was applied in eight-hour sets with four laterals per set which resulted in a period of 32 hours for the irrigation. The water pressure and nozzle size were selected to apply approximately 5 cm per irrigation. Irrigations in both years were made on approximately a seven day schedule. The exact irrigation schedule for both years is listed in Table I.

Herbicide was applied each year preplant: 1973-Treflan at 0.56 kg/ha and 1974-Balan at 1.12 kg/ha. The weeds not controlled by herbicide were controlled by hoeing. In 1973 some repression in yield appeared in some of the plots as a result of room competition from horsenettle (Solanum carolinense, L.). To counter this repression in 1974, 2, 4-DB (4(2,4 dichlorophenoxybutyric acid)) was sprayed by hand in replication 1 in two applications: July 2 and July 12. The 2,4-DB was applied at the recommended rate of 0.45 kg/ha. Fungicide and insecicide were applied periodically, the fungicide being Dithane and the insecticide methyl-parathion. 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 then incorporated by disc.

On October 9, 1973 and October 24, 1974 an area 4.9 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. Yields were then reported as pounds of cleaned, dried pods per acre.

Goodwell

The study was conducted on Richfield clay loam. In 1973 and 1974 there were two treatments with three replications. The treatments were 142 and 45 cm row spacing with all rows oriented in a north-south direction. The plots were laid out in beds with 142 cm centers with the 142 cm treatment having one row in the center of the bed and 45 cm treatment row with three rows equally spaced on the bed. Figure 3 illustrated the field layout for both years. The plots were planted on June 2, 1973 and May 29, 1974. The plots size was 30.5 m square. The population down the row was held constant.

During 1973 and 1974 water was applied as needed by furrow irrigation on approximately a 10 day schedule with each plot irrigated separately. The exact irrigation schedules are listed in Table I. The amount of water at each application was monitored only to insure approximately equal application across the experiment.

In both years Milogard 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 fertilizer was applied at the rate of 280 kg/ha of actual nitrogen.

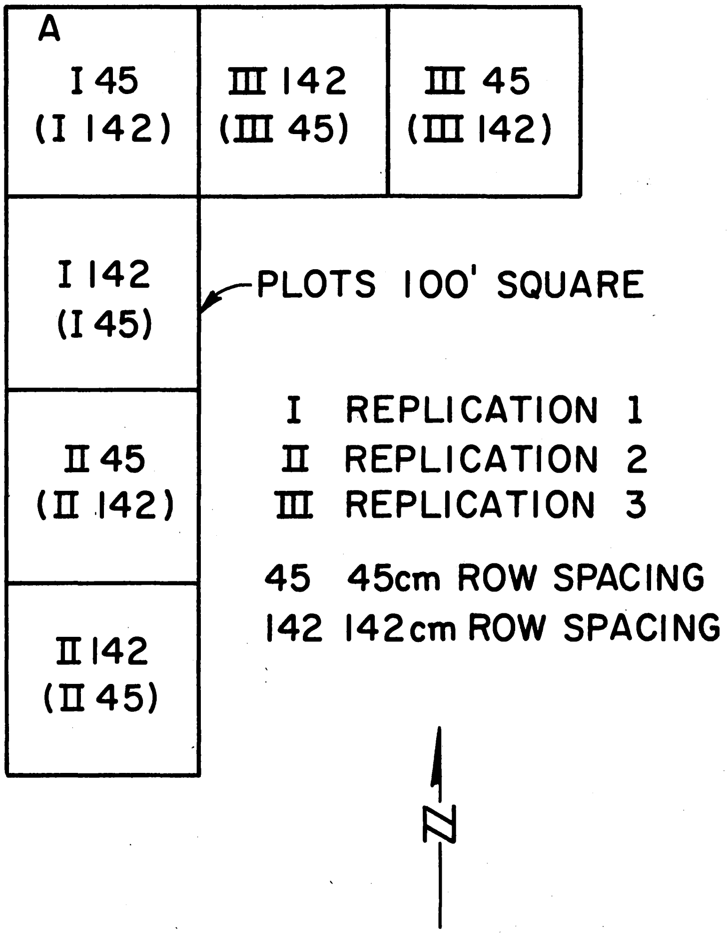

Figure 3. Field layout of 1973 and 1974 grain sorghum study. Number in parenthesis refer to 1969 study.

Water Budget

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

TABLE I

IRRIGATION SCHEDULE FOR PEANUTS AT FT. COBB AND GRAIN SORGHUM AT GOODWELL IN 1973 AND 1974

	Ft. Cobb		Goodwell	
	1973	1974	1973	1974
1	July 20	June 25	May 14-15	March 7
2	Aug. 1	July 8	June 15-16	June 17-21
3	Aug. 10	July 12	July 17-20	
4	Aug. 17	July 19	Aug. 15	July 16-17
5	Aug. 24	July 26	Sept. 5	
6	Aug. 31	Aug. 9		
7	Sept. 7	Aug. 16		
8		Aug. 23		

As indicated earlier it is necessary to correct this value for downward water loss. Water flux across and accumulation in the 120 to 150 cm layer were used to estimate downward loss. Near the end of the season it is 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 soil water neutron probe. While the flux across and the accumulation in the 120 to 150 cm layer were determined from the tensiometer and pressure versus soil water content relation. No attempt was made to account for runoff or evaporation from the irrigation or rainfall. For this reason only periods which included small or low intensity rainfalls could be used. The runoff would be more critical at Ft. Cobb where there were no borders for furrow irrigation as at Goodwell.

In the 1973 and 1974 at Goodwell and 1973 at Ft. Cobb a neutron scattering soil water probe (Nuclear Chicago P-19) was used to determine the soil water content of the 120 cm profile. For the 1974 study at Ft. Cobb two locations in each plot were monitored for soil water content with 24 access tubes being used in the total study. A modified p-19 probe was developed to reduce time of measurement. The probe was modified by replacing the source in a p-19 probe with a 238 Pu:Be source having 10 times the previous neutron flux. The probe was equipped with a rapid lowering device to decrease the time to change depth and a larger safety shield. Because of the new source a different high speed scaler was used. With this modified probe it was possible to take counts of only 5 seconds, instead of the usual one minute counts using the standard probe, with the same error in soil water determinations. The access tubes for the entire experiment could be read in 1.5 hours.

The tensiometers used in the study were constructed in the laboratory and were similar to those described by Perrier and Evans (25). The installations consisted of a tensiometer placed in the plots

4.5 m from the leeward side (north end) of the plots and a mercury manometer was mounted on a meter stick stake placed at the edge of the plots. The tensiometers were connected to the manometers by 4 mm O. D. nylon tubing. This tubing was covered with soil to help deter rodent damage and to prevent error which might have been introduced from thermal expansion of the water in the nylon tubing.

At both locations and in both years the tensiometers were reprimed whenever an air bubble appeared at the top of the tensiometer and always before each irrigation. The Ft. Cobb study had the advantage of an extra tensiometer at 90 cm to use in case either the 120 or 150 cm tensiometers became inoperative. If a tensiometer at Goodwell or more than one at Ft. Cobb 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 little error as they were rarely inoperative more than one day. Special care was taken during the later part of the growing season to keep all tensiometers working. Three tensiometers were installed in each plot at Ft. Cobb because of a severe problem with rodents in previous studies.

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

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

where

ET = evapotranspiration
H = water loss by neutron determination
q = flux across the 120 to 150 cm layer
C = change in water content of the 120 to 150 cm layer
R = rainfall

The water loss H was determined from the difference in the soil water content as determined with the neutron probe after one irrigation and before the next irrigation and 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 2 probe reading the exact amount of irrigation water applied and that lost by evaporation or runoff need not be taken into account. The use of the two probe readings relate only to the moisture that was lost either by evapotranspiration or deep percolation from the 120 cm profile.

The flux across the 120 to 150 cm layer q was determined from the Darcy Equation:

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

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:

Goodwell $K(\text{cm/day}) = 3.069 \times 10^{-8} \exp(48.174\theta)$

Ft. Cobb A $K(\text{cm/day}) = 9.63 \times 10^{-5} \exp(43.98\theta)$

B $K(\text{cm/day}) = 3.267 \times 10^{-5} \exp(37.62\theta)$

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. (9). The soil water pressure versus θ relation was determined using undisturbed 7.6 cm cores in the laboratory. The two locations at Ft. Cobb noted A and B in Figure 1 were used to characterize the soil. Upward flux is designated by a negative sign.

The change in water content of the 120 to 150 cm layer, C, was determined from tensiometer data since the neutron probe was read to only 120 cm. The 120 to 150 cm layer has been neglected in most studies but could result in considerable error over the period of time between irrigations. The procedure used to estimate C was used to calculate the average water content for the 120 to 150 cm layer using the soil water pressure data and the pressure versus θ relation. The change in θ from one day to the next was calculated. The change in θ was then multiplied by 30 cm to get the amount of water that moved into or out of this layer.

Rainfall R was measured at both research locations in 1973 and 1974. Periods with little or no rainfall were selected so the assumption that all rainfall entered the soil could be made with very little error. Periods with high intensity rainfall were discarded completely because the runoff was not determined.

Goodwell

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 120 cm tensiometer was located nearest to 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. The irrigation schedule is listed in Table I.

Ft. Cobb

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 making it about 1.5 m between the two access tubes.

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. Water was applied at approximately every seven days. The exact irrigation schedule for both years is indicated in Figure 1.

Aerodynamics

The aerodynamic study was conducted at Ft. Cobb during 1974 on

August 13, 14, 15, and 16. The study consisted of measuring the wind speed at 30, 80, 130, and 180 cm above the top of the plant canopy. The anemometers used in this study were constructed in the laboratory and were similar to the light interruption type described by Fritschen (16). The main difference was that the light interruption device used gave two pulses per revolution compared to one pulse in the device described by Fritschen. The anemometers were calibrated in a wind tunnel equipped with a pitot tube for wind speed determination. The model of the form W = a+bP where P is pulse per second and W is the wind speed was fitted to the data using the least squares method. First, second and third degree equations were tried but the best results were obtained with first degree equation. The calibration was W = 1.2937 + 3.728 P. All 51 anemometers 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 with analog output. The circuit had a time constant of approximately seven minutes. Forty-eight of these circuits were built, one for each anemometer deployed in the field. These circuits were calibrated using a Beckman 9054 pulse generator and Non-Linear Systems MX-2 digital voltmeter. Regression analysis using least squares method was used to fit the data to a model of the form P = c+dV where V is output voltage and P is pulses per second. Individual calibration equations were used to keep the error introduced from these circuits below 5 percent.

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 2K ohm thermistors (Fenwal type GB32P6) mounted in 50 cm intervals between the heights of 0.5 m and 4 m above the ground. These thermistors were calibrated in the laboratory against a National Bureau of Standards secondary thermometer that was scaled in increments of 0.1 C. Regression analysis using the least square 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, error could be held to ± 0.1 C.

Energy Budget

The energy budget study was conducted at Ft. Cobb 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 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 in the literature review an assumption is generally made that the soil heat flux component usually accounts for less than three percent of the net radiation. Thus the heat flux term can generally be neglected especially after the crop canopy shades the ground. Since peanuts have rather high leaf area index (visually estimated at greater than 3.5) the ground became completely shaded early in August. Thus the soil heat flux term was neglected.

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 (12, 13, 15) with the modification described by Idso (20, 21). 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, and thus had higher sensitivity than the Fritschen units. The net radiometers were calibrated in a box similar to that described by Fritschen (12, 13). Four Thornthwaite net radiometers were used to measure radiant flux inside the box. The Thornthwaite net radiometers were used as standards and had been individually factory calibrated. 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 three percent variation from the Thornthwaite net radiometers. Test for linear response was conducted by reading the net radiometer in the chamber then inverting them to achieve negative flux of the same value. It was found that it could be assumed that the calibration curve passed through the origin with less than three percent error from the Thornthwaite net radiometers. Regression analysis by the least squares method was then used to fit data with the model Rn = aV where V equals voltage output and

Rn is net radiation. It was found that the error from the net radiometer data would be less than 5 percent if separate calibration curves were used for each net radiometer.

The sensible heat flux H and the evaporative flux E cannot be individually determined in the field unless eddy diffusivities for heat and water evaporation are known. Commonly E and H are determined jointly by using the Bowen Ratio:

$$\beta = \frac{A}{E} = \gamma \frac{(\Delta T)}{(\Delta e)}$$

where

β = Bowen Ratio
γ = psychrometric constant
ΔT = temperature difference
Δe = vapor pressure difference

A self aspirated instrument to determine the Bowen Ratio was constructed. This instrument was designed to sample air from two separate heights and draw the samples across humidity and temperature sensors. A 2K ohm thermistor (Fenwal Type GB32P6) was placed in one air stream for temperature determination. A 40 junction thermopile was located in a position such that the top face was in contact with the upper air stream and the bottom face was in contact with the lower air stream. The thermopile measured the temperature difference between the two heights. Lithium chloride cells were placed in each air stream to determine the vapor pressures. The lithium chloride cells were calibrated in a closed system against a Cambridge Systems model 880 thermoelectric dew point hygrometer. Regression analysis by the least squares method was used with the model VP = $B_0+B_1V+B_2V^2+B_3V^3+B_4V^4+B_5V^5+B_6T$ where T is the temperature, V is voltage and VP is the vapor pressure. All 24 lithium chloride cells fit one calibration with r^2 of 0.98. The coefficients were B_o, -19.9843; B_1, 49.865; B_2, -138.9553; B_3, 181.2930; B_4, -105.5740; B_5, 22.4801; B_6, 1.1795. The coefficient of variation of regression was 1.44 percent over the entire range of vapor pressure (10 to 50 mb). Checks were conducted on the variation at three points over the calibration range. The vapor pressures checked were 10, 25, and 50 mb and the coefficient of variation at these points were 3.1, 2.1 and 4.4 percent respectively. The measurements were assumed to be valid over the range of calibration to 5 percent.

The thermopile used to measure ΔT was calibrated by exposing each side to various temperatures. Copper-constantan thermocouples were used to determine the temperature of each surface, and two thermocouples in series to determine the temperature difference was used as a check. Regression analysis by the least squares method was computed using the model DT=a-bV where V is voltage and DT is temperature difference between the two surfaces in degrees centigrade. To keep the error below the three percent level it was necessary to use individual calibration equations for each thermopile.

By combining the energy balance equation with the Bowen Ratio another estimate of evapotranspiration can be obtained. The equation that arises from this combination is as follows:

$$E = \frac{Rn}{L(1+\beta)}$$

The estimates of evapotranspiration obtained from this equation were used to compare to the estimates from the water budget portion of the study. Several other variables were monitored to relate to the energy budget. Solar radiation was monitored during the periods that the energy budget was calculated. A Kipp and Zonen solarimeter was used. The solarimeter was mounted on a platform 1.5 m above the ground which was located approximately 45.7 m east of the northeast corner of plot IN30 in Figure 1. This location was chosen because it provided an unobstructed southern exposure and was the 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 of a southernly component.

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 Lambda Instrument Company diffusive resistance meter with a tubular sensor as described by van Bavel et al. (43). The diffusion porometer was calibrated in the laboratory as described by Kanemasu et al. (22).

Data Acquisition System

The aerodynamic characteristics and the energy balance are necessary components to gain insight into an evapotransipiration study. But for either parameter to have any meaning the measurements must be effectively measured 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 an insurmountable 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 Computer Automation Incorporation model Alpha 16 minicomputer. The acquired data were then recorded both on a Computer Automation, Inc. cassette system and printed out on a Teletype model (ASR 33 teleprinter). This system was programmed to scan the instruments every ten minutes over the period of interest. This system was very satisfactory and made a very close approach to theoretical instantaneous readings in that the system can scan 96 different inputs in approximately eleven seconds. The system was equipped with a Monsanto Electronics, model 505A digital clock that was set to CDT, this clock controlled the scan interval.

TABLE II

PEANUT CROP AND NET RADIOMETER HEIGHTS IN 1974

	1974 Peanut Study	
Plot	Crop Height (cm)	Net radiometer Height Above Crop (cm)
1 E 30	41.5	108.5
1 N 30	49.0	101.0
1 E 90	51.7	98.3
1 N 90	48.0	102.0
2 N 90	51.5	98.5
2 E 90	44.8	105.2
2 E 30	66.8	83.2
2 N 30	52.9	97.1
3 E 90	59.1	90.9
3 N 30	56.5	93.5
3 N 30	57.8	98.2
3 N 90	50.0	100.0

CHAPTER IV

RESULTS AND DISCUSSION

Yield

Ft. Cobb

As can be seen from Table III in 1973 the highest yield was exhibited by the north-south 30 cm rows. The lowest yield was jointly from the 30 and 90 cm spacing plots of east-west orientation. The treatment yields were different at the 8 percent significance level. The higher variance may have been due to root suppression from horsenettle in three plots. The plots affected by horsenettle were treatments E 30 and E 36 in replication 1 and treatment E 30 in replication 2. The fact that two of the east-west 30 cm plots were suppressed could account for the low yield from this treatment.

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 III show the same results reported in the literature (6, 33) in that narrow rows produced the highest yields. There was a difference in yields between the treatments at the 2 percent level of significance in 1974.

Goodwell

In 1973 and 1974 the narrow-row plots had the highest yields. The treatment yields were different only at the 35 percent level of significance in 1973 and at the 6 percent level of significant in 1974. Plants in the wide row plots and the center row on the 140 cm beds of the narrow plots matured earlier than plants in the rest of the narrow plots. The differences in maturity resulted in differential bird damage in both years. The bird damage may have contributed to the level of significance of treatment yields in 1973. An attempt was made to compensate for the bird damage in 1974. Instead of harvesting one row as in 1973, two nonadjacent rows near the east-west center of the plots were harvested.

TABLE III

YIELD OF PEANUTS AT FT. COBB AND GRAIN SORGHUM AT GOODWELL IN RESPONSE TO ROW ORIENTATION AND SPACING

Location	Treatment (row orientation and spacing)	Kg/ha 1973	Kg/ha 1974
Ft. Cobb	E 30	2812	3185
	N 30	3964	3032
	E 90	2812	2101
	N 90	3134	2558
	LSD(.05)	681	411
Goodwell	45	8009	7614
	142	7602	5923
	LSD(.05)	1772	1039

Water Use

Goodwell

There were three periods in 1973 when evapotranspiration (ET) could be calculated by the equation (page 23) described in the literature review. These periods are illustrated in Figure 5 and can be recognized as the time periods during which the soil water content continually decreased. The various profile water contents diverge and converge at different periods of the season, but the graphs never cross throughout the season. Both treatments gained soil water over the season. Figure 4 shows that only the last period was free of rainfall. The rain fell in such amounts and intensity that there should have been no runoff. This assumption is no doubt valid since the plots were bordered for furrow irrigation.

Table IV lists the ET rate and ratio between treatments from the water budget data. The narrow-row treatments used the least water in each of the periods. The treatment differences during the period for the first part of August were significant at the 10 percent level. The treatment differences for the other two periods would be significant only at approximately the 50 percent level. From Table IV it can be seen the late July period exhibited the widest treatment differential in ET. During this period the narrow rows used approximately 75 percent as much water as the wide rows. The period covering the first 16 days of August had the highest ET. During this period the narrow row treatments used approximately 17 percent less water than the wide rows. The period in the later part of August had the lowest ET. The narrow

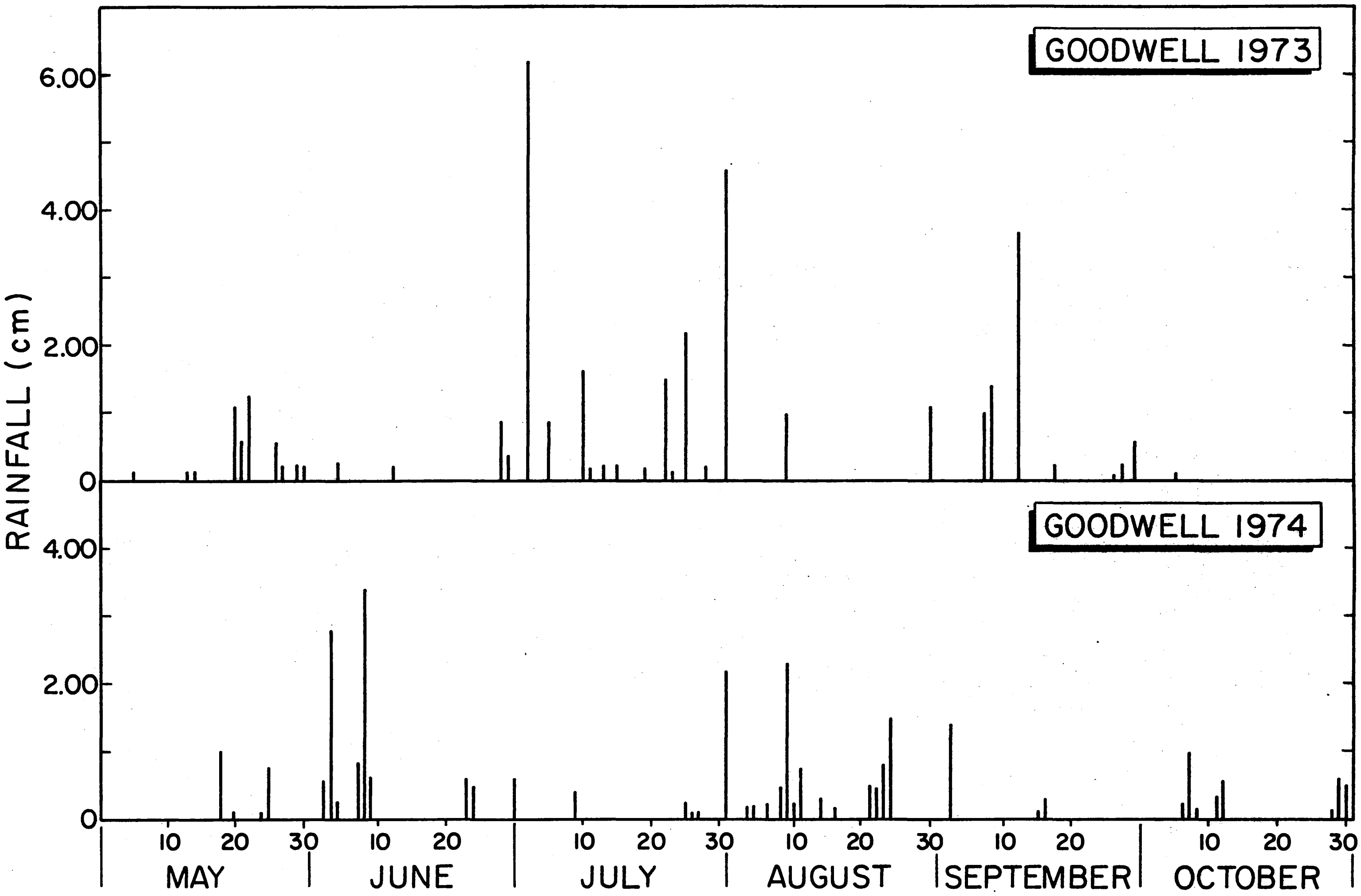

Figure 4. Precipitation pattern, Goodwell, Oklahoma, 1973 and 1974.

TABLE IV

EVAPOTRANSPIRATION FROM THE WATER BUDGET FOR THE GRAIN SORGHUM ROW SPACING STUDY, 1973 AND 1974 GOODWELL, OKLAHOMA

Date	Period	Row Spacings 142 cm Daily	 45 cm Daily	Ratio 45:142
1973	July 23-27	.255	.17	.67
	Aug. 1-15	.244	.202	.83
	Aug. 20-28	.163	.14	.86
1974	Aug. 2-5	.395	.589	1.49
	Aug. 5-14	.627	.426	.68
	Aug. 14-20	.488	.389	.80
	Aug. 28-Sept. 4	.300	.410	1.37

rows treatments used approximately 17 percent less water than the wide rows. The 45:142 ratio of ET in both years during August was approximately equal, although the ET rates themselves were widely different. The first period in August in 1973 had the highest ET rate of the season and the third period in August of 1974 had the lowest ET rate of the season.

Measured ET is often compared to potential ET (5, 28, 29, 31) for characterization of treatment effectiveness. Potential ET is a composite term of the general meteorological conditions and assumes that soil water conditions are not limiting. Only part of the components of potential ET were monitored during this study. Estimated evaporative demand will be used here in a subjective composite of solar radiation (cloud cover), temperature and wind. Evaporative demand will be referred to as demand. Pan evaporation is another composite term that can be measured encompassing much the same meteorological factors as potential ET and demand. The measured ET for both locations in 1974 will be compared to the demand. The measured ET at Goodwell for 1973 will be compared to both the demand and the pan evaporation. Table V lists the meteorological conditions during the three periods of 1973. In the period July 23 to 27 demand was the lowest. The average conditions were maximum temperature 30.30°C, pan evaporation 0.93 cm/day and wind 115.1 km/day at pan height. The most severe conditions during this period occurred on July 25 with a pan evaporation of 1.68 cm/day and this one day greatly influenced the average. The average ET was considerably less than the average pan evaporation. This is seen by the ratio of ET to pan evaporation: wide 0.22 and narrow 0.15. The demand during the second period was slightly greater than the first period.

TABLE V

METEOROLOGICAL DATA 1973 PANHANDLE RESEARCH STATION GOODWELL, OKLAHOMA

Date	Maximum Temperature(°C)	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	59.6	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

The average conditions during this period were maximum temperature 31.2° C, pan evaporation 0.88 cm/day and wind 78.9 km/day. The evaporation ratio for this period was wide rows 0.26 and narrow row 0.21. The last period was one of extreme demand. The average conditions during this period were maximum temperature 36.4° C, pan evaporation 1.22 cm/day and wind 193.4 km/day. Every day during this period the high temperature was over 32.2° C; 3 days had a high temperature of over 37.8° C. The evaporation ratio was much lower during this period: wide row 0.12 and narrow row 0.1.

The strong relationship between net radiation and ET has already been noted in the literature review. The net radiation above the crop will follow very closely the pattern of total radiation. The demand of the periods is further influenced by the cloud cover. This will greatly reduce the net radiation and energy available for ET. In the second period only 2 of the 14 days had complete cloud cover and half of the days had clear skies. Every day in the last period had clear sky conditions.

In the first two periods the ET rate followed the pattern that might be predicted from the demand analysis. As the demand conditions increased, the ET rate increased and the narrow to wide treatment ratio of ET decreased. The third period did not follow the pattern that might be predicted from the meteorological data on the first observation. The third period had the most extreme demand although the ET rate was the lowest of the three periods. An explanation for this could lie in the self protection mechanism of the plants. The demand during this period became so great that the stomates of the plants closed. When the stomates closed the transpiration decreased and the excess energy was advected from the plots in the strong wind. During this part of the season the soil surface was fully shaded. With the soil surface fully shaded transpiration will be the major fraction of ET. The greatest treatment difference in ET between narrow and wide plots occurred during the period of lowest demand. As the demand increased the narrow to wide treatment ratio of ET decreased.

Figure 6 illustrates the soil water content pattern for 1974. The patterns of 1973 (Figure 5) and 1974 were different. The frequent rainfall during the season kept the soil water content much more uniform than during the 1973 season. During the 1974 season both plots lost moisture. The wide rows lost slightly more water than did the narrow rows. During the 1974 season four periods were selected for ET calculation. The assumption of no runoff was made on the same basis as in 1973.

The ET rate and narrow to wide row spacing treatment ratio for 1974 are listed in Table IV. In 1974, unlike 1973, the wide rows used the lesser water in two of the four periods. The first and second period ET rates were significantly different at the 20 percent level of probability.

The third and fourth period treatment ET rates were significantly different only at the 25 and 40 percent levels, respectively. In the first and last periods the wide rows had the lowest ET rate. During the first period the wide rows used approximately 67 percent less water than the narrow rows. This period had the second lowest ET rate of the season for the wide rows. The ET rate for the narrow rows was the highest. In the periods from August 5 to 14 and August 14 to 20 the narrow rows used less water than the wide rows. The ET

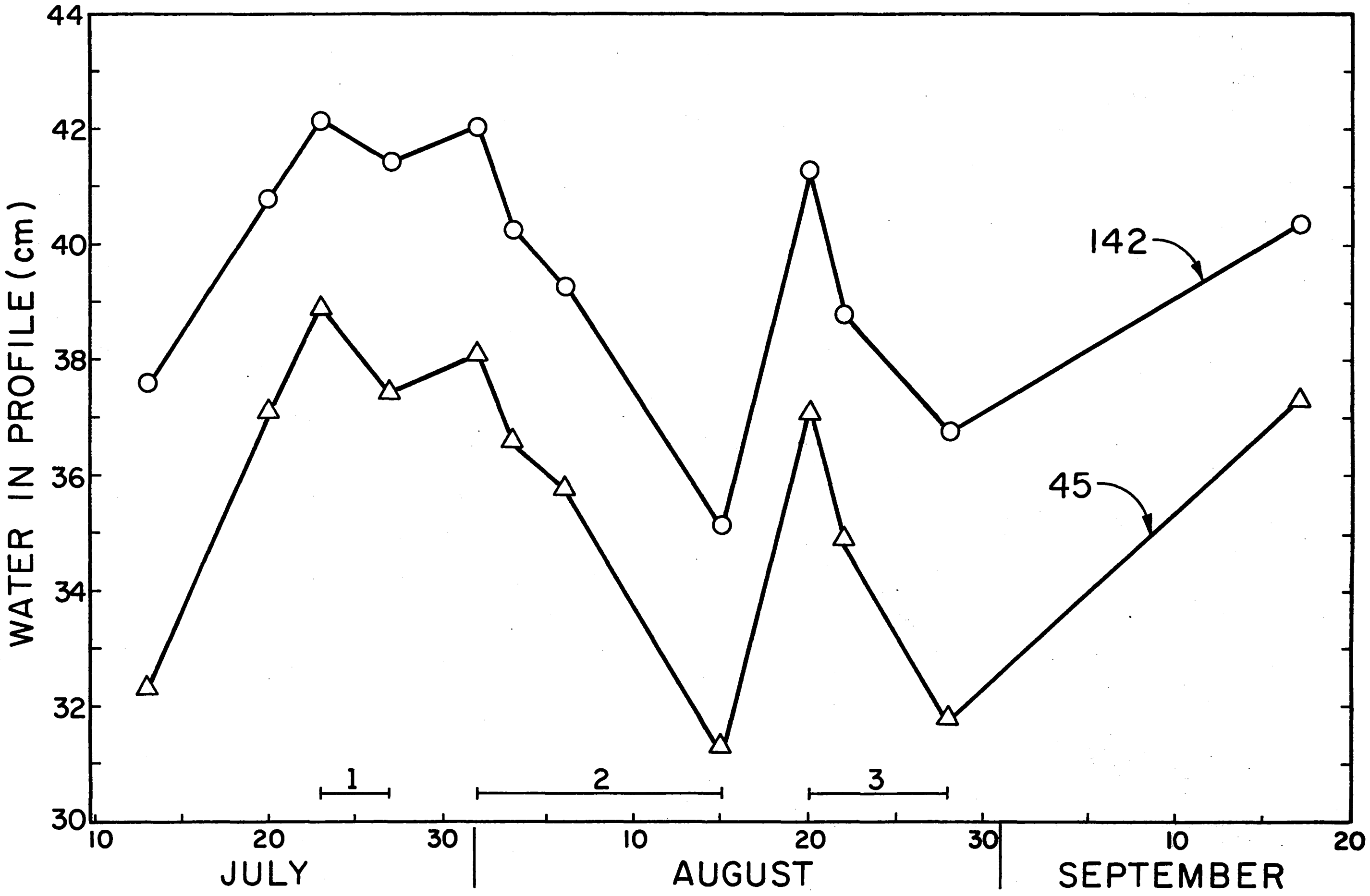

Figure 5. 1973 Neutron determined soil water content in the growing season.

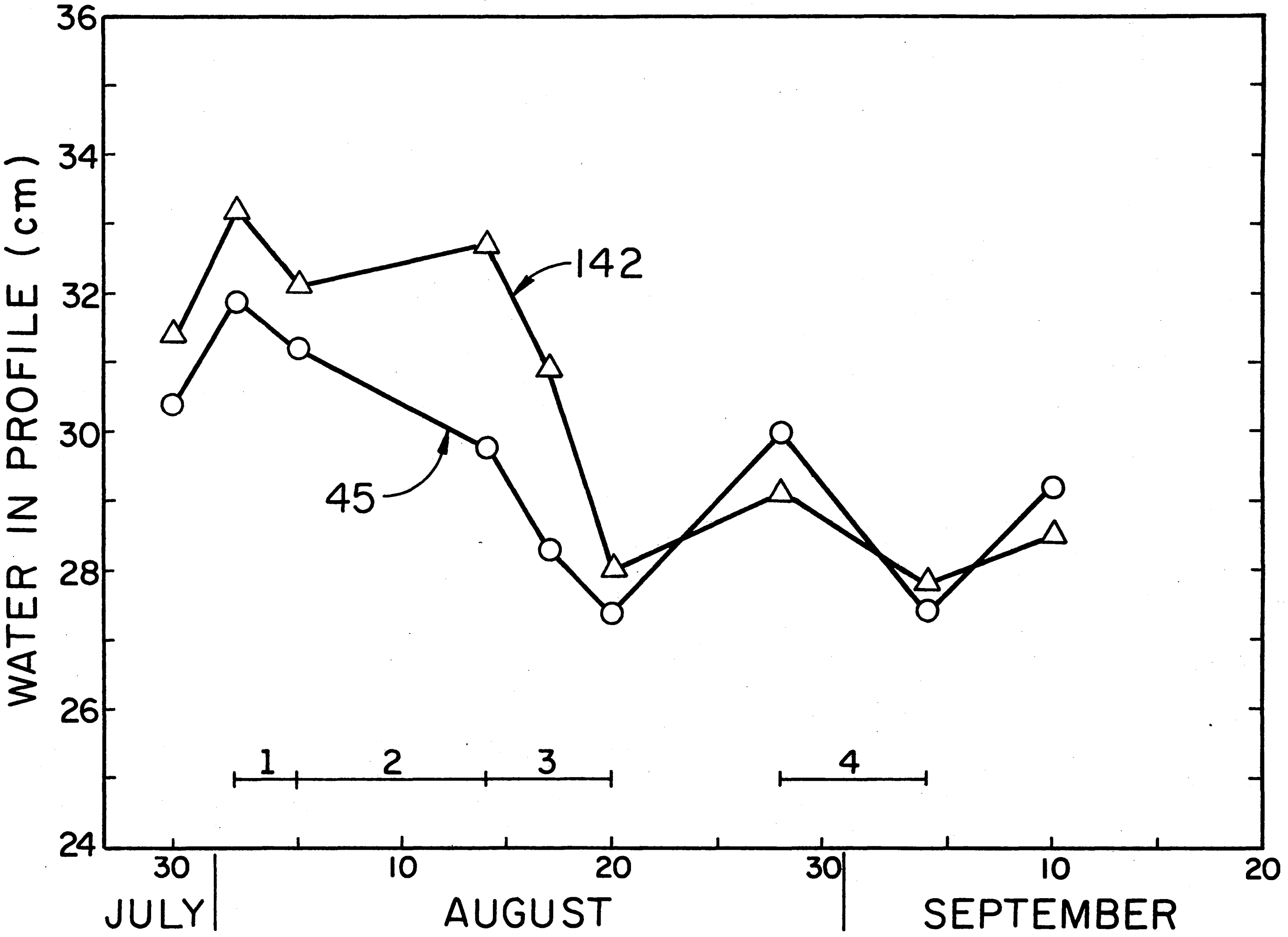

Figure 6. 1974 Neutron determined soil water content in the growing season.

rate for 1974 was considerably higher than in 1973. This was probably due to the higher rainfall during the periods of interest. The higher rainfall maintained the profile water content at a higher, more uniform level in 1974. In 1973 the soil water content of the 120 cm profile reached a much lower value before being irrigated. During these periods of low soil water content the plants probably became wilted, resulting in a lower ET rate.

The meteorological data for Goodwell in 1974 is listed in Table VI. During the first and last periods the maximum temperatures were unseasonably cool. Most of the days in these periods had some degree of cloud cover. These were periods of relatively low demand. The second and third periods of 1974 follow the pattern of the first and third periods of 1973. The second period of 1974 had a high ET rate and wide water use differential. The period was characterized by moderate temperatures. The average maximum temperature was 93.5° F, and approximately 80 percent of the days had clear skies. In spite of the moderately high demand conditions the water use rate declined. The decline was probably due to the plants closing their stomates.

The plots were in the 40 and 50 percent boot stage during the first and second periods of 1974. These were the periods when the highest ET rate occurred. During the third period the plots were in the soft dough stage. The lowest ET rate for the wide row plots and second lowest for narrow row plots was in the last period. The plots were in the hard dough stage and grain was showing color during this period.

TABLE VI

METEOROLOGICAL DATA 1974 PANHANDLE RESEARCH STATION GOODWELL, OKLAHOMA

Date	Maximum Temperature	Cloud Cover
Aug. 3	31.7	Cloudy
4	20.6	Clear
5	26.7	P. Cloudy
6	31.1	Cloudy
7	23.3	Cloudy
8	28.3	Clear
9	30.0	Clear
10	27.2	Cloudy
11	27.8	Cloudy
12	28.3	Cloudy
13	32.8	Cloudy
14	32.2	P. Cloudy
15	33.9	Clear
16	33.3	Clear
17	33.3	Clear
18	36.1	Clear
19	33.9	Clear
20	34.4	P. Cloudy
29	24.4	P. Cloudy
30	28.3	Clear
31	31.7	Clear
Sept. 1	28.3	Cloudy
2	21.7	Cloudy
3	13.9	P. Cloudy
4	18.9	P. Cloudy

Ft. Cobb

Figure 8 illustrated the 1973 profile soil water content for the treatments averaged over replications. There were three periods for which ET could be calculated. Only the third period had no rainfall (Figure 7). Table VII lists the ET rate and relation to the other treatments for the four treatments. The narrow rows of north-south orientation (N 30) used less water than the east-west orientations of either spacing in all three periods. During the first and third periods the north-south oriented treatments used less water than the east-west oriented rows. Stone (33) has reported that the north-south wide rows usually use the most water. However in 1973 the E 30 treatment used the most water in every period. The first period had the lowest ET rate than during the second period the ET rate increased to it's highest peak of the season and then the ET rate decreased in the third period. Thus the ET rate followed the same seasonal trends as at Goodwell in 1973. No meteorological data was available for Ft. Cobb in 1973. Therefore no comparison between the ET rate and estimated demand was possible. The treatment differences of ET for the first period were significant at the 15 percent level. The treatment differences of ET for the other periods would be significant only at the 50 percent level.

Figure 9 illustrates the 1974 profile of soil water content for treatments averaged over replications. There were four periods for which ET could be calculated. All of the periods were free of rainfall (Figure 7). Table VII lists the ET rate and the relation between the four treatments. The treatment ET sequence was not as consistent over

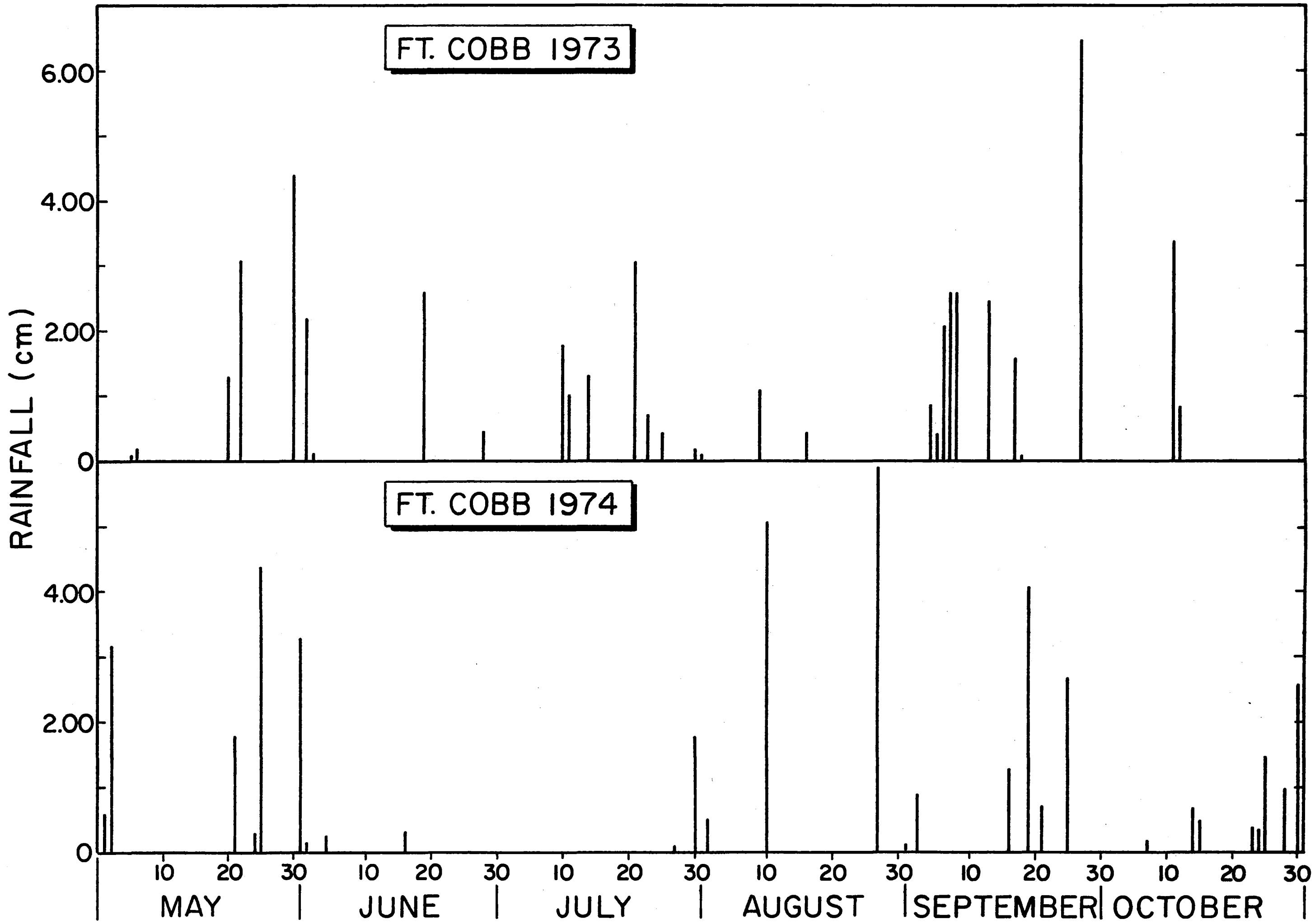

Figure 7. Precipitation pattern, Ft. Cobb, Oklahoma, 1973 and 1974.

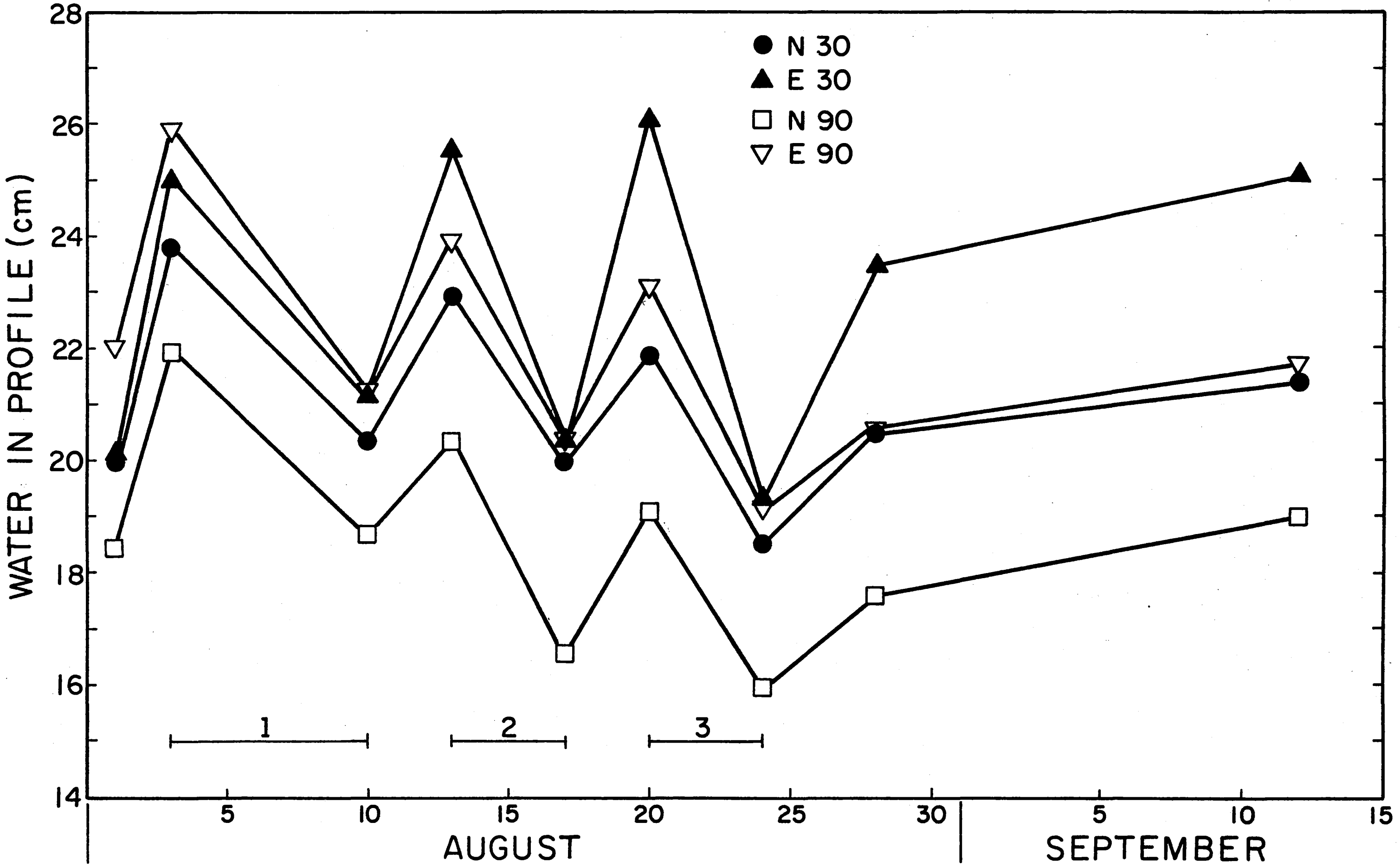

Figure 8. 1973 Neutron determined soil water content in the growing season.

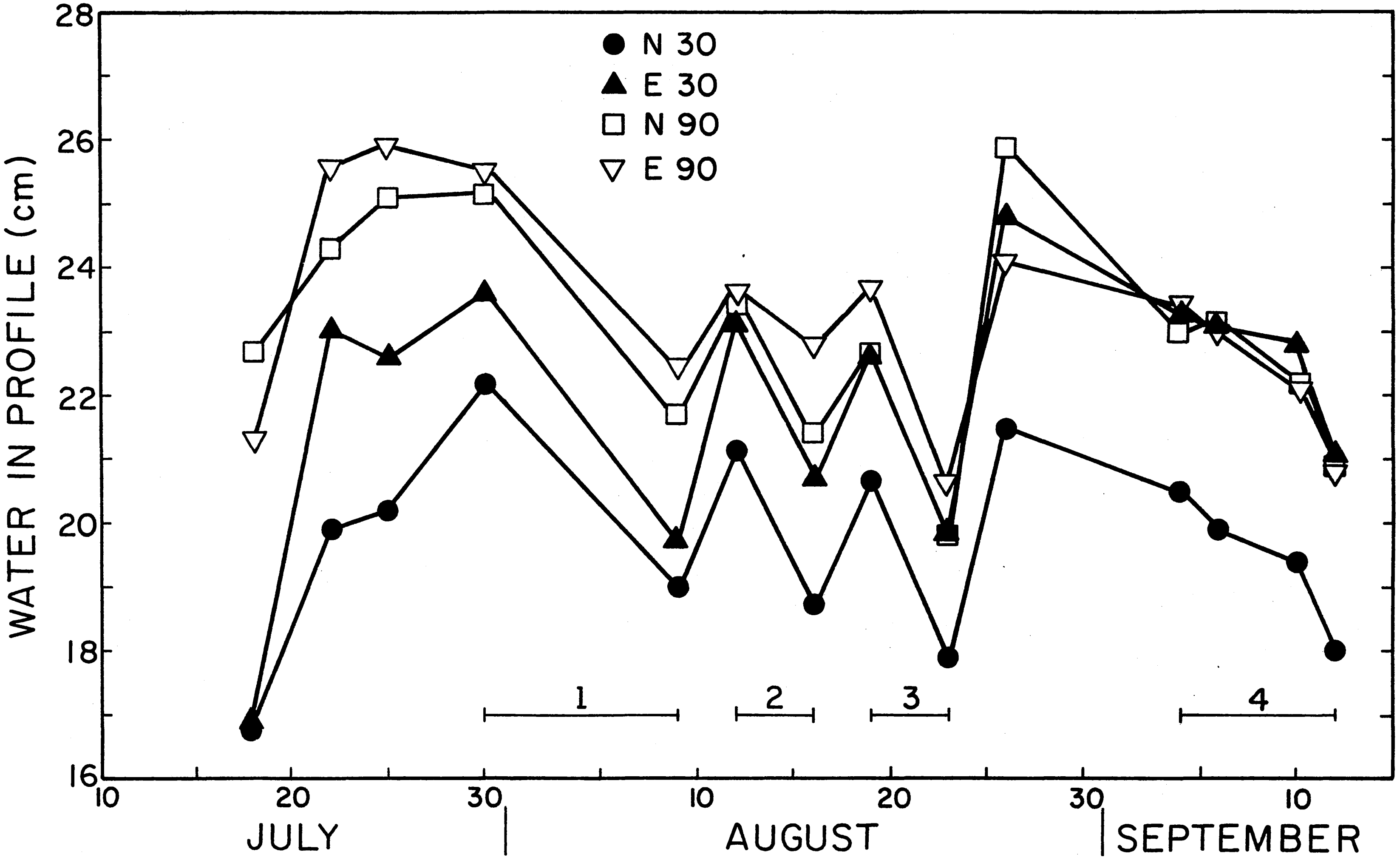

Figure 9. 1974 Neutron determined soil water content in the growing season.

TABLE VII

WATER BUDGET EVAPOTRANSPIRATION DATA FOR THE PEANUT STUDY, FT. COBB, 1973 AND 1974

	1973							
	Daily Rate				Treatment Ratio*			
Period	N30	N90	E30	N90	N30	N90	E30	E90
Aug. 3-10	.170	.165	.340	.236	.50	.49	1.00	.69
13-17	.242	.420	.726	.350	.33	.58	1.00	.48
20-27	.165	.144	.479	.203	.34	.30	1.00	.42
	1974							
July 30-Aug. 9	.314	.402	.415	.304	.75	.97	1.00	.73
Aug. 12-16	.500	.412	.542	.288	.92	.76	1.00	.53
19-23	.598	.594	.710	.718	.83	.83	.99	1.00
Oct. 4-12	.370	.307	.444	.321	.83	.69	1.00	.72

*1.00 being assigned to the Highest Value Within a Given Period.

the 1974 season as in 1973. The north-south oriented treatments had the lowest ET only in the third period. The third period had the highest ET rate of the four periods. In the second period most of the treatments had the second highest ET rate of the season, although the E 90 treatment in the second period had the lowest ET rate of the season for that treatment. In the first period the N 30 and E 30 treatments had the lowest ET rate of the season for those treatments. In 1973 and 1974, except for one period, E 30 had the highest ET rate of all the treatments. The third period was the only departure from this pattern. There was practically no difference between the narrow and wide spacing of east-west orientation in the third period. At Ft. Cobb as at Goodwell the ET rate was higher through most of the season in 1974 than in 1973. This may have been because of the higher average soil water content over the season. With the higher average soil water content the plants were not under periods of low soil water availability where the stomates would be expected to close. In 1974 the treatment ET differences for second period were significant at the 10 percent level. The treatment ET differences for the other three periods could be considered significant only at the 50 percent level.

The meteorological conditions during the periods in 1974 for Ft. Cobb are listed in Table VIII. The wind was southerly throughout the periods of ET calculations. The first period had a fairly low demand. This is the period of lowest ET rate. During this period the E 90 and N 30 treatments had the lowest ET. The fourth period 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. The second period has second highest demand and ET rate of the season. In this

TABLE VIII

DAILY METEOROLOGICAL, 1974, CADDO PEANUT RESEARCH STATION, FT. COBB, OKLAHOMA

Date	Wind Direction	Wind Speed (km/hn)	Relative Humidity (%)	Maximum Temperature
July 30	S	13.2	57.08	29.4
31	S	11.4	60.42	31.1
Aug. 1	SE	11.8	72.08	30.0
2	SW	12.4	60.04	28.9
3	SW	10.5	59.96	25.0
4	SW	8.2	60.96	31.1
5	S	15.6	72.58	25.6
6	SW	10.9	81.73	22.2
7	S	9.5	67.36	28.9
8	S	15.2	69.22	31.1
9	S	23.3	69.13	32.8
12	S	12.6	65.21	31.1
13	SE	12.1	66.62	32.2
14	SE	18.5	67.71	31.1
15	S	19.1	61.78	32.8
16	S	16.2	57.03	33.9
19	S	13.6	48.04	33.3
20	S	19.1	51.71	33.9
21	S	16.6	55.61	33.3
22	SE	11.5	62.29	33.3
23	E	13.8	73.29	26.7
Sept. 4	SE	7.8	64.76	21.1
5	SE	10.0	65.57	23.9
6	SE	12.1	65.61	24.4
7	S	6.4	60.88	27.2
8	E	9.8	65.91	27.8
9	SE	12.9	71.66	27.8
10	SE	7.5	79.29	26.7
11	S	20.4	71.47	31.1
12	NE	23.8	77.44	22.8

period the E 90 and N 90 treatments had the lowest ET rate. The third period 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. At Ft. Cobb, unlike Goodwell, there were no differences between the narrow and wide row spacing of north-south orientation during this period with highest demand.

In 1973 the narrow row treatment at Goodwell and the narrow north-south treatment at Ft. Cobb had the lowest ET. The results were in fairly close agreement with the findings reported in the literature review. The periods of 1974 did not support the same treatment ET sequence over the season observed in 1973. Several factors could have contributed to the 1974 ET rates. The most apparent is the abnormal meteorological conditions. There was more rainfall over the periods of interest in 1974. This is indicated by the fact that only three irrigations were required in 1974 at Goodwell (Table I). The temperature was also approximately 5 to 10° F below normal during the periods of interest.

Energy Budget

First Period

Energy budget measurements were obtained at Ft. Cobb on August 20 and 21 in the period August 19-23. The estimated average daily ET rate from the energy budget is listed in Table IX. The two days are considerably different as both days do not relate the same treatment ET sequence. August 21 completely reverses the treatment ET sequence of the water budget and the second day. The differences in water use on the first day were significant at the 10 percent level. The second day agreed with the treatment ET sequence from the water budget study. The treatment differences on August 22 were significant at the 6 percent level. When the results from the two days were combined to give a average daily ET rate. The results were significant at the 7 percent level. Looking at the average daily ET rate there is very good agreement with the water budget. The north-south treatments were in very close agreement with approximately 1 percent deviation between the two methods. The difference between the two methods was 6 percent for the E 90 treatment and 10 percent for the E 30 treatment. This is not as close as the 5 percent mentioned in the literature review but is satisfactory.

Figure 10 illustrates the net radiation Rn, solar radiation Rs and latent heat of evaporation LE for the treatments on August 21. The day was clear as can be seen from smoothness of the Rs data. The Rn for the treatments does not follow the order that would be predicted from the literature. The order observed from high to low was N 90, N 30, E 30, E 90. The E 30 treatment had a higher Rn than would have been expected from row spacing analysis. The row orientation did not have the effect that would be predicted from the work of Yao and Shaw (46). During the morning hours and after 1630, the LE followed the Rn very closely. But during midday LE falls below Rn. During midday when radiation is at its maximum, the plants possibly cannot maintain the high rate of transpiration and close their stomates. This has been described in the literature as the "midday depression". The N 30 treatment has a completely different LE pattern. For this treatment LE follows Rn closely before 1030 and after 1730. There are two

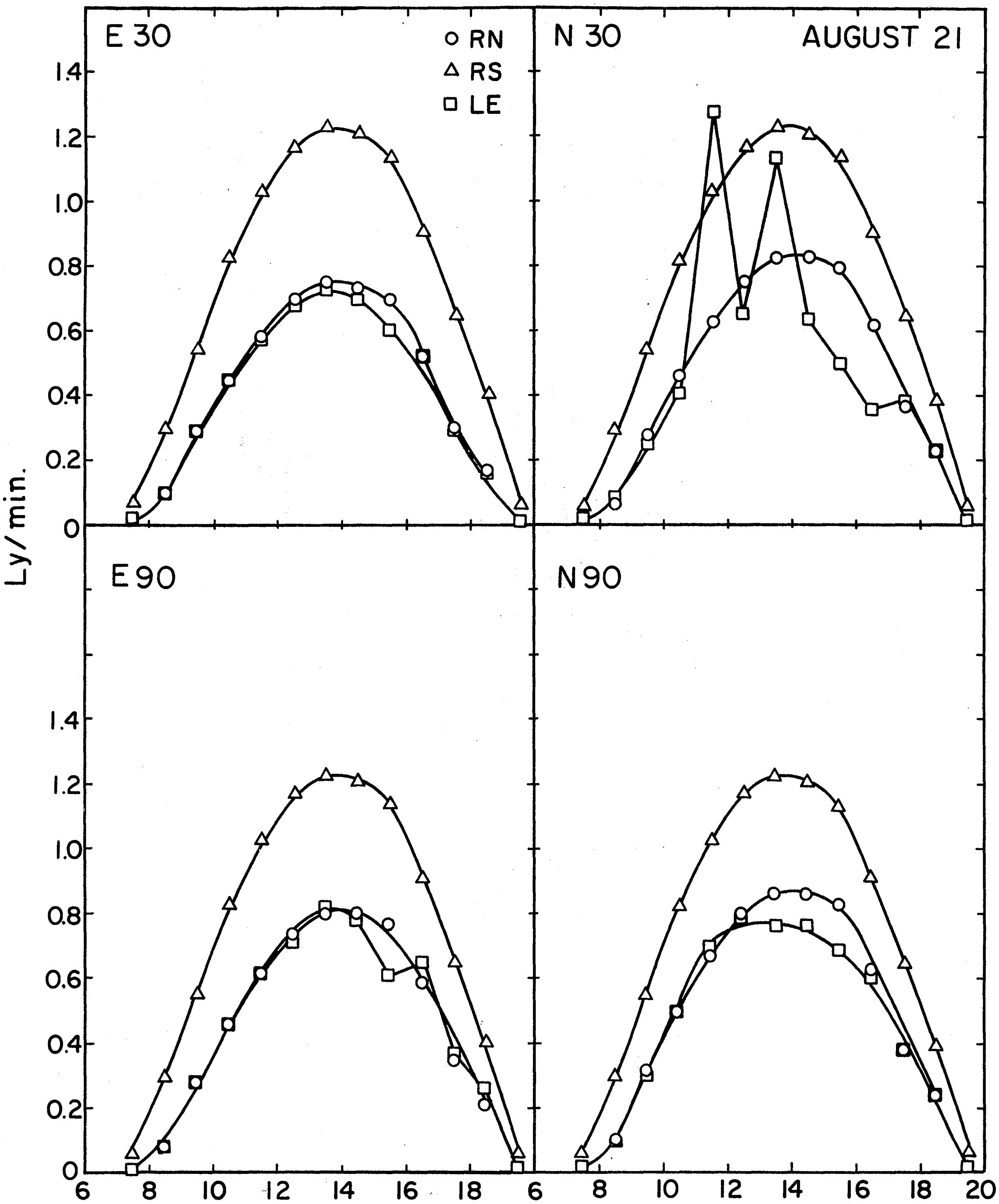

Figure 10. Solar radiation Rs, net radiation Rn and latent heat of evaporation LE for August 21.

periods of very strong advective energy where LE greatly exceeds Rn. As might be expected, in the period following a period of advected energy LE drops considerably below Rn. This drop of LE is possibly due to the plants reacting to the situation by closing their stomates. The stress was so great between 1030 and 1430 that the plants did not recover until 1730. From Figure 2 it is seen that there is at least one plot upwind of all the N 30 plots. This makes it very difficult to visualize why it should be the only treatment exhibiting the advective energy of this intensity. It is presumed to be real because both the action and reaction occur.

Figure 11 illustrates the Rn, Rs and LE for August 22. By looking at the Rs data it is seen that there was variable cloud cover through most of the day. The period of more cloud cover at 1130 and 1530 are reflected in the Rn and LE data. Again Rn does not follow the order which might be expected with regard to row orientation. The pattern for August 22 from high to low Rn is N 90, N 30, E 90 and E 30. There is very little difference between the N 30 and E 90 treatments. For the east-west treatments, LE follows Rn closely through most of the day. The E 90 treatments indicate slight advective energy conditions from 1230 to 1330 and the subsequent depression of ET through the afternoon hours. In the N 90 treatment, LE follows Rn before 1230. For the remainder of the day LE falls below Rn. In the N 30 treatment advective conditions exist throughout the morning hours prior to 1315. Throughout the remainder of the day, after 1315, LE falls below Rn.

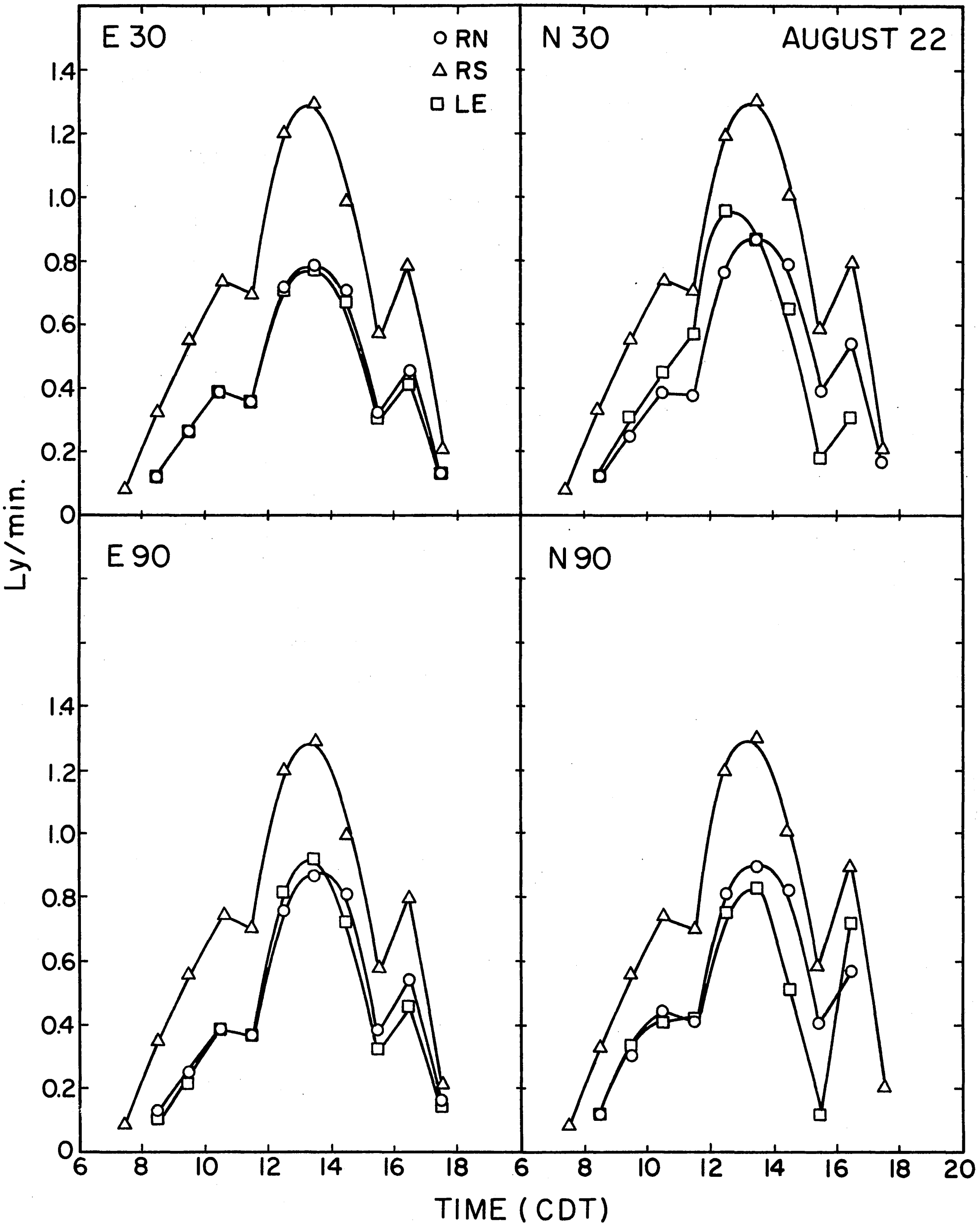

Figure 11. Solar radiation Rs, net radiation Rn and latent heat of evaporation LE for August 22.

Second Period

Energy budget measurements were obtained September 4, 5, 6, 11 and 12 during the period of September 4-12. Estimated daily ET rate and average daily ET rate are listed in Table IX. The average daily ET rate for the treatments from the energy budget did not agree closely with the results of the water budget. The energy budget and the water budget showed that the wide rows used less water than the narrow rows of either orientation. The two methods showed different treatments had the lowest ET. The energy budget ET values were different from the water budget ET values by as much as 22 percent for N 90, 16 percent for E 90 and 5 percent for the narrow treatments. The estimated ET for the treatments of September 4 were significantly different at the 3 percent level. The treatment ET differences for September 6 were significantly different at the 14 percent level. The values reported for September 4 and 12 are for only a half day. On these days the energy budget measurement began immediately after the soil water was read by the neutron probe. The values and order listed for September 4 look more like a typical day from the first period than the second. The significance level for the treatment differences was below 10 percent which is also true of the first period. It appears that September 5, 11, and 12 are transition days and treatments effects from these transition days would be significant only at the 14 percent on September 11 and less than 50 percent on the other two days. In fact it is hard to determine what pattern is developing for some of these transition days.

Figure 12 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 occurred in Rn. This is probably not real as only the last three 10-minute readings were available due to equipment problems. The Rn for N 90 and E 30 was 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. The post advective depression occurred as before 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. The post advective depression appeared to coincide with the midday depression, as 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 E 30 treatment, was 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 it did occur late in the day when 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 slight period of advective conditions existed. Then after 1545 LE again fell below Rn. The midday depression was quite apparent between 1230 and 1430. On September 5 as on August 21 part of the treatments exhibited varied degrees of advection during different periods of the day. On September 5, three of the four treatments experienced periods of advection of varing

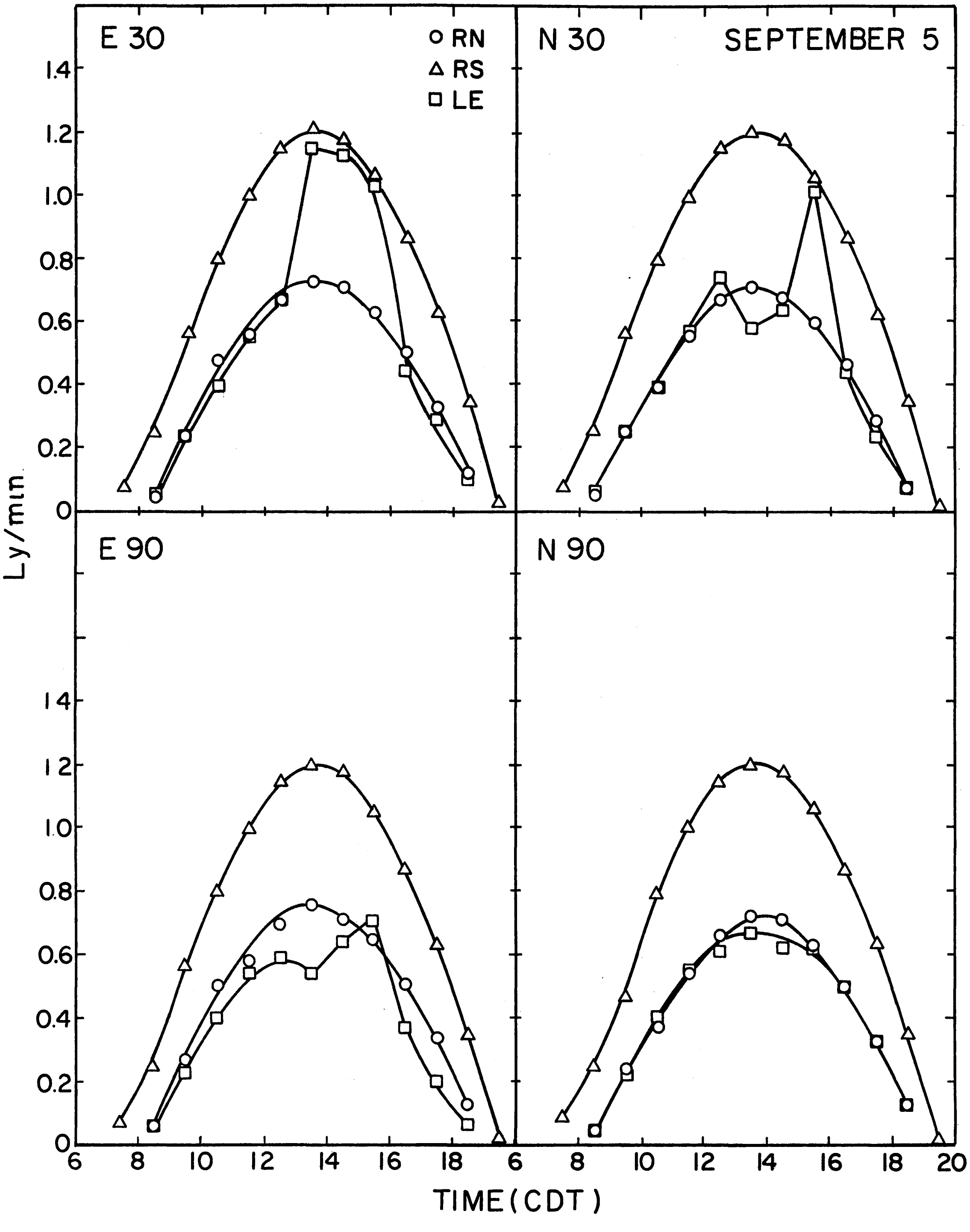

Figure 12. Solar radiation Rs, net radiation Rn and latent heat of evaporation LE for September 5.

intensities. Treatment E 90 had a strong LE depression centered at 1330. Following the LE depression there was a slight drop off 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 would cause a drop in Rn.

Figure 13 illustrates Rs, Rn and LE for September 6. This was another day with very clear sky conditions as can be seen from the data. The E 30 treatment had the highest Rn for the day with little differences in the other three treatments. Only slight periods of LE depression occurred at various times of the day for the four treatments.

Figure 14 illustrates Rs, Rn and LE for September 11. On this day clear sky conditions existed. N 30 treatment had the highest Rn while E 90 had the lowest. Rn 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.

Leaf Resistance

Leaf resistance (r_s) for one day in each period is illustrated in

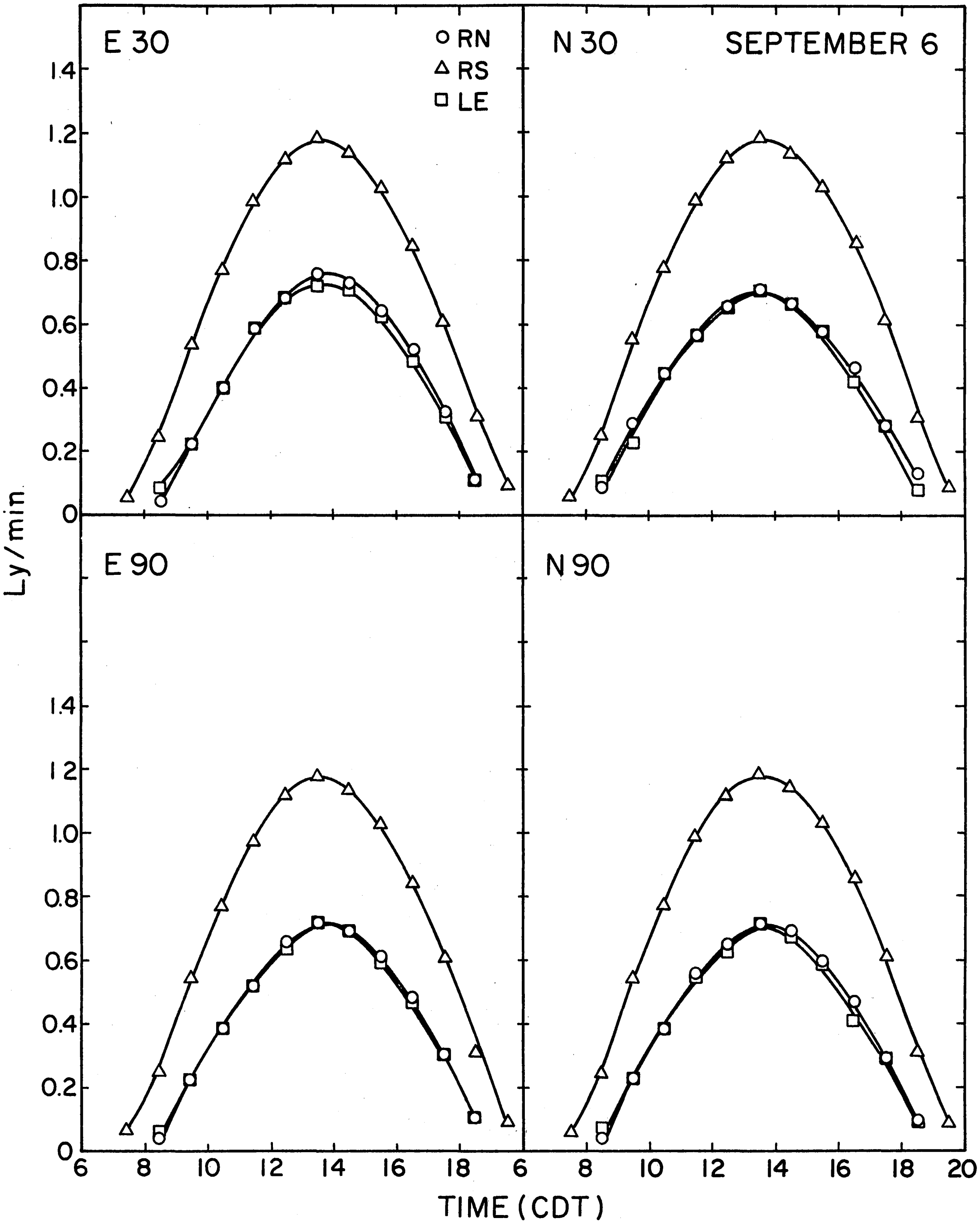

Figure 13. Solar radiation Rs, net radiation Rn and latent heat of evaporation LE for September 6.

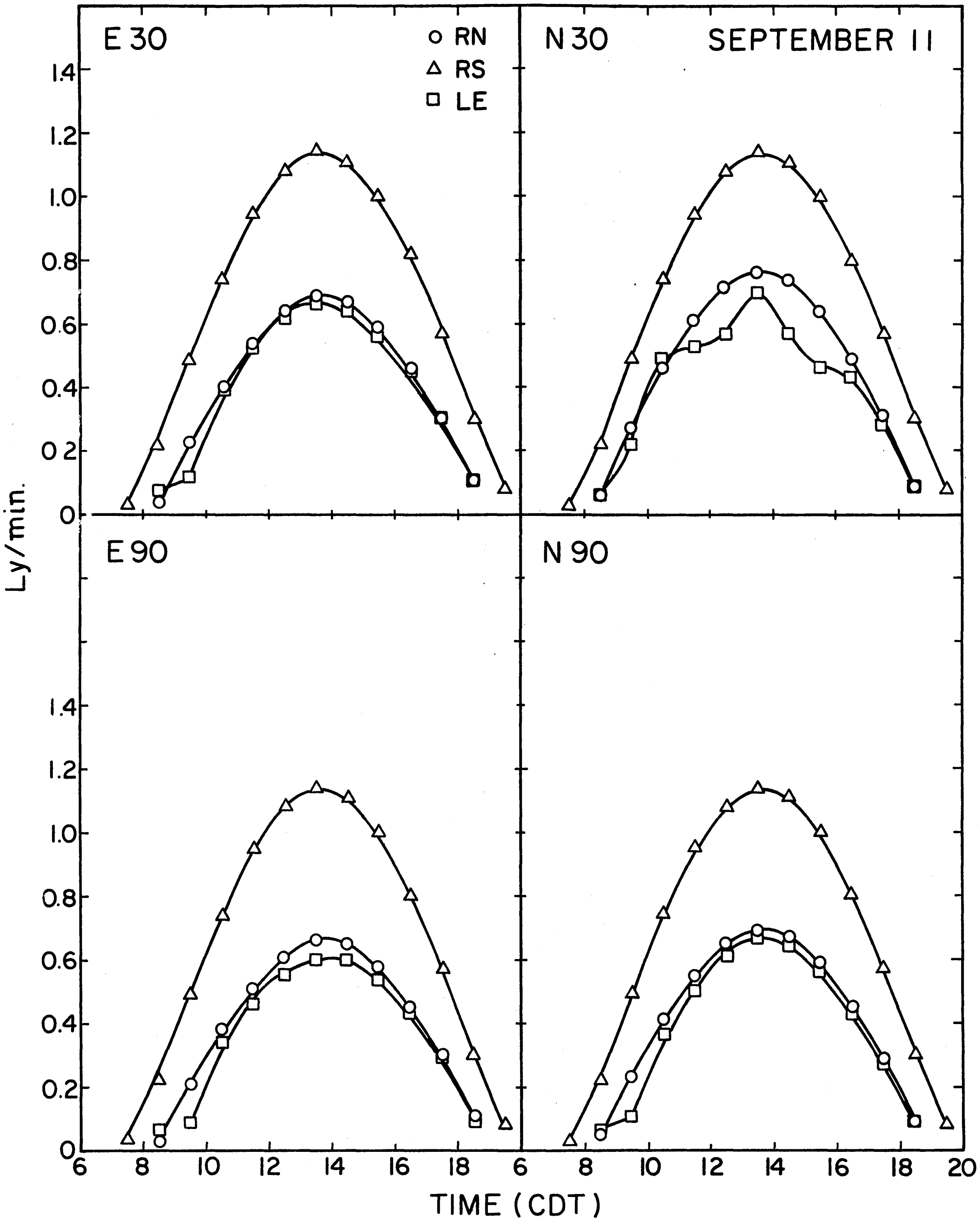

Figure 14. Solar radiation Rs, net radiation Rn and latent heat of evaporation LE for September 11.

Figure 15. The pattern of resistance estimated for each day were considerably different. The pattern for August 21 was smooth and showed only two sharp changes from one observation to the next. The r_s data (Figure 15) indicate the same treatment ET sequence as the water budget (Table VII) and energy budget (Table IX). The north-south oriented rows had the highest r_s for the period of highest transpiration around midday. On September 11 the wide row plots had the highest r_s during the mid part of the day. The r_s data for September 11 showed sharp changes in r_s from one measurement to the next. The data from both days indicates the r_s was negative during various periods of the day. This is not possible. It is believed the negative indications were due to lack of calibration points at low values of r_s. Refinement of the calibration method could be accomplished by the addition of more calibration points in this region. The calibration plate furnished with the diffusion porometer provided only 5 calibration points. The 5 calibration points were spaced such that a large gap existed in the lower r_s values.

The exact relation between transpiration from each plot and the r_s data would be hard to relate without leaf area index (LAI) measurements in each of the treatments. No attempt was made to determine the LAI. But the narrow plots will have a higher (LAI) than the wide row plots. The transpiration per leaf will be inversely proportional to the r_s. Then the r_s value for individual leaves illustrated in Figure 15 supports the treatment ET sequence from both other methods previously described (Table VII and Table IX).

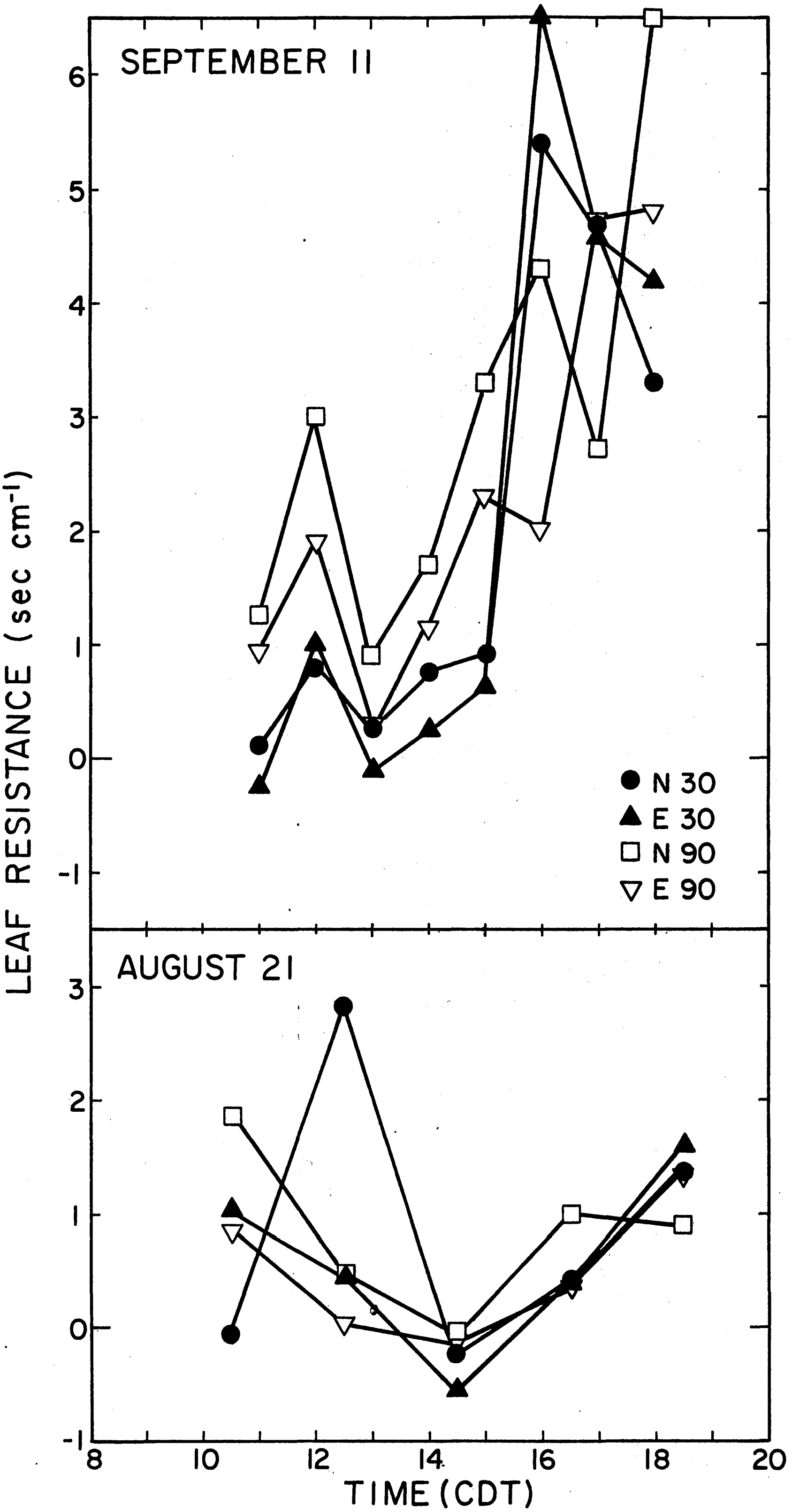

Figure 15. Leaf resistance data for August 21 and September 11.

TABLE IX

EVAPOTRANSPIRATION FROM THE ENERGY BUDGET STUDY, 1974, FT. COBB, OKLAHOMA

	E 30	N 30	E 90	N 90
Aug. 21	.57	.66	.60	.62
22	.71	.51	.75	.59
Average Rate	.64	.59	.68	.61
Water Budget	.71	.60	.72	.59
Sept. 4	.326	.301	.325	.301
5	.624	.513	.451	.488
6	.514	.489	.492	.483
11	.471	.462	.436	.466
12	.177	.162	.156	.139
Average Rate	.422	.385	.372	.375
Water Budget	.444	.370	.321	.307

Aerodynamic

Wind profile measurements were obtained during neutral conditions that existed for several hours before sunset on August 15. The Ri for this period was between 0.00001 and 0.03. The wind speed at 6 m during this period varied from 600 to 800 cm/sec from the south. The temperature in a Stevenson screen ranged between 89 to 92° C.

Typical wind profiles for the plots are illustrated in Figure 16. No allowance has been made for d(zero plane displacement) which should be in the order of 26 to 42 cm as estimated from the d prediction equation (page 7). The wind profiles do not fit the semi-log law discussed in the literature review. Any attempt to correct for d only results in greater deviation from the semi-log law. Because of the form of the wind profiles no estimate of z_0 can be obtained from the data. The maximum deviation that can be explained by equipment error was estimated to be less than 8 percent. Equipment error thus does not completely explain the deviation from the semi-log law.

Several different types of deviations are indicated in the profiles. These profiles are time averages of the 10 minute reading over a three hour period. Other length periods were tried from 30 minutes to 5 hours but this did change the general shape of the profiles. The N 30 profiles were anomalous in the top two observations. This type of profile would indicate that these anemometers were above the boundary layer or under severe lapse conditions. The height of the top anemometer was approximately 2.2 m. This is well below the boundary layer heights of 6.6 m as estimated from the boundary layer prediction equation (page 9). The top anemometer should be well within the boundary layer after accounting for any reasonable error in the equation. The critical values of Ri where lapse conditions prevail is -0.02. The values of Ri during the three hour period were all greater than zero. The E 30 and E 90 profile were anomalous in both the top and bottom anemometers. The deviation in the lower anemometers would indicate turbulent interference from the crop surface. The bottom anemometer was located 30 cm above the canopy. Combining the estimate of z_0

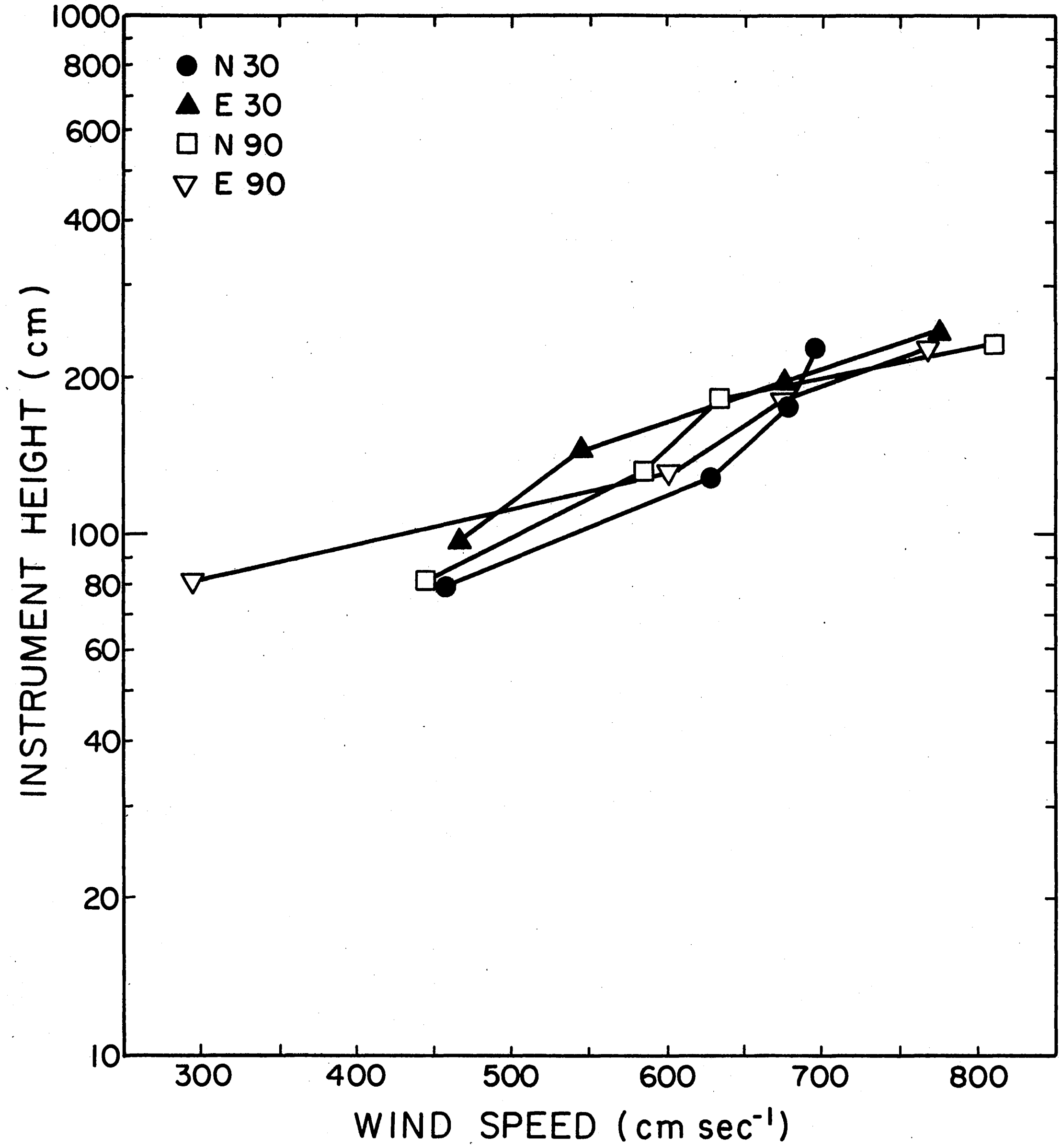

Figure 16. Typical wind profiles for August 15.

(approximately 6 cm equation page 8) and the general rule of 5 z_o indicates the lower anemometer could be placed as low as approximately 30 cm. The exact estimate was used to properly characterize the lower section of the profile. The profiles indicate that a 10 to 20 cm should have been added to the 5 z_o as a safety buffer. This would place the lower anemometer at 50 cm above the crop canopy. The top anemometer of the E 30, E 90 and N 90 show the same general characteristics. The data from the top anemometer in these plots indicates a much higher wind speed than would be predicted from the semi-log law. This type of deviation would normally occur at strongly stable conditions when the Ri value would be greater than .25. This is at least one order of magnitude greater than Ri observed during the period of measurement. Webb (44) reports similar results as those observed in these profiles. Webb found these deviations to occur only at values of Ri greater than .25 and at heights of 12 to 16 m. The wind during Webb's reported measurements did not exhibit the gusty nature observed during this study.

The general characteristics of the different treatment profiles (general slope and windspeed from Figure 16) indicated that there may be aerodynamic differences between treatments. All reports in the literature cited indicate that at least the top three aneomometers should have complied with the semi-log law. The combination of these two facts indicate that a more intensified study could be very productive. Some modifications that should be made are: 1) locate the lower anemometer at 50 cm above the crop canopy, 2) increase the number of observation points by placing an anemometer at 50, 75, 100, 125, 150, 175, 200 and 225 cm above the canopy, 3) place two thermistors on each mast for determination of Richardson's Number, and 4) use individual anemometer calibrations.

Evapotranspiration Period

Two types of periods have been mentioned in the preceeding sections. The two types are natural ET periods and investigator defined ET periods hereafter referred to as defined ET period. Natural ET periods are determined by the prevailing meteorological conditions. The ET rate will maintain a pattern as long as the meteorological conditions remain constant. As meteorological conditions change the ET rate will change and establish a new pattern. Between the natural ET perios where the ET pattern is clearly defined is a transition type natural ET period. The treatment differences in ET rate during natural ET periods is generally more significant than the treatment differences during the transition type natural ET period. The natural ET periods can be seen by examining the meteorological data (Table V, VI and VIII) and by examining the daily ET rate from the energy budget (Table IX). The treatment differences for August 21 and 22 are significant as described earlier. By looking at Table VIII it can be seen that these two days appear to be in the midst of a 5 or 6 day natural ET period. For September 5 no clear treatment differences exist. From Table VIII it appears that the meteorological conditions were changing. Thus August 21 and 22 would be in one of the natural ET periods while September 5 would be in one of the transition type natural ET periods. Comparing the natural ET periods at Goodwell (Table VI) to those at Ft. Cobb for 1974 (Table VIII) reveals that the same periods seemed to exist with a time lag between the two locations. The meteorological conditions were also moderated at Ft. Cobb. The natural ET periods can be of short duration from one to several days in length.

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 the third period of 1974.

For the 1973 study, Tables IV and VII show that the same general ET pattern for the defined ET periods existed for the two locations in that the ET rate was low in the first period then increased in the second period and decreased again in the third period. The Goodwell meteorological data have already been used to explain the ET pattern. No comparison can be made of the natural ET periods for the two locations as no meteorological data was 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 IV 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 V and Table VI reveal that the meteorological condition 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 indicate that the same meteorological conditions exist but this has previously been attributed to the difference in soil water conditions.

Table IV and Table VII list the four defined ET periods for each location in 1974. The treatment responses for these defined ET periods were quite similar and again the dates were not too far apart considering the time lag. For the first defined ET period at Goodwell, the wide rows had the lowest ET and at Ft. Cobb the N 30 and E 90 had the lowest ET. The demand (Tables VI and VIII) for both locations was rather low. The daily maximum temperature ranged from 20 to 30° C. The 45 cm treatment had the lowest ET at Goodwell while east-west treatments had the lowest ET at Ft. Cobb. The third defined ET period had the highest demand of the season for both locations. The daily maximum temperature for both locations ranged from 33 to 36° C. The 45 cm treatments at Goodwell and the north-south treatments at Ft. Cobb had the lowest ET and by approximately the same ratio of 0.80. In the fourth defined ET period, the 142 cm treatment at Goodwell and the 90 cm treatments at Ft. Cobb had the lowest ET. The demand was low for this period and similar to the first period. The daily maximum temperature for the period ranged from 13 to 30°C which was unseasonably cool.

At Goodwell the second defined ET period in 1973 and the third defined ET period in 1974 and the third defined ET period at Ft. Cobb in 1974 show similar characteristics. The 45 cm treatment at Goodwell and the north-south treatments at Ft. Cobb had the lowest ET. At both locations the treatments with the lowest ET had approximately the same ratio (0.08) to the other treatments. The demand for the three periods seem to be quite similar since the daily maximum temperature ranged from 27 to 36° C and the sky was generally clear. The 1973 Goodwell results indicate that this was about the maximum demand the plants could tolerate before the stomates closed to reduce the transpiration rate.

The treatment ET sequence appears to be strongly related to the demand. In natural ET periods with a high demand(maximum temperature about 33° C and clear skies) the treatment ET sequences were strongly influenced by advective energy and LE depression. Advective energy and LE depression occurred more frequently in the N 30 treatments. The N 30 treatment had the lowest ET on the days with advective energy and LE depression. Days with a high demand the treatment 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 about 27° C and clear skies) the treatment ET sequence followed closely to treatment Rn. The order of treatment Rn from high to low was N 30, E 30, N 90 and E 90.

Natural ET Period Effect

Natural ET periods were observed in 1973 and 1974 at Goodwell and in 1974 at Ft. Cobb. Natural ET period consists of from one to several days when the meteorological conditions are stable. The natural ET periods were determined from the meteorological conditions measured at the two locations. The treatment ET sequence was similar for days in the same natural ET period. The treatment ET sequence was similar for natural ET periods with similar demand even in different years. Treatment ET's for days in natural ET periods were distinct and strong statistically as seen from the energy budget data for August 21 and 22. These two days occurred near the end of a long natural ET period of moderately high demand.

The LE, ET and Rn indicates that plants in the N 30 treatment do not transpire at a rate proportional to the demand in high demand periods. Evidence for this can be seen in the r_s measurements. The r_s was lower for September 11 than August 22 but they were not proportionally lower for all the treatments. In a period of high demand the plants in the N 30 treatments have lower ET because they close their stomates. The stomates appear to be partially closed in August 22 as r_s is lower than on September 11. When the stomates of peanuts (legumes) close they fold their leaves and the reflectance appears to increase (visual observation). With the increased reflectance the Rn would be lower. This was indicated by the Rn levels for August 21 (high demand) and September 11 (low demand). The plants seem to be able to dispose of the excess energy not lost to ET by simply reflecting it away. However, in periods of low demand the plants maintain a transpiration rate proportional to the demand. This was evidenced in the last defined ET period of 1974 when LE was closely related to Rn. In this period N 30 did not have the lowest ET and it did have the highest level of Rn. This does not explain why the E 30 treatment fails to respond the same as the N 30 treatment. The answer to this could also be in the Rn differences. With the peanut leaves in the folded position, the treatment stem alignment differences could be much more evident. The difference in the stems could influence the light penetration into the canopy.

The Goodwell results could be interpreted in a similar manner but no conclusion could 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.

CHAPTER V

SUMMARY AND CONCLUSIONS

Experiments were conducted at two locations in 1973 and 1974. One study investigated the effect of row spacing on evapotranspiration (ET) for grain sorghum near Goodwell, Oklahoma. The row spacings used in this study were 45 and 142 cm. All treatments were oriented north-south. The other study investigated the effect of row spacing and row orientation on ET for peanuts near Ft. Cobb, Oklahoma. The treatments used in this study were 30 and 90 cm row spacings of north-south and east-west orientation. The experiments were replicated three times. 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 soil moisture neutron probe and tensiometers, for periods of a few days to a week in length. Meteorological conditions were monitored during the study 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 two lithum chloride cells vertically separated 30 cm. 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 net radiation Rn, solar radiation r_s and wind direction. In one period at Ft. Cobb in 1974, wind profile measurements were made for each of the treatments. Each instrument used had either an electrical or mechanical time constant of approximately 8 minutes. The instruments were read every 10 minutes by a 96 channel data scanner. The 96 channels could be read in approximately 11 seconds. The data were immediately transferred to a mini-computer then stored on cassette tapes.

During the two years, in five of seven periods of measurements, grain sorghum planted in 45 cm rows had a lower ET, by the water budget, than 142 cm rows. In 1973 in the three periods of measurement the 45 cm rows had the lowest ET. The evaporative demand was moderate to high throughout the season as the meteorological conditions were close to normal in 1973. In two periods of measurement in 1974, the 142 cm rows had the lowest ET. The demand was moderate in these periods but the meteorological conditions were still slightly subnormal.

In five of seven periods during the two years of measurements, peanuts planted in 30 cm north-south rows generally had a lower ET than the other treatments. However, in four of the five periods other treatments had equally low ET levels. With the exception of the second period in 1974, in all periods of moderate to high demand (maximum temperature greater than about 27° C and clear skies), the N 30 treatment had the lowest ET. In the second period of 1974 the demand was moderate but the wide treatments had the lowest ET. In the fourth period of 1974 the demand was low (maximum temperature ranging from 21 to 28° C with clear skies) and the wide treatments had the lowest ET.

During the last two periods of 1974 at Ft. Cobb ET was estimated from the energy budget as well as from the water budget. The treatment ET sequence estimated from the energy budget was much the same as from the water budget. In periods of moderate to high demand part 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 and LE depression more than the other treatments. When the demand was moderate to high, the net ratiation (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 N 30, E 30, N 90 and E 90. In periods of low demand the wide treatments had the lowest ET.

On one day 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 sequence 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 sequence, though most of the individual measurements did not convey great confidence. However, the 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 to several days in length. Thus, not all defined periods represent constant meteorological conditions.

In the second defined ET period of 1974 at Ft. Cobb, wind profile measurements were made at four heights above each plot. No insight into treatment differences as related to ET was obtained from the aerodynamic measurements. The wind profiles above the four treatments did not comply with the semi-log law as would be predicted from the literature. The deviations from the semi-log law were not similar for the various treatments. However, the profile deviations for a given treatment seemed to be reproducible in spite of the compliance with the conditions and precautions for wind profile measurements presented in the literature.

Natural ET periods were observed. These varied in length from one to several days through a growing season. Treatments responded characteristically during the course of a natural ET period depending on the demand. In natural ET periods with high demand the plants in north-south narrow rows had the lowest ET. The mechanism causing this effect seemed to be related to Rn and r_s. In several cases the leaves closed their stomates and the leaves folded, giving a lighter appearance to the plot. This may have reduced Rn by reflecting more energy and caused a lower demand.

Recommendations

There appears to be definite differences in water use of the treatments as supported by three independent measures. But no single treatment maintained the lowest ET throughout the two seasons. In 1973 the narrow rows with peanuts used less water. In 1974 the treatment with the lowest ET rate changed markedly from week to week and from day to day. Further investigation is suggested with modifications to improve the estimates. The best approach might be to isolate some of the variables and parameters and study them independently. If the effect of some of these parameters which require large plots size could be understood or found to have no effect then the plot size could be reduced. With the reduction of plot size the number of replications could be increased thereby improving the estimate of the treatment differences of ET.

The energy budget study provides the strongest evidence for the differences in ET of the four treatments, ET is very closely related to Rn especially during days with low demand. In days with a high demand the ET is heavily influenced by periods of advective energy and ET depression. Further investigation into the energy budget above a peanut canopy could be very rewarding. Looking into the components of Rn could give some insight into the patterns observed with measurements above the treatments. One component which should be separated out is reflectivity. Reflectivity could be a very important part with the differences in row spacing. Rn below the crop canopy could give an estimate of the relative importance of evaporation from the soil. There could be differences in soil evaporation due to both wide versus narrow rows and east-west versus north-south rows. More information as to the specific periods of advection for some of the treatments would help to clarify part of the treatment differences. The measurement period should be lengthened to include all of July and August.

In the first period much of the treatment differences appear to be related to advective energy and ET depression both at midday and following the advective periods. Employing a leaf resistance model could give insight into the plant response during periods of advective energy and ET depression. To satisfy a resistance model two added variables should be measured: leaf area index and surface temperature.

The aerodynamic profiles provided no insight into the cause of the differences in water use because the profiles did not comply with the semi-log law. As a result of this no estimate of z_o or d could be obtained. There appears to be a difference in the treatment profile from the general profile characteristics. Further investigation is indicated with some modifications that should be made are: 1) locate the lower anemometer at 50 cm above the crop canopy, 2) increase the number of observation points by placing anemometers at 50, 75, 100, 125, 150, 175, 200, and 225 cm above the crop canopy, 3) place two thermistors on each mast for determination of Richardson's Number and 4) use individual anemometer calibrations.

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