EVALUATION OF WATER APPLICATION OF A CENTER-PIVOT SPRINKLER IRRIGATION SYSTEM

By

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CHAPTER I

INTRODUCTION

The Problem

The number of center-pivot sprinkler irrigation systems is increasing in Oklahoma. The reasons for the increasing popularity are their labor saving advantages and their tremendous versatility. The system's ability to irrigate rolling terrain with a wide range of application depths accounts for its versatility. The center-pivot system has proven to be very useful in applying light applications very quickly to prevent wind erosion on soil. The light applications can also be beneficial in promoting seed germination after planting. Greater depths of application can be applied when desired to meet water requirements fo several different types of crops.

A recent survey conducted by Schwab (16) states that a total of 757,000 acres are under irrigation in Oklahoma. Approximately 312,600 of the 757,000 acres are irrigated by sprinkler systems. About 700 of the 3231 sprinkler systems in Oklahoma are self-propelled. The survey lists 465 of these as being center-pivot systems. The initial cost of these center-pivot systems is in excess of nine million dollars.

A USDA Inter-Agency Committee was appointed in 1970 to study the suitability of center-pivot sprinkler irrigation systems under Oklahoma conditions. Three factors were responsible for the study: (1) increasing farmer interest in such systems, (2) the difficulties some farmers have experienced with these systems, and (3) the need for developing uniform guidelines for agency use when advising farmers.

Some excerpts from the engineering guidelines of the committee report are:

> The irrigation system should have the capacity to meet the peak moisture demands of all crops that the purchaser may desire to irrigate within the design area.
>
> The application rate for the particular length of the sprinkler line to be used should not cause runoff during the water application period.
>
> Total depth of application (equivalent rainfall) per irrigation should be governed by the moisture storage capacity of the soil and the principle root zone depth of the crop irrigated.
>
> Uniformity of water application on the field in total is affected by sprinkler discharge rate, sprinkler spacing, and the constancy of speed of travel over the ground.
>
> Successful operation of self-propelled irrigation systems is dependent upon maintaining traction on wetted soils.
>
> Two inches of water applied every 6 days will result in approximately 20 percent less evaporation losses than using two 1-inch applications 3 days apart.

Because of the nature and use of most center-pivot systems, it is sometimes not possible to meet the recommended guidelines for the systems. Center-pivot systems have high rates of application and can cause undesired runoff on soils with low infiltration capacities. Infiltration rates are not used as a basis for the design of center-pivot systems. Center-pivot systems sometimes have difficulty applying enough water to meet certain crop demands. Trafficability of these systems also can be a problem on certain soil types. It is because of such factors that extensive research is needed to evaluate the effectiveness of water application from center-pivot systems.

Scope of Investigation

The study described in this thesis was designed to evaluate the effectiveness of water application from a single center-pivot system. The system was 1299 feet in length and irrigated approximately 125 acres of peanuts and milo. All tests were made while irrigating peanuts. The soil type as defined by the USDA soil type triangle was sand.

Measurements were taken in the field to evaluate the following pertinent variables:

1. Wind speed and direction
2. Rainfall
3. Flow rate
4. System pressure

Attempts were made to keep a record of temperature and humidity, using a hygrothermograph. However, the hygrothermograph failed to function correctly and the data was not used.

Objectives

1. To evaluate the depth, rate, and uniformity of application of a self-propelled center-pivot sprinkler irrigation system.
2. To determine the depth of water stored in the crop root zone of the soil.
3. To determine the evaporation losses for recommended light applications with high pressure nozzles under Oklahoma's windy conditions.
4. To evaluate the trafficability of the system.
5. To determine crop yields per acre and yield per acre-inch of water applied.

CHAPTER II

REVIEW OF LITERATURE

Considerable literature has been written on several aspects of sprinkler irrigation. The variables reviewed for this study were depth, rate, and uniformity of application, application losses due to evaporation and evapotranspiration, apparent specific gravity, and soil moisture measurements by both the neutron probe and gravimetric methods.

Depth and Uniformity of Application

Christiansen's coefficient of uniformity is generally used as a basis for describing uniformities of application in sprinkler irrigation (15). The formula used in calculating the coefficient is

$$Cu = 100\ (1.0 - \frac{\Sigma X}{MN})$$

where

Cu = Uniformity coefficient

X = Deviation of individual observations

M = Mean value

N = Number of observations

Pair (14), Sternberg (17), and Davis (5) used catch cans to collect spray samples from operating sprinkler systems. The catch cans were made of quart oil cans and were placed in a grid system. The most commonly used grid spacing was 5 feet. The volume collected in the cans was measured with graduated cylinders. Kerosene was placed in the cans to surpress evaporation during sampling.

Heermann and Hein (7) compared theoretical distributions from center-pivot systems with actual field distributions. The center-pivot system used was 1300 feet in length and irrigated approximately 135 acres in one revolution. Experimental uniformities were reported as being 90.5 and 87.3 for flow rates of 950 and 600 gallons per minute, respectively. These values were compared to theoretical distributions for triangular patterns and elliptical patterns. The coefficients of uniformity were 89.0 and 89.3 for the triangular pattern and 89.5 and 89.3 for the elliptical pattern, respectively for the 950 and 600 gallons per minute flow rates.

Pair (14) found uniformity coefficients from a center-pivot system of 81 for a 7.1 miles per hour wind and 86 for a 5.0 miles per hour wind. The system tested travelled at a rate of 1 revolution in 48 hours.

Rate of Application

Kincaid, Heermann, and Kraus (10) found that the application rates are directly proportional to the distance from the pivot. Pair (14) found that application rates vary from 0.21 inches per hour at the first tower to 1.01 inches per hour at the last tower. The first tower was approximately 95 feet from the pivot and the last tower was 1445 feet from the pivot. The higher rates of application can only be absorbed by soils with a high infiltration rate.

Heermann and Hein (7) developed mathematical equations for application rates and depths on center-pivot systems. They found that application rates are low near the pivot, but time of application is long. Further from the pivot, application rates become extremely high. This creates problems of design on soils of low infiltration rate.

Application Losses Due to Evaporation and Evapotranspiration

Probably the most researched subject about sprinkler irrigation is that of application losses. This involves losses due to drift, evaporation, and evapotranspiration.

In an extensive study of sprinkler irrigation, Christiansen (3) investigated spray evaporation losses. The catch can method was employed and values of loss ranged from 10 to 42 percent. No correlations of losses with climatic variables was observed.

Frost and Schwalen (6) investigated combined spray evaporation and drift losses, also by the catch can method. They obtained good correlation between spray losses and vapor pressure deficit. They also found that losses were approximately proportional to nozzle pressure and wind speed and inversely proportional to nozzle diameter.

In research conducted by Kraus (11), it was found that total application losses from sprinkler systems ranged from 3.4 to 17 percent. A direct relationship between loss and humidity was established. No accurate correlation was made with wind because of its difficulty to measure. Kraus also reported that 36 percent of the total loss was due to drift.

Frost and Schwalen (6) also investigated evapotranspiration loss in sprinkler irrigations. It was found that evapotranspiration losses during sprinkling may be neglected when calculating application losses. This is because they are about equal to normal evapotranspiration losses when not sprinkling. Evapotranspiration losses reached a peak near midday and also increased with vapor pressure deficit and wind velocity.

Evapotranspiration from irrigated peanuts has been studied at the Caddo Peanut Research Station at Fort Cobb, Oklahoma (19). The values for evapotranspiration obtained from these studies are listed in Tables I and II.

Neutron Probe

The neutron scattering technique of measuring soil moisture is based on the interaction of fast neutrons with soil water. When a source of fast neutrons is placed in a medium, the neutrons interact with nuclei by both inelastic and elastic collisions. Elastic collisions are by far the most common in soil (12). During the elastic collisions, the neutrons change direction and lose energy resulting in moderation or slowing down. The terms fast and slow are indicative of the energy level of the neutrons. Fast neutrons have energy levels greater than 10 keV while slow neutrons have energy levels less than 100eV (12). As more neutrons are slowed down, the moderating material in the medium becomes surrounded by a cloud of slow neutrons. The density of the slow neutrons is proportional to the concentration of the moderating material.

When a source of fast neutrons is placed in moist soil, the neutrons undergo a moderation process as previously described. The moderating ability of nuclei present in the soil is extremely small compared with that of hydrogen. The hydrogen nuclei is very effective in slowing down the fast neutrons. This means that if the soil contains

TABLE I

EVAPOTRANSPIRATION FOR 1969, BASED ON
NEUTRON PROBE DETERMINATION

Date	Total ET for Period (In. Water)			
	North-South Oriented Rows		East-West Oriented Rows	
	** 12"	36"	12"	36"
August 11-20	0.48	1.22	0.81	1.36
August 22-30	0.38	0.85	0.75	0.72
September 4-10	1.04	1.86	1.25	1.18

TABLE II

EVAPOTRANSPIRATION FOR 1971, BASED ON
NEUTRON PROBE DETERMINATION

Date	Total ET for Period (In. Water)			
	North-South Oriented Rows		East-West Oriented Rows	
	** 12"	36"	12"	36"
August 2-12	0.56	0.67*	0.82	-
August 16-21	0.85	1.47*	1.04	1.39

* Value from 1 tube

** Row Spacings

a large amount of hydrogen, the neutrons are slowed down before they get very far from the source. Practically all of the hydrogen in the soil is contained within the soil water. This allows a relationship to be developed between the number of existing slow neutrons and the soil moisture content.

The neutron probe is initially calibrated by comparison with gravimetric moisture measurements. Extensive gravimetric soil moisture measurements are taken at a wide range of soil moisture percentages to calibrate the probe and evaluate a calibration curve. Once one probe has been calibrated, it can be used to calibrate others. After calibration of a probe has been completed, periodic checks should be made to insure the validity of the calibration curve against drift (12). The calibration can be checked easily by using devices such as salt solutions, polyethylene cylinders, or cadmium shields (21, 20, 2).

The calibration curve for the meter is based on the ratio method. The majority of neutron meters will show slightly different count rates for a constant moisture content over a period of time. The ratio method for reporting readings of the neutron probe eliminates most errors due to change in equipment behavior (12). This ratio consists of the readings or counts made in the soil divided by a standard reading. This standard reading is obtained in the paraffin shield which houses the probe. The standard reading is referred to as a can count.

The overall performance of the neutron method of evaluating soil moisture is generally noted to be very acceptable (18). Temperature has been found to have a slight influence on the probe (4). It was found that the probe is fairly stable below 32°C. but drifts from 32°C. to 46°C. The probe reached zero counts per minute at 46°C. The sensitivity is due to the transistors in the circuit. The presence of boron and chlorine in the soil also effects the results of the probe. Concentrations as small as 100 parts per million of boron and 1000 parts per million of chlorine can have a pronounced effect (8, 22). However, in the majority of soils, hardly any boron or chlorine can be found.

Apparent Specific Gravity

The apparent specific gravity of a soil is defined as the ratio of the weight of a given volume of dry soil, air space included, to the weight of an equal volume of water (9). The most common method of determining the apparent specific gravity is to obtain a soil sample of known volume. This can be done by driving a sharp edged tube into the soil and obtaining an uncompacted core within the tube. Other methods involve the removing of soil from a pit or hole and then determining the volume of the hole. The volume of the hole can be determined by the balloon method or the sand cone method (13).

CHAPTER III

EXPERIMENTAL EQUIPMENT

The System

The data collected for this research project was collected from the Zimmatic, Model-310, self-propelled center-pivot sprinkler irrigation system shown in Figures 1 and 2. The system was a standard ten tower unit with an overall length of 1299 feet. The system was electrically driven. Each tower contained a 1 horsepower drive motor. The motors were supplied with a direct drive to the wheels eliminating any slippage in the drive mechanism.

The time of rotation for the system could vary from 20 hours to 200 hours. This rotation time was controlled by a speed setting control based on a percentage of time. This means that the system was only moving a certain percentage of the time. For example, if the speed setting was 50 percent, the system would be moving fifty percent of the time. The 20 hour rotation time required a setting of 98 percent, while the 200 hour required 10 percent. The 40 percent setting was used most often while data were collected. As the speed setting is increased, the depth of application is decreased.

Center-pivot systems vary a great deal in sprinkler design. Some pivot systems have only one size of sprinkler nozzle and vary the spacing of the sprinkler heads to obtain desired application rates. Other sprinkler systems use constant spacings and vary the size of the

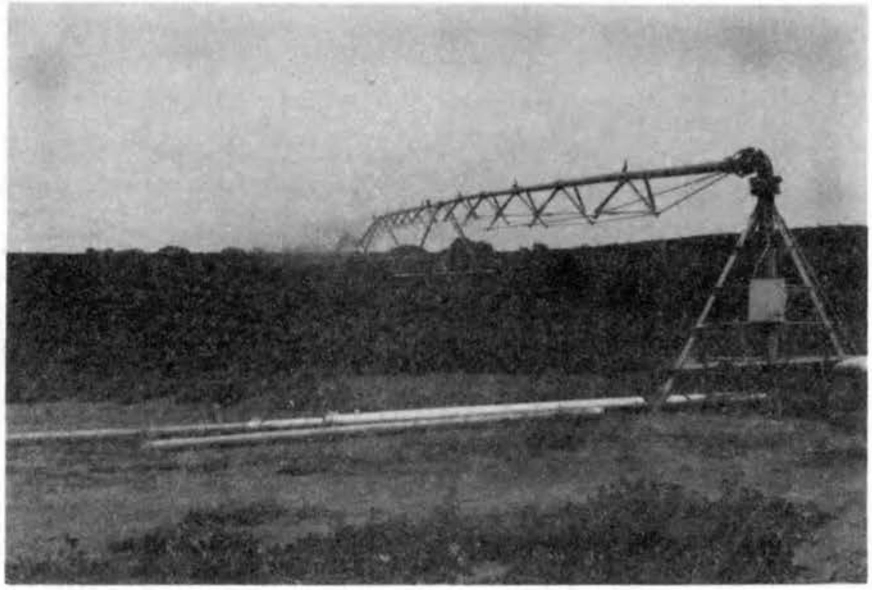

Figure 1. Zimmatic Self-Propelled Center Pivot System

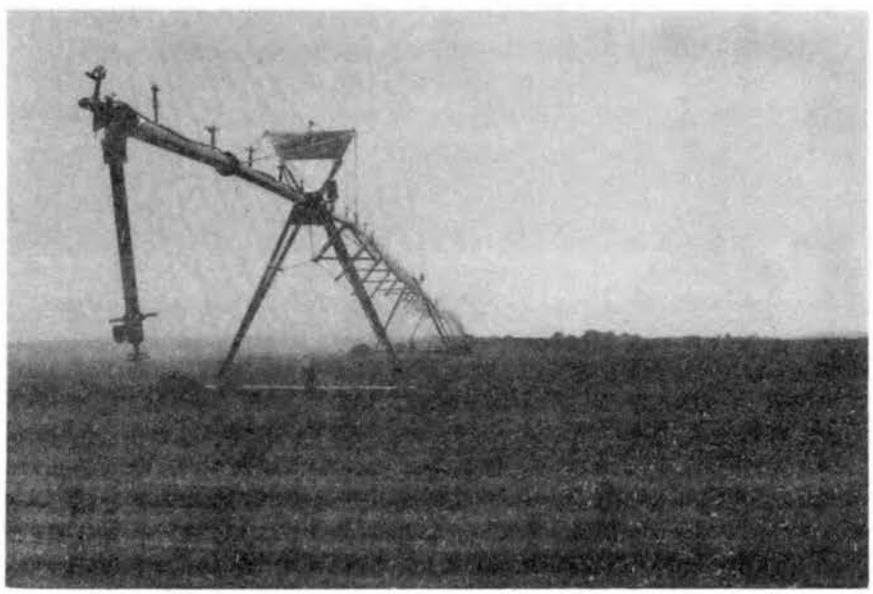

Figure 2. Last Tower of Pivot System

sprinkler nozzles. On the Zimmatic system, both the spacings of the heads and the size of the nozzles are varied to obtain desired application rates. The Zimmatic system was designed to deliver 800 gallons per minute at a pivot pressure of 77 pounds per square inch. Manufacture's data also suggests that the system will deliver 774 gallons per minute at a pivot pressure of 72 pounds pwer square inch. Pressures lower than these are not recommended as satisfactory operating pressures.

Crop and Topography

The sprinkler system was used to irrigate the center 125 acres of a quarter section of land. Peanuts were grown on the north half of this 125 acres and milo was grown on the south half. All data were collected while irrigating peanuts. The peanuts were planted in rows with spacings of 33-11-16-11. These numbers are the distance between adjacent rows in inches. The rows were planted in the east, west direction.

The field topography was very hilly with several steep slopes. However, as the soil was very sandy, no runoff occurred due to irrigation. A contour of the land was established in several directions from the pivot. The contours are shown in Figure 3.

Spray Sampling

The catch can method was used to collect sprinkler spray samples. The catch cans, number 3 squat cans obtained from a food canning plant, were 3 7/16 inches in height and 4 1/8 inches in diameter with a sharp edge and no lids.

Flow Measurement

The inflow into the irrigation system was measured with the 8-inch

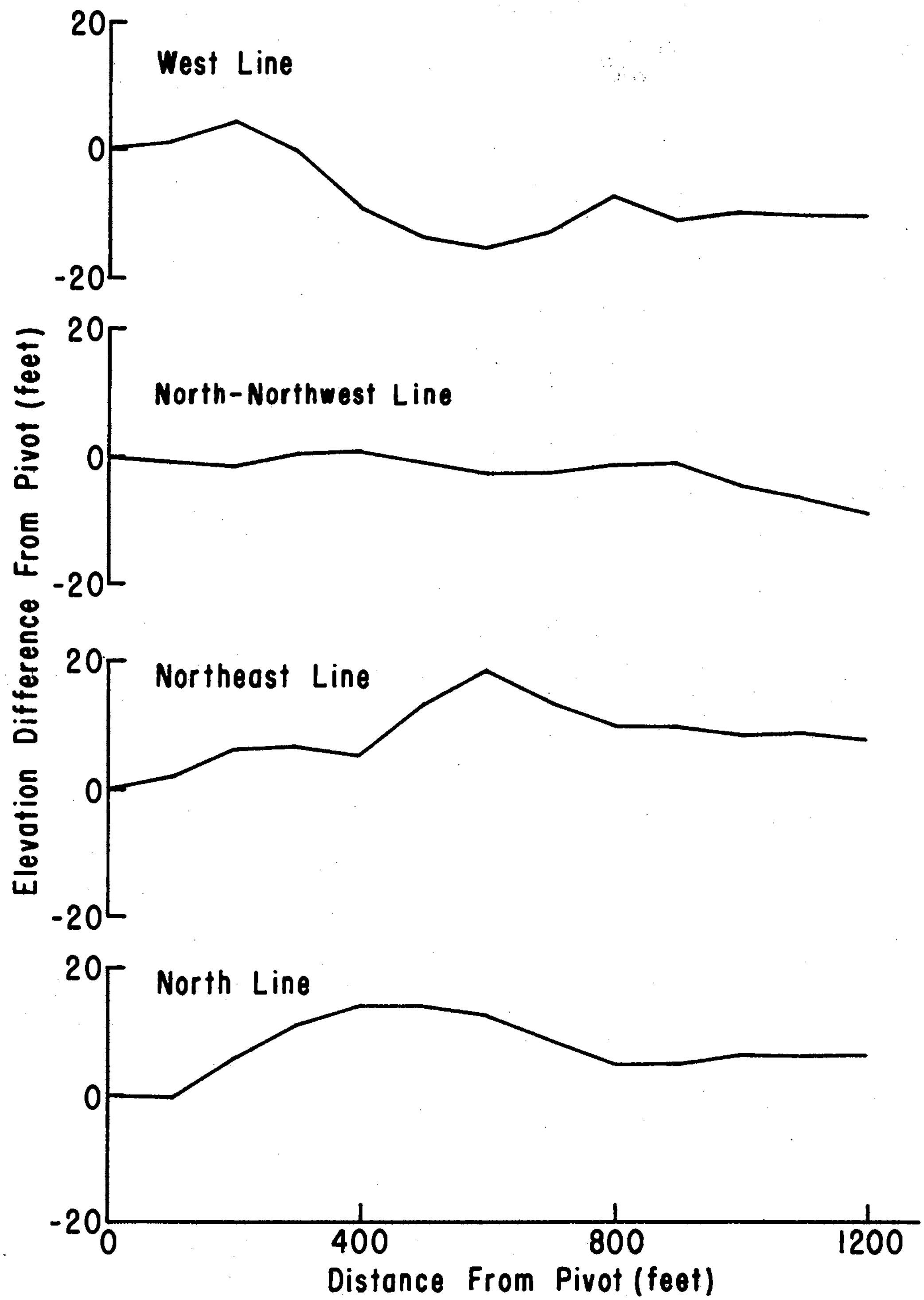

Figure 3. Contours of Irrigated Land

flow meter shown in Figure 4. The flow meter was calibrated in the Agricultural Engineering Laboratory at Oklahoma State University using a 6-inch flow meter that had been calibrated with a sharp-edge orfice and a U-tube manometer at the Outdoor Hydraulic Laboratory near Stillwater, Oklahoma. The meter was installed in a 20 foot length of 8-inch aluminum irrigation pipe.

Wind Measurement and Rainfall

The measurement of wind consisted of both speed and direction. The speed was measured with a cup type anemometer and the direction with a wind vane. A recording-type rain gage was used to measure precipitation. These instruments are shown in Figure 5. The instrument shelter shown in Figure 5 was used to house a hygrothermograph to keep a record of temperature and humidity. Shortly after the start of the irrigation season, the hygrothermograph failed to operate correctly and was discarded.

The calibration of the anemometer was checked with one that was being used for lake evaporation studies by F. R. Crow, Agricultural Engineer at Oklahoma State University.

Soil Moisture Measurements

Soil moisture measurements were taken by both the gravimetric or oven-dry method and the neutron probe.

The gravimetric sampling device was an Oak Field Soil Sampler made of cadmium plated steel and was approximately 36 inches in length. The soil samples were kept in tin sampling cans and were dried in a portable bench-type oven.

Figure 4. 8-Inch Flow Meter

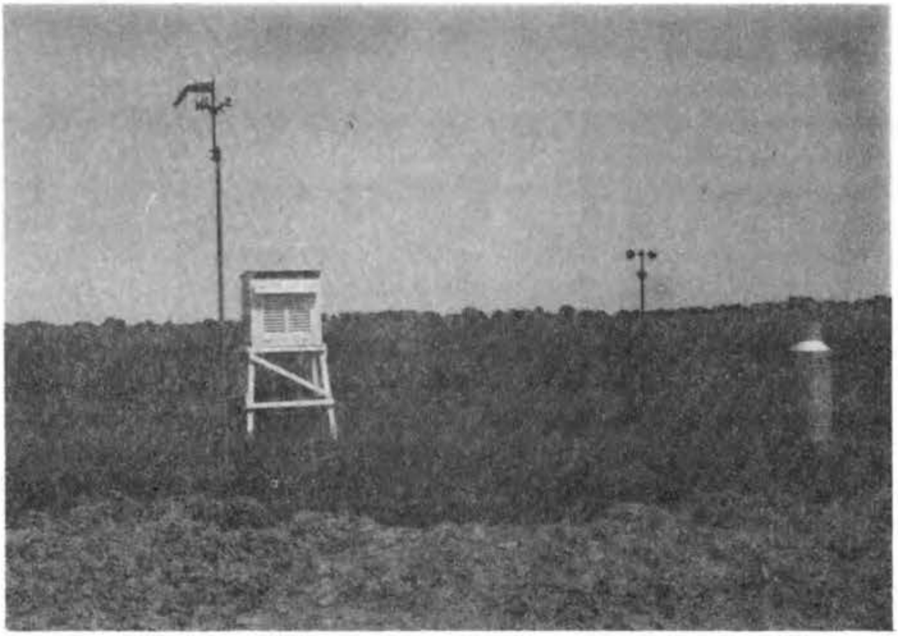

Figure 5. Meterological Instrumentation

The neutron probe used was a Nuclear-Chicago Model P-19.

Pressure Measurements

Pressure measurements were taken at the pivot by means of a standard pressure gage, with a range of 0 to 100 pounds per square inch. Pressures along the system were measured by a pitot tube and pressure gage combination.

CHAPTER IV

PROCEDURE

Uniformity and Depth of Application

Catch cans were placed in single lines which extended radially from the pivot. The direction of these lines from the pivot were northeast, north, north-northwest, and west. The cans were spaced at 20 foot intervals in the field prior to an irrigation. The volume of water caught in each can was measured with a graduated cylinder and recorded. Flow, wind, and pressure measurements were also taken during each irrigation. The catch cans are shown in Figure 6.

Gravimetric Soil Moisture Measurements

Gravimetric soil samples were taken throughout the irrigation season. These samples were taken to a depth of 24 inches in the soil profile. Four samples were obtained from the 24 inch profile. They were 0-6 inch, 6-12 inch, 12-18 inch, and 18-24 inch. The soil moisture samples were kept in air-tight metal sample cans until they were weighed before drying. The samples were dried in a bench oven at 105°C. for approximately 12 hours and then weighed again.

The soil samples were taken along the west and northeast test lines. Four sample locations were chosen along each line at approximately 300 foot increments from the pivot. At each test location, three samples of the soil were taken. This gave three samples for each

Figure 6. Spray Collection Cans

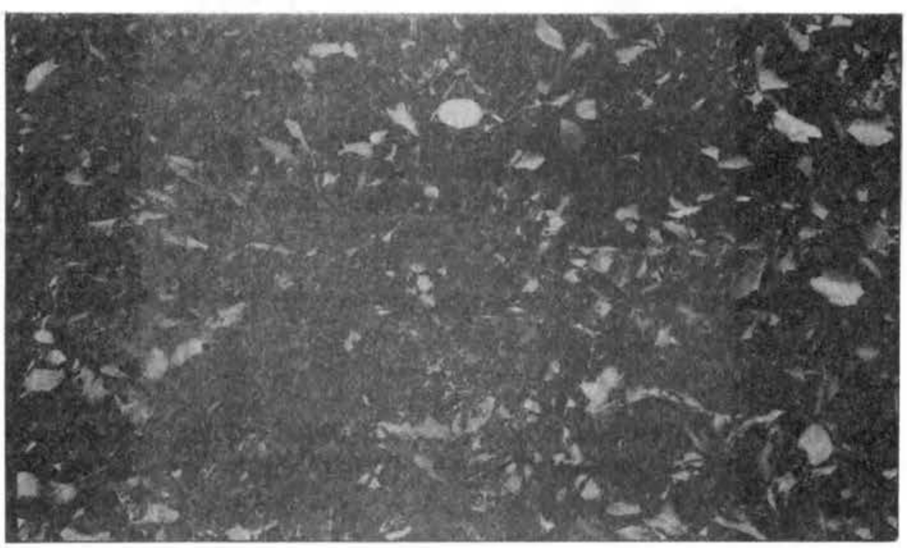

Figure 7. Access Tube for Neutron Probe

of the 4 depths in profile at each of the 4 locations in the individual lines. The three samples were put in the same sample can. This allowed a good average soil moisture to be determined for each depth.

Soil Moisture Measurements
With the Neutron Probe

Neutron probe readings were also taken extensively during the irrigation season. Access tubes for the probe were installed at eight locations in the field along the northeast and west test lines. Four tubes were installed on each line at 300 foot increments from the pivot. When not in use, the tubes were kept covered with steel caps. A tube is shown in Figure 7.

Probe readings were taken to a 45-inch depth in the soil profile. The probe was positioned in the profile at depths of 6, 12, 18, 24, 30, 36, and 42 inches. The 6-inch position sampled the 0-9 inch zone while the remainder of the sample positions had a sampling zone of 6 inches.

Three separate two minute can counts were always taken on the first access tube tested. A single two minute can count was taken on the remainder of the tubes. Counting was done for one minute periods while sampling the moisture in the soil profile.

Crop Yield Determinations

Sample plots in the field were harvested to determine the yield per acre of the peanut crop. Eight plots were harvested at each of the eight soil moisture testing locations. The plots consisted of two rows, eleven inches apart and ten feet in length. The plots were harvested by hand and were left on the vine to air dry to about 10 percent moisture content. The peanuts were then removed from the vine and were hand shelled. The moisture content of the shelled peanuts was determined with an electronic tester. A calibration curve for the electronic tester was used to convert the moisture to an oven-dry basis. The peanuts were then weighed to determine the total weight for each sample location.

Apparent Specific Gravity

An uncompacted soil sample was obtained with a cylindrical tube type sampling device. The soil sample was 3 inches in diameter and 3 inches in height. Samples were taken at each test location on each test line. The samples were taken at the midpoints of each 6-inch increment to the 24 inch depth in the soil profile. For example, the 0 to 6 inch sample was taken from a depth of 1.5 to 4.5 inches.

The soil samples were thoroughly dried in a bench oven and weighed to determine the dry weight. The dry weight divided by the calculated volume gave the dry unit weight of the soil. This unit weight divided by the unit weight of water is the apparent specific gravity.

CHAPTER V

ANALYSIS OF DATA AND PRESENTATION OF RESULTS

System Uniformity

The volume of water from each catch can was obtained by pouring it into a two inch diameter graduated cylinder. The depth of application was calculated by dividing the volume by the cross-sectional area of the can. These depths were then analyzed for uniformity using Christiansen's uniformity coefficient as expressed by

$$Cu = 100(1.0 - \frac{\Sigma X}{MN})$$

where

Cu = Uniformity coefficient

X = Deviation of individual observations

M = Mean value

N = Number of observations.

The uniformity of each individual irrigation was calculated with an IBM 360 computer. The results of this analysis are presented in Table III.

Data for wind speed and direction were collected during each irrigation. The wind speed was taken to be the average over the entire irrigation. This data is also presented in Table III.

The uniformity of the system was found to decrease slightly with wind speed as shown in Figure 8. The relationship between the coefficient of uniformity and wind speed appears linear. The overall

TABLE III

SYSTEM UNIFORMITY OF APPLICATION

Location	Date	Depth of Application (Inches)	Uniformity Coefficient	Speed Setting (%)	Average Wind Speed (MPH)	Direction Of Wind	Pressure At Pivot (PSI)
West	8-07	0.56	83.7	35	4.8	SSE	60
NE	8-14	0.26	84.0	95	5.2	SE	70
North	8-14	0.26	85.6	95	5.2	SE	69
NNW	8-14	0.27	90.4	95	5.2	S	69
North	8-16	0.60	87.3	40	5.8	SSE	72
NE	8-20	0.57	86.1	40	5.8	ESE	73
North	8-21	0.69	85.1	40	2.8	S	75
NNW	8-21	0.52	81.5	40	6.9	SE	69
NNW	8-24	0.54	85.5	40	11.8	SSW	62
North	8-24	0.60	81.8	40	13.9	S	64
NE	8-25	0.56	85.9	40	9.0	S	65

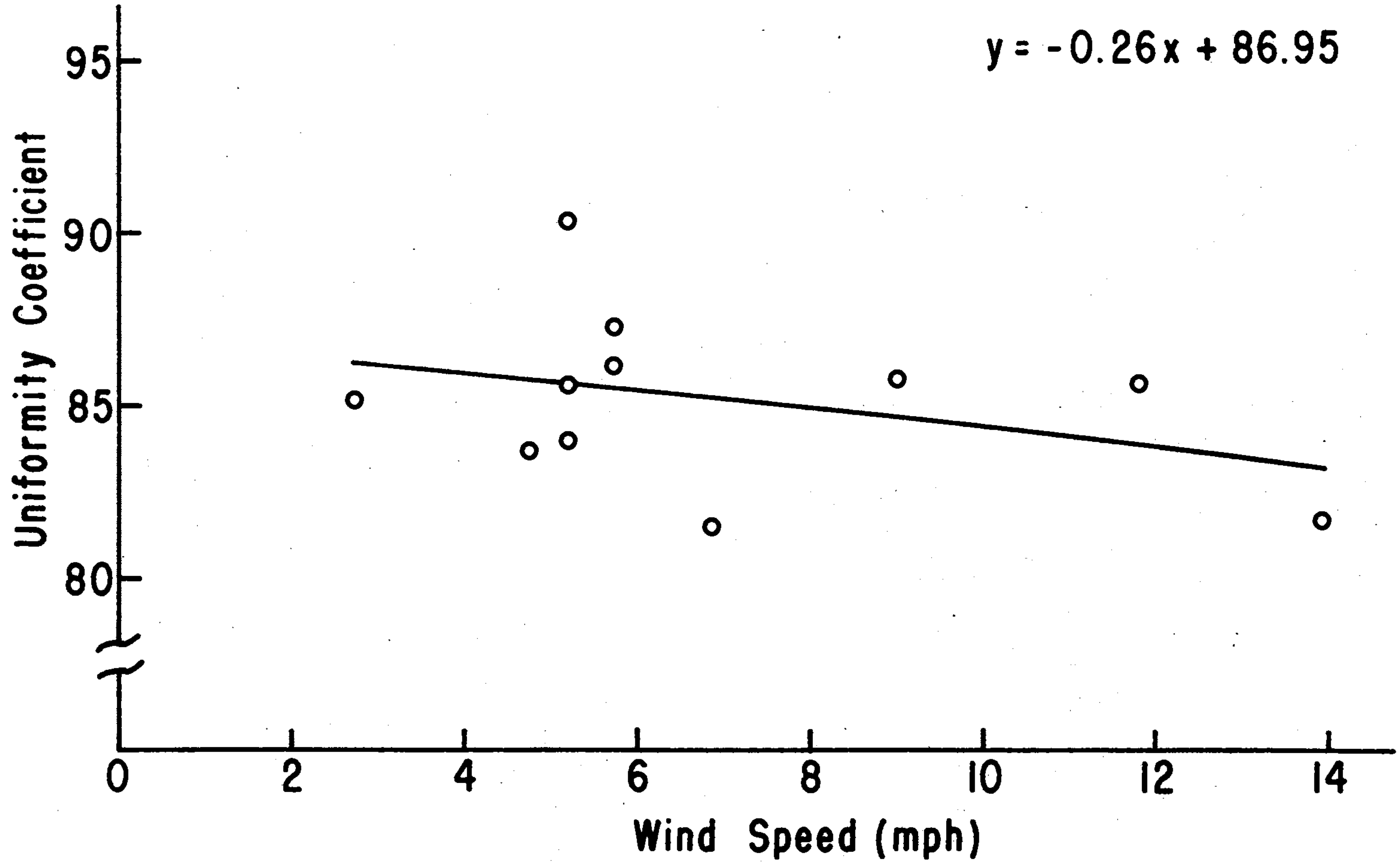

Figure 8. Coefficient of Uniformity Verses Wind Speed

uniformity of the system was found to be very good with all coefficients above 80. A coefficient of 100 indicates perfect uniformity.

Soil Moisture

The soil moisture data collected with the neutron probe were converted from slow neutron counts to volumetric moisture percentages. This was done by means of a computer program for the calibration of the probe. An Olliveti 101 Programa was used for this conversion. The volumetric moisture percentages were then multiplied by the depth of the sampling zone to obtain the depth of water in the soil profile. The data are presented for each sample location in Tables VIII through XV, Appendix A.

The data obtained from the oven-dry method were processed with a desk calculator. From the data, the percent moisture on the dry-weight basis was obtained. The equation used to calculate this percent moisture was

$$SM = \frac{WW-DW}{DW} \times 100$$

where

SM = Percent soil moisture, dry basis

WW = Wet weight of soil and water

DW = Dry weight of soil

The dry weight moisture percentage was converted to a volumetric percentage by multiplying the dry weight percentage by the apparent specific gravity of the soil. The values of apparent specific gravities are given in Tables XXVII and XXVIII, Appendix D.

The equation used for this conversion was

$$SMV = SM(A_s)$$

where

SMV = Moisture percentage, volume basis

SM = Moisture percentage, dry weight basis

A_s = Apparent specific gravity

The depth of water stored in the soil profile was obtained by multiplying the volumetric percentage by the depth of the sampling zone. The depth of water stored in the soil profile is given in Tables XVI through XXIII, Appendix B, for each test location.

Evapotranspiration

The soil moisture data from both methods were used to determine values of evapotranspiration. Evapotranspiration as used here is the sum total of evaporation and transpiration of the water after it has come in contact with the ground and vegetation surfaces. This does not include losses between the system and the ground. The term evapotranspiration is sometimes referred to as consumptive use.

The total depths of water stored in a particular depth of soil profile were plotted against date for each individual test location. The different moisture contents were connected by straight lines as shown in Figures 9 and 10. The values of evapotranspiration were calculated by combining the soil moisture content and the amount of rainfall and irrigation water that was applied to the crop. When no moisture was added to the soil between two consecutive soil moisture measurements, the evapotranspiration was calculated by dividing the difference in the moisture measurements by the time interval in days between the two soil moisture measurements. When water was added to the soil between soil moisture measurements, the amount of water added

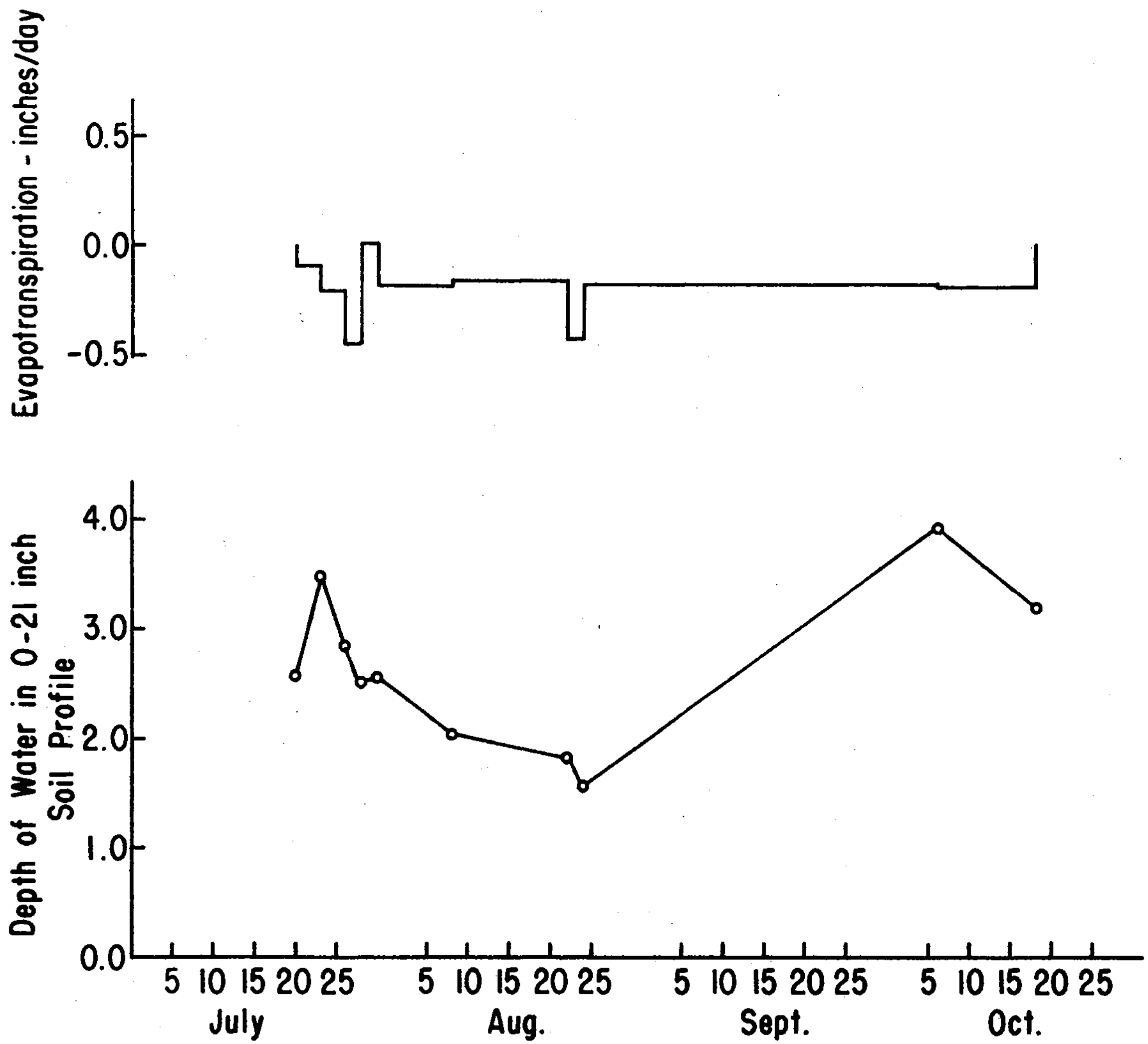

Figure 9. Gravimetric Determination of Evapotranspiration

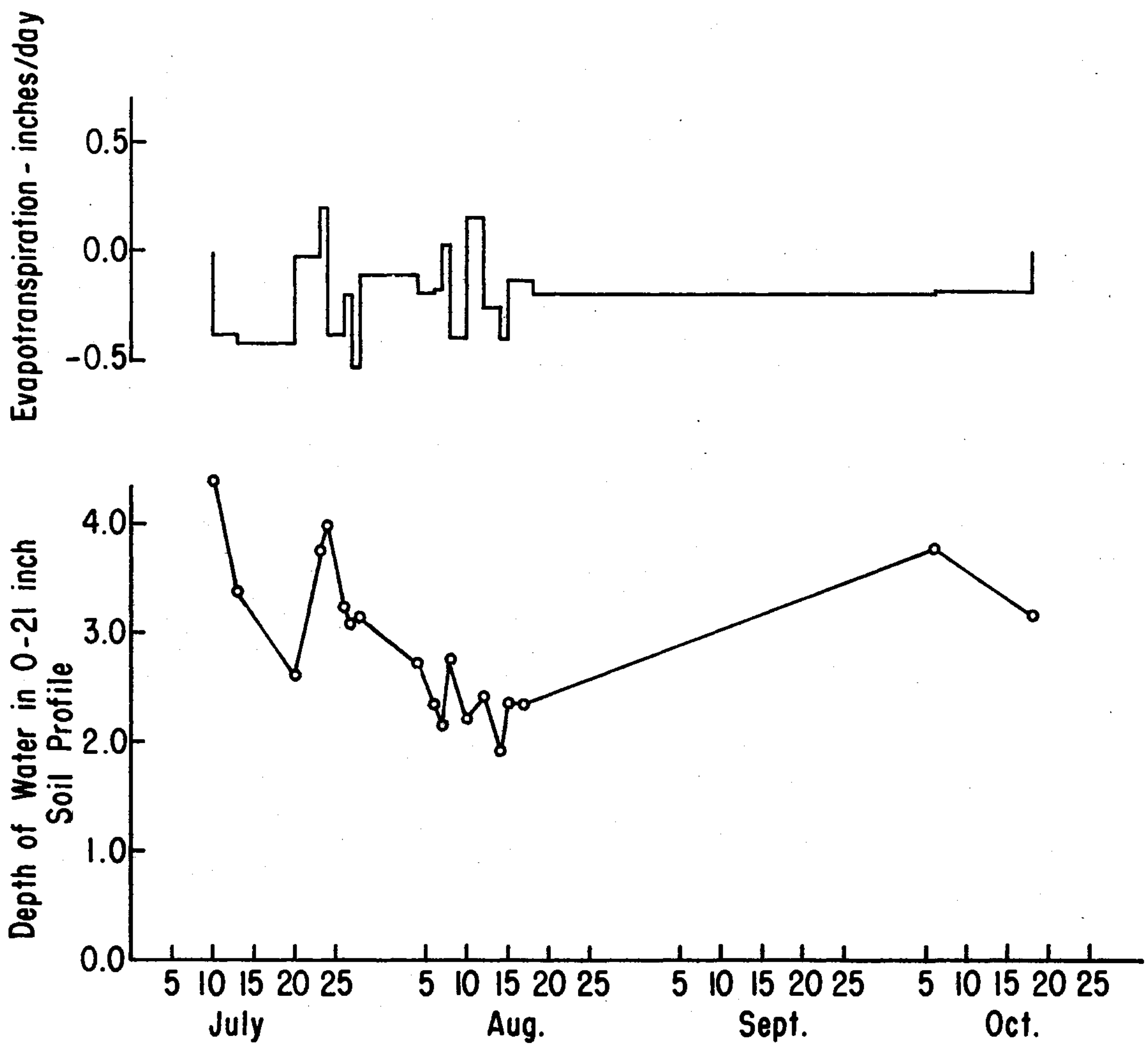

Figure 10. Neutron Probe Determination of Evapotranspiration

was subtracted from the latter soil moisture measurement and the difference in this value and the previous soil moisture measurement was divided by the time interval. A histogram of the evapotranspiration values is also shown in Figures 9 and 10. From this, the average evapotranspiration for any period of time could be found. This process was repeated for several different depths in the soil profile. The 9, 12, 15, 21, and 45-inch soil profiles were used in the preceeding analysis. The average evapotranspiration values given by this analysis are listed in Tables IV and V. These values compared well with those reported by Stone (19).

The analysis of the soil moisture data to determine evapotranspiration was repeated by averaging the soil moisture readings for the four test locations on each line. These values were plotted and analyzed by the same method as described previously. In the previous analysis, each individual location was analyzed and then averaged, whereas, in this analysis an average of the locations was analyzed. The average percent difference in the results was 1.44.

Evaporation Losses

The evaporation loss considered in this section occurred between the sprinkler nozzle and the ground surface. The difference between the depth of water caught in the catch cans and the amount of water leaving the system was considered to be the evaporation loss. Some of this loss was in the form of drift instead of actual evaporation. The drift element was not considered independent of evaporation.

The amount of water leaving the system is by continuity equal to the amount entering the system. This quantity of water was measured

TABLE IV

EVAPOTRANSPIRATION VALUES OBTAINED FROM ANALYSIS OF GRAVIMETRIC SOIL MOISTURE DATA

LOCATION	DEPTH IN SOIL	JUL 20-OCT 18 (IN/DAY)	JUL 20-AUG 25 (IN/DAY)
W	21	0.181	0.174
W	15	0.170	0.163
W	12	0.172	0.160
		JUL 11-OCT 18 (IN/DAY)	JUL 11-AUG 25 (IN/DAY)
*NE	21	0.168	0.166
*NE	15	0.177	0.165
*NE	12	0.175	0.156

*VALUES OBTAINED WERE FROM LOCATION NE-1 AND NE-2 ONLY

TABLE V

EVAPOTRANSPIRATION VALUES OBTAINED FROM ANALYSIS OF NEUTRON PROBE SOIL MOISTURE DATA

LOCATION	DEPTH IN SOIL	JUL 10-OCT 18 (IN/DAY)	JUL 10-AUG 25 (IN/DAY)
*W	45	0.212	0.225
NE	45	0.189	0.205
W	21	0.186	0.209
NE	21	0.169	0.160
W	15	0.190	0.196
NE	15	0.177	0.166
W	12	0.189	0.195
NE	12	0.178	0.154

*VALUES OBTAINED WERE FROM LOCATION W-1,W-2 AND W-4 ONLY with the flow meter. The following relationship was used to calculate the depth of application assuming no losses.

$$D = \frac{96.3QT}{A}$$

where

D = depth in inches

Q = flow rate in gallons per minute

T = time of irrigation in hours

A = irrigated area in square feet

The percent difference in the calculated depth and that caught in the catch cans was the percent evaporation loss. This percentage is given as follows:

$$Evap = \frac{d_c - d_a}{d_c} \times 100$$

where

Evap = percent evaporation

d_c = calculated depth

d_a = depth caught in catch cans

The actual values of loss were found to range from -18.3 to 12.5 with an average loss of -3.0 percent. The values obtained were not acceptable because it is not possible to obtain negative evaporation losses. It was observed that all negative values were obtained from data that were collected at night. Loss values slightly above zero were expected for night irrigations. This implies that some factor was not taken into account which would result in shifting all the values of loss at night to zero. This would also shift the losses for daytime irrigations upward.

The average slippage of the system over the entire field was not measured. The value of time used to calculate the theoretical depth of application was taken from manufacture's data assuming no slippage of the tires on the sand. The slippage of the system was assumed to be 18.3 percent which results in eliminating all negative evaporation. The value of 18.3 was the largest negative loss. This loss occurred at night with low wind speed. The corrected evaporation losses are tabulated in Table VI. The loss ranged from zero to 30.9 percent with an average of 15.5. The average night evaporation was 10.6 percent and the average day evaporation was 20.4.

Crop Yield

The weight of the peanut samples was obtained for each plot harvested. The weight was recorded at 10 percent moisture content. The effective area of the plot was reported in acres. The sample plot consisted of two rows, eleven inches apart and ten feet in length. The total row spacing of the crop was 33-11-16-11. One-half of the skip distance between rows was taken on each side of the eleven inch skip to be effective width. Thus, the effective width was 16.5 plus 11 plus 8 or 35.5 inches. The total area of the rectangular plot was calculated to be 0.000679 acres. The crop yields are reported in tons per acre in Table VII.

The total amount of water applied to each test location was recorded for the season. This enabled the yields per acre-inch of water applied to be determined. These results are also tabulated in Table VII.

From the results of yield per acre-inch of water applied, the values for the west test locations were 15.02 percent less than those for the northeast test locations. This can be explained by comparing

TABLE VI

EVAPORATION LOSSES

Location	Date	Time	Depth Caught (Inches)	Speed Setting (%)	Flow (GPM)	Calculated Depth* (INCH)	Percent Evap.
West	8-07	Day	0.56	35	600	0.81	30.9
NE	8-14	Night	0.26	95	636	0.29	10.3
North	8-14	Night	0.26	95	636	0.29	10.3
NNW	8-14	Night	0.27	95	636	0.29	6.9
North	8-16	Day	0.60	40	650	0.73	17.8
NE	8-20	Day	0.57	40	641	0.73	21.9
North	8-21	Day	0.69	40	645	0.70	1.4
NNW	8-21	Day	0.52	40	636	0.73	28.8
NNW	8-24	Day	0.54	40	630	0.72	25.0
North	8-24	Day	0.60	40	641	0.72	16.7
NE	8-25	Night	0.56	40	641	0.73	23.3
NE	8-16	Night	0.71	40	650	0.71	0.0
West	8-22	Night	0.66	40	641	0.71	7.0
West	8-24	Night	0.60	40	641	0.72	16.7

* Corrected for percent slippage.

TABLE VII

CROPS YIELDS PER ACRE-INCH OF WATER APPLIED

LOCATION	% MOISTURE (STEINLITE)	% MOISTURE (OVEN-DRY)	WEIGHT (GRAMS)	WEIGHT IN GRAMS AT 10% MOISTURE (OVEN-DRY)	YIELD IN TONS/ACRE AT 10% MOISTURE (OVEN-DRY)	AVERAGE YIELD IN (TONS/ACRE)	TOTAL WATER APPLIED (INCHES)	YIELD/ACRE-INCH OF WATER APPLIED (TONS/ACRE-INCH)
NE-1	12.47	13.10	1439.50	1400.05	2.27			0.116
NE-2	10.73	11.06	1236.90	1225.09	1.99			0.101
NE-3	10.50	10.80	1245.20	1236.32	2.00			0.102
NE-4	14.86	15.90	1472.60	1397.54	2.27	2.13	19.65	0.116
W-1	8.28	8.20	1084.00	1102.45	1.79			0.091
W-2	7.34	7.10	1168.00	1199.63	1.94			0.098
W-3	10.42	10.65	1163.50	1156.66	1.88			0.095
W-4	10.38	10.64	1018.20	1012.67	1.64	1.81	19.72	0.083

the values of evapotranspiration for both lines. The values of evapotranspiration observed for both lines should be for the same time period. The values calculated using the neutron proble soil moisture data were calculated for the same time period. The values show a significant difference between the two lines. The west line indicates 21.27 percent more evapotranspiration than the northeast line. In effect, the northeast line had more water available for crop production.

Pressure Effects

Pressure is very important for satisfactory sprinkler operation. Low pressures cause poor distribution and lower discharge rates from sprinklers. In a sprinkler irrigation system, the pressure is an important design consideration. ASAE recommendations for good design state that the pressure drop in a sprinkler lateral not exceed 20 percent of the pressure at the beginning of the lateral (1).

The Zimmatic center-pivot system was designed to be operated at a pressure of 77 pounds per square inch at the pivot with an 800 gallons per minute discharge. The theoretical pressure drop at the last sprinkler under these conditions is 13.7 pounds per square inch; therefore, the pressure at the last tower is 63.3 pounds per square inch. This constitutes a 17.8 percent drop which is satisfactory for good design. These are theoretical pressures for the system operating on level ground.

In actual field conditions, the system was not operating on level ground. The change in elevation over the field greatly effected the pressure drops in the system. Pressure data were taken on the north and north-northwest lines. The elevation contours on the lines were known. The drop on the north line was found to be 12 pounds per square inch at the last tower of the system. The last tower was 7.83 feet higher than the pivot. The drop on the north-northwest line was 6.5 pounds per square inch. The last tower on this line was 9.61 feet lower than the pivot. The system was operating at a discharge of 640 gallons per minute when these data were taken. From these values, the average pressure drop of the system on level ground between the base of the pivot and the last tower would be 9.63 pounds per square inch. The average pivot pressure for these tests was 63 pounds per square inch. The calculated pressure drop was therefore 15.3 percent.

SUMMARY

of sticking becomes more critical. On sandy soils, the increase in application depth was observed to have no effect on trafficability.

The depths of application from the center-pivot system were typically light. The light applications were applied in a relatively short period of time. For crops that require light, frequent irrigations, such as peanuts, the center-pivot system proved to be ideal. The light applications also proved to be a tremendous asset in the prevention of wind erosion. The light applications may also be desirable for seed germination.

The evapotranspiration of the peanuts under the center-pivot system was found to be similar to that found under other types of sprinkler irrigation systems. Stone (19) reported evapotranspiration values for peanuts in western Oklahoma. These values were shown to be dependent upon both row spacing and the direction of orientation of the rows. Because of the varying row spacing in the field tested, it was not possible to directly compare the results of this research to Stone's (19). However, the values reported in this research are in the same general range as those reported by Stone (19).

The evaporation loss from the system compared very well with those reported in previous research. Christiansen (3) found evaporation losses of 10 to 42 percent. The losses found in this research ranged from zero to 30.9 percent. The average loss during night irrigation was 9.8 percent less than the average loss for daytime irrigation.

Conclusions

1. The average coefficient of uniformity of the center-pivot system was 85.2 with a standard deviation of 2.48.

2. The uniformity of application of the center-pivot system decreased linearly with wind speed for the range of wind speeds tested.

3. Crop yields were 0.109 ton per acre-inch of water applied for the northeast test line and 0.092 for the west line.

4. Crop yields were inversely related to evapotranspiration.

5. The average value of evapotranspiration for the entire growing season of peanuts in Caddo county, Oklahoma was 0.186 inches per day.

6. The average evaporative loss from the system was 15.5 percent. The average loss during daytime irrigations was 20.4 percent and the average at night was 10.6 percent.

7. Trafficability of the center-pivot system was extremely good on sandy soil. Trafficability does become a problem on clay soils for large depths of application.

Suggestions for Future Research

1. A study of the effects of wind on the different types of sprinkler designs of center-pivot systems.

2. Compare water application from center-pivot systems which differ in sprinkler design.

3. Compare the trafficability of water driven, electrically driven, and hydraulically driven center-pivot systems.

4. Compare center-pivot spray systems with center-pivot sprinkler systems.

5. Compare water application from center-pivot systems of different lengths.

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APPENDIX A

NEUTRON PROBE SOIL MOISTURE DATA

TABLE VIII

SOIL MOISTURE DETERMINATION BY NEUTRON PROBE METHOD FOR LOCATION W-1

DATE	DEPTH OF WATER STORED IN SOIL PROFILE (INCHES)							TOTAL	TOTAL	TOTAL	TOTAL	TOTAL
	0-9	9-15	15-21	21-27	27-33	33-39	39-45	0-6	0-12	0-15	0-21	0-45
7-10	1.660	1.280	1.490	1.330	0.970	0.760	0.840	1.106	2.300	2.940	4.430	8.330
7-13	1.190	1.100	1.410	1.410	1.120	0.840	0.850	0.793	1.740	2.290	3.700	7.920
7-20	0.672	1.022	1.345	1.419	1.174	0.876	0.938	0.448	1.183	1.694	3.039	7.446
7-23	2.034	1.124	1.359	1.533	1.159	0.987	1.094	1.356	2.596	3.158	4.517	9.290
7-24	1.719	1.066	1.322	1.450	1.230	1.015	1.059	1.145	2.252	2.785	4.107	8.861
7-26	1.676	1.201	1.418	1.549	1.258	1.110	1.184	1.117	2.275	2.877	4.295	9.396
7-27	1.204	0.979	1.320	1.419	1.284	1.015	1.041	0.802	1.693	2.183	3.503	8.262
7-28	1.157	0.872	1.088	1.273	1.093	0.927	1.069	0.771	1.593	2.029	3.117	7.479
7-30	1.122	0.879	1.096	1.296	1.107	0.970	1.028	0.748	1.561	2.001	3.097	7.498
8-04	1.358	0.851	1.073	1.202	1.146	1.012	1.050	0.905	1.783	2.209	3.282	7.692
8-06	0.862	0.693	0.986	1.227	1.195	0.982	1.083	0.574	1.208	1.555	2.541	7.028
8-07	0.471	0.592	0.796	0.981	0.902	0.771	0.841	0.314	0.767	1.063	1.859	5.354
8-08	1.163	0.716	0.875	1.090	1.044	0.969	1.020	0.775	1.521	1.879	2.754	6.877
8-10	0.906	0.638	0.790	0.987	1.035	0.907	0.993	0.604	1.225	1.544	2.334	6.256
8-12	0.863	0.665	0.909	0.933	0.966	0.947	1.018	0.575	1.195	1.528	2.437	6.301
8-14	0.870	0.579	0.718	0.864	1.012	0.976	1.042	0.579	1.159	1.449	2.167	6.061
8-15	1.198	0.569	0.686	0.844	0.884	0.948	1.048	0.798	1.482	1.767	2.453	6.177
8-17	1.125	0.576	0.695	0.818	0.898	0.814	0.905	0.749	1.413	1.701	2.396	5.831
10-06	1.567	1.088	1.390	1.238	0.906	0.666	0.628	1.044	2.111	2.655	4.045	7.483
10-18	1.114	0.934	1.208	1.202	0.960	0.729	0.733	0.742	1.581	2.048	3.256	6.880

TABLE IX

SOIL MOISTURE DETERMINATION BY NEUTRON PROBE METHOD FOR LOCATION W-2

	DEPTH OF WATER STORED IN SOIL PROFILE (INCHES)							TOTAL	TOTAL	TOTAL	TOTAL	TOTAL
DATE	0-9	9-15	15-21	21-27	27-33	33-39	39-45	0-6	0-12	0-15	0-21	0-45
7-10	2.270	1.280	1.180	1.060	1.220	1.260	1.330	1.512	2.910	3.550	4.730	9.600
7-13	1.510	1.140	1.210	1.120	1.170	1.220	1.410	1.006	2.080	2.265	3.860	8.780
7-20	0.902	0.826	1.091	1.052	1.153	1.269	1.381	0.601	1.315	1.728	2.819	7.674
7-23	1.164	0.682	0.893	0.983	1.062	1.238	1.339	0.775	1.505	1.846	2.739	7.361
7-24	1.613	0.933	1.114	1.151	1.286	1.484	1.539	1.074	2.079	2.546	3.660	9.120
7-26	1.114	0.751	1.029	1.067	1.063	1.227	1.384	0.742	1.489	1.865	2.894	7.635
7-27	1.269	0.782	1.040	1.080	1.171	1.323	1.383	0.845	1.660	2.051	3.091	8.048
7-28	1.441	0.778	0.997	1.076	1.185	1.323	1.438	0.960	1.830	2.219	3.216	8.238
7-30	1.117	0.676	0.906	0.898	1.062	1.172	1.307	0.744	1.455	1.793	2.699	7.138
8-04	0.910	0.761	0.862	0.904	1.029	1.368	1.386	0.606	1.290	1.671	2.533	7.220
8-06	1.071	0.649	0.771	0.819	1.096	1.344	1.479	0.713	1.395	1.720	2.491	7.229
8-07	0.917	0.618	0.726	0.758	1.025	1.281	1.420	0.611	1.226	1.535	2.261	6.745
8-08	1.428	0.689	0.757	0.761	0.987	1.172	1.307	0.951	1.772	2.117	2.874	7.101
8-10	1.154	0.661	0.693	0.679	0.900	1.152	1.250	0.769	1.484	1.815	2.508	6.489
8-12	1.165	0.688	0.708	0.668	0.920	1.119	1.359	0.776	1.509	1.853	2.561	6.627
8-14	0.813	0.562	0.637	0.651	0.853	1.135	1.405	0.541	1.094	1.375	2.012	6.056
8-15	1.376	0.585	0.589	0.588	0.751	1.095	1.416	0.916	1.668	1.961	2.550	6.400
8-17	1.326	0.654	0.683	0.680	0.804	1.085	1.242	0.883	1.317	1.980	2.663	6.474
10-06	2.162	1.215	1.108	0.975	1.065	1.162	1.171	1.440	2.769	3.377	4.485	8.858
10-18	1.844	1.093	1.049	0.977	1.057	1.158	1.209	1.228	2.390	2.937	3.986	8.387

TABLE X

SOIL MOISTURE DETERMINATION BY NEUTRON PROBE METHOD FOR LOCATION W-3

	DEPTH OF WATER STORED IN SOIL PROFILE (INCHES)							TOTAL	TOTAL	TOTAL	TOTAL	TOTAL
DATE	0-9	9-15	15-21	21-27	27-33	33-39	39-45	0-6	0-12	0-15	0-21	0-45
7-13	0.790	0.840	1.060	1.090	1.000	1.070	1.410	0.526	1.210	1.630	2.690	7.260
7-20	0.273	0.619	0.998	1.088	1.067	1.076	1.468	0.182	0.582	0.892	1.890	6.592
7-23	1.650	0.970	1.112	1.246	1.262	1.319	1.599	1.101	2.135	2.620	3.732	9.158
7-24	1.630	0.930	1.051	1.096	1.130	1.156	1.483	1.086	2.095	2.560	3.611	8.476
7-26	0.793	0.679	0.872	0.939	0.990	1.096	1.301	0.528	1.132	1.472	2.344	6.670
7-27	0.766	0.669	0.910	1.008	1.051	1.135	1.370	0.510	1.101	1.435	2.345	6.910
7-28	1.056	0.652	0.889	1.013	1.029	1.072	1.305	0.704	1.382	1.708	2.597	7.015
7-30	0.835	0.618	0.836	0.963	0.982	1.051	1.253	0.556	1.144	1.453	2.289	6.538
8-04	0.987	0.638	0.849	0.983	1.145	1.192	1.468	0.657	1.306	1.625	2.474	7.262
8-06	0.730	0.534	0.686	0.776	0.902	1.061	1.201	0.486	0.997	1.264	1.950	5.890
8-07	0.833	0.523	0.661	0.754	0.901	1.062	1.334	0.555	1.094	1.356	2.017	6.068
8-08	0.986	0.560	0.652	0.766	0.815	0.902	1.035	0.657	1.266	1.546	2.198	5.716
8-10	0.488	0.447	0.580	0.718	0.741	0.835	0.943	0.325	0.711	0.935	1.515	4.752
8-12	0.749	0.531	0.686	0.752	0.805	0.906	1.071	0.499	1.014	1.280	1.966	5.500
8-14	0.592	0.499	0.624	0.686	0.734	0.837	0.985	0.394	0.841	1.091	1.715	4.957
8-15	0.957	0.473	0.478	0.612	0.679	0.816	0.968	0.638	1.193	1.430	1.908	4.983
10-06	1.155	0.827	1.043	0.944	0.843	0.811	0.968	0.769	1.568	1.982	3.025	6.591
10-18	0.826	0.711	0.959	0.786	0.834	0.812	1.053	0.550	1.181	1.537	2.496	5.981

TABLE XI

SOIL MOISTURE DETERMINATION BY NEUTRON PROBE METHOD FOR LOCATION W-4

	DEPTH OF WATER STORED IN SOIL PROFILE (INCHES)							TOTAL	TOTAL	TOTAL	TOTAL	TOTAL
DATE	0-9	9-15	15-21	21-27	27-33	33-39	39-45	0-6	0-12	0-15	0-21	0-45
7-10	1.860	1.100	1.050	1.330	1.710	1.820	1.750	1.239	2.410	2.290	4.010	10.620
7-13	1.200	1.010	1.050	1.320	1.670	1.870	1.720	0.799	1.700	2.210	3.260	9.840
7-20	0.679	0.942	1.088	1.287	1.812	2.121	1.841	0.452	1.150	1.621	2.709	9.770
7-23	2.077	1.071	0.888	1.005	1.487	1.644	1.448	1.383	2.612	3.148	4.036	9.620
7-24	2.064	1.278	1.184	1.391	1.882	2.017	1.802	1.375	2.703	3.342	4.526	11.618
7-26	1.404	0.993	0.981	1.117	1.694	1.849	1.617	0.935	1.900	2.397	3.378	9.655
7-27	1.272	1.009	1.070	1.245	1.845	1.962	1.855	0.847	1.776	2.281	3.351	10.258
7-28	1.532	0.961	1.117	1.319	1.853	2.156	1.882	1.020	2.012	2.493	3.610	10.820
7-30	1.107	0.876	0.946	1.078	1.557	1.768	1.665	0.737	1.545	1.983	2.929	8.997
8-04	0.829	0.787	0.918	1.133	1.726	2.023	1.863	0.552	1.222	1.616	2.534	9.279
8-06	0.641	0.782	0.946	1.065	1.672	1.876	1.663	0.427	1.032	1.423	2.369	8.645
8-07	0.736	0.832	0.971	1.050	1.779	1.907	1.772	0.490	1.152	1.568	2.539	9.047
8-08	1.362	0.838	1.050	1.187	1.821	1.926	1.843	0.907	1.781	2.200	3.250	10.027
8-10	0.850	0.754	0.866	0.967	1.514	1.760	1.574	0.566	1.227	1.604	2.470	8.285
8-12	0.893	0.855	0.963	1.073	1.665	1.864	1.702	0.595	1.320	1.748	2.711	9.015
8-14	0.371	0.600	0.778	0.882	1.484	1.703	1.600	0.247	0.671	0.971	1.749	7.418
8-15	0.906	0.739	0.874	1.003	1.636	2.022	1.890	0.603	1.275	1.645	2.519	9.070
10-06	1.584	1.023	0.920	1.035	1.589	1.883	1.667	1.055	2.095	2.607	3.527	9.701
10-18	1.053	0.891	0.915	1.021	1.551	1.834	1.724	0.701	1.498	1.944	2.859	8.989

TABLE XII

SOIL MOISTURE DETERMINATION BY NEUTRON PROBE METHOD FOR LOCATION NE-1

	DEPTH OF WATER STORED IN SOIL PROFILE (INCHES)							TOTAL	TOTAL	TOTAL	TOTAL	TOTAL
DATE	0-9	9-15	15-21	21-27	27-33	33-39	39-45	0-6	0-12	0-15	0-21	0-45
7-10	1.200	0.520	0.550	0.520	0.500	0.500	0.510	0.799	1.460	1.720	2.270	4.300
7-20	0.479	0.585	0.688	0.639	0.580	0.591	0.580	0.319	0.771	1.064	1.752	4.142
7-23	2.103	0.919	0.999	0.983	0.908	0.908	0.857	1.402	2.562	3.022	4.021	7.677
7-26	1.274	0.691	0.685	0.713	0.673	0.746	0.777	0.849	1.619	1.965	2.260	5.559
7-30	0.910	0.585	0.701	0.726	0.711	0.768	0.750	0.606	1.202	1.495	2.196	5.151
8-04	1.094	0.604	0.736	0.616	0.618	0.624	0.634	0.729	1.396	1.698	2.434	4.926
8-05	1.438	0.644	0.647	0.586	0.570	0.605	0.567	0.958	1.760	2.082	2.729	5.057
8-07	1.257	0.648	0.747	0.697	0.704	0.737	0.771	0.838	1.581	1.905	2.652	5.561
8-09	1.323	0.699	0.803	0.732	0.672	0.698	0.723	0.882	1.672	2.022	2.825	5.650
8-10	1.160	0.675	0.752	0.719	0.610	0.696	0.700	0.773	1.497	1.835	2.587	5.312
8-13	1.212	0.632	0.657	0.668	0.673	0.672	0.635	0.808	1.528	1.844	2.501	5.149
10-06	1.357	0.787	0.720	0.621	0.545	0.528	0.514	0.904	1.750	2.144	2.864	5.072
10-18	1.017	0.606	0.677	0.581	0.551	0.527	0.559	0.678	1.320	1.623	2.300	4.518

TABLE XIII

SOIL MOISTURE DETERMINATION BY NEUTRON PROBE METHOD FOR LOCATION NE-2

	DEPTH OF WATER STORED IN SOIL PROFILE (INCHES)							TOTAL	TOTAL	TOTAL	TOTAL	TOTAL
DATE	0-9	9-15	15-21	21-27	27-33	33-39	39-45	0-6	0-12	0-15	0-21	0-45
7-10	1.200	0.660	0.540	0.570	0.700	1.160	1.670	0.799	1.530	1.860	2.400	6.500
7-20	0.345	0.562	0.637	0.669	0.844	1.324	1.830	0.229	0.626	0.907	1.544	6.211
7-23	1.784	0.950	0.934	0.964	1.050	1.494	2.009	1.189	2.259	2.734	3.668	9.185
7-26	1.166	0.782	0.785	0.803	0.967	1.342	1.779	0.777	1.557	1.948	2.733	7.624
7-30	0.773	0.681	0.763	0.813	0.956	1.386	1.674	0.515	1.113	1.454	2.217	7.046
8-04	0.787	0.606	0.666	0.704	0.853	1.133	1.552	0.524	1.090	1.393	2.059	6.301
8-05	1.221	0.638	0.705	0.724	0.952	1.214	1.672	0.814	1.540	1.859	2.564	7.126
8-07	0.875	0.609	0.602	0.649	0.816	1.138	1.674	0.583	1.179	1.484	2.086	6.363
8-09	1.059	0.739	0.770	0.815	0.885	1.140	1.636	0.706	1.428	1.798	2.568	7.044
8-10	0.968	0.685	0.794	0.785	0.948	1.200	1.652	0.645	1.310	1.653	2.447	7.032
8-13	0.850	0.561	0.593	0.590	0.736	0.884	1.332	0.566	1.130	1.411	2.004	5.546
10-06	0.960	0.704	0.662	0.604	0.663	0.897	1.485	0.639	1.312	1.664	2.326	5.975
10-18	0.771	0.549	0.600	0.578	0.673	0.968	1.565	0.513	1.045	1.320	1.920	5.704

TABLE XIV

SOIL MOISTURE DETERMINATION BY NEUTRON PROBE METHOD FOR LOCATION NE-3

	DEPTH OF WATER STORED IN SOIL PROFILE (INCHES)							TOTAL	TOTAL	TOTAL	TOTAL	TOTAL
DATE	0-9	9-15	15-21	21-27	27-33	33-39	39-45	0-6	0-12	0-15	0-21	0-45
7-10	1.340	0.830	1.300	1.790	1.630	1.330	1.200	0.893	1.760	2.170	3.470	9.420
7-20	0.509	0.832	1.413	1.868	1.710	1.414	1.235	0.339	0.925	1.341	2.754	8.981
7-23	2.085	1.183	1.529	2.052	1.870	1.611	1.574	1.389	2.676	3.268	4.797	11.904
7-26	1.521	1.016	1.412	1.916	1.812	1.455	1.362	1.014	2.029	2.537	3.949	10.494
7-30	1.231	0.817	1.257	1.763	1.634	1.394	1.382	0.820	1.639	2.048	3.305	9.478
8-04	0.871	0.682	0.955	1.377	1.330	1.165	1.181	0.580	1.212	1.553	2.508	7.561
8-05	1.470	0.781	1.066	1.571	1.558	1.323	1.238	0.979	1.860	2.251	3.317	9.007
8-07	1.135	0.717	0.994	1.355	1.441	1.215	1.133	0.756	1.493	1.852	2.846	7.990
8-09	1.284	0.820	1.046	0.736	0.813	1.282	1.091	0.856	1.694	2.104	3.150	7.072
8-10	1.116	0.669	0.892	1.214	1.368	1.233	1.187	0.743	1.450	1.785	2.677	7.679
10-06	1.441	1.073	1.345	1.727	1.528	1.163	0.791	0.960	1.977	2.514	3.859	9.068
10-18	1.159	0.879	1.293	1.693	1.538	1.327	1.182	0.772	1.598	2.038	3.331	9.071

TABLE XV

SOIL MOISTURE DETERMINATION BY NEUTRON PROBE METHOD FOR LOCATION NE-4

	DEPTH OF WATER STORED IN SOIL PROFILE (INCHES)							TOTAL	TOTAL	TOTAL	TOTAL	TOTAL
DATE	0-9	9-15	15-21	21-27	27-33	33-39	39-45	0-6	0-12	0-15	0-21	0-45
7-10	1.120	0.680	0.700	0.840	1.460	1.910	2.050	0.746	1.460	1.800	2.500	8.760
7-20	0.361	0.673	0.849	0.867	1.460	2.027	2.218	0.241	0.697	1.034	1.883	8.455
7-23	1.736	0.931	0.947	1.079	1.601	2.148	2.305	1.157	2.201	2.667	3.614	10.747
7-26	1.303	0.807	0.842	0.958	1.433	1.953	2.129	0.858	1.706	2.110	2.952	9.425
7-30	0.993	0.718	0.840	0.954	1.060	1.968	2.217	0.662	1.352	1.711	2.551	8.750
8-04	0.702	0.550	0.605	0.736	1.098	1.618	1.950	0.468	0.977	1.252	1.857	7.259
8-05	1.309	0.659	0.707	0.867	1.226	1.851	2.133	0.872	1.638	1.968	2.675	8.752
8-07	1.394	0.633	0.699	0.812	1.064	1.713	2.085	0.929	1.710	2.027	2.726	8.400
8-09	1.438	0.680	0.710	0.815	1.102	1.498	1.387	0.958	1.778	2.118	2.828	7.630
8-10	1.056	0.611	0.646	0.713	1.013	1.458	1.925	0.703	1.361	1.667	2.313	7.422
10-06	1.356	0.989	0.970	0.722	0.824	1.417	1.864	0.903	1.851	2.345	3.315	8.142

APPENDIX B

GRAVIMETRIC SOIL MOISTURE DATA

TABLE XVI

SOIL MOISTURE DETERMINATION BY OVEN DRY METHOD FOR LOCATION W-1

	DEPTH OF WATER STORED IN SOIL PROFILE (INCHES)				TOTAL	TOTAL	TOTAL	TOTAL
DATE	0-6	6-12	12-18	18-24	0-9	0-12	0-15	0-21
7-20	0.381	0.937	0.974	0.925	0.849	1.318	1.804	2.754
7-23	1.015	0.908	0.824	1.205	1.469	1.923	2.335	3.349
7-26	0.618	0.636	0.908	1.142	0.936	1.254	1.708	2.733
7-28	0.643	0.559	0.750	1.112	0.922	1.202	1.576	2.507
7-30	0.662	0.596	0.727	1.109	0.960	1.258	1.622	2.540
8-08	0.637	0.261	0.521	1.088	0.767	0.898	1.158	1.963
8-14	0.164	0.231	0.342	0.392	0.279	0.395	0.565	0.932
10-06	0.828	1.055	1.345	1.312	1.355	1.883	2.555	3.884
10-18	0.646	0.830	1.067	1.315	1.061	1.476	2.010	3.201

TABLE XVII

SOIL MOISTURE DETERMINATION BY OVEN DRY METHOD FOR LOCATION W-2

	DEPTH OF WATER STORED IN SOIL PROFILE (INCHES)				TOTAL	TOTAL	TOTAL	TOTAL
DATE	0-6	6-12	12-18	18-24	0-9	0-12	0-15	0-21
7-20	0.556	0.718	0.992	1.137	0.915	1.274	1.770	2.834
7-23	1.382	0.979	1.072	0.966	1.871	2.361	2.896	3.915
7-26	0.773	0.764	0.989	0.886	1.155	1.537	2.035	2.970
7-30	0.911	0.824	0.956	0.995	1.323	1.735	2.213	3.188
8-08	0.914	0.533	0.775	0.749	1.180	1.447	1.834	2.596
10-06	1.321	1.351	1.359	1.132	1.996	2.672	3.351	4.597
10-18	0.917	1.184	1.184	1.088	1.509	2.101	2.693	3.829

TABLE XVIII

SOIL MOISTURE DETERMINATION BY OVEN DRY METHOD FOR LOCATION W-3

	DEPTH OF WATER STORED IN SOIL PROFILE (INCHES)				TOTAL	TOTAL	TOTAL	TOTAL
DATE	0-6	6-12	12-18	18-24	0-9	0-12	0-15	0-21
7-20	0.284	0.582	1.064	1.146	0.575	0.866	1.398	2.503
7-23	0.957	0.827	0.860	0.980	1.370	1.784	2.213	3.133
7-26	0.530	0.587	0.899	1.073	0.823	1.117	1.566	2.552
7-30	0.507	0.286	0.830	0.964	0.650	0.793	1.208	2.105
8-08	0.620	0.247	0.496	0.604	0.743	0.867	1.114	1.664
8-22	0.694	0.218	0.389	0.454	0.803	0.912	1.107	1.529
8-24	0.726	0.240	0.299	0.634	0.846	0.966	1.116	1.583
10-06	0.869	0.998	1.229	1.093	1.368	1.867	2.482	3.643
10-18	0.638	0.753	0.922	0.996	1.014	1.391	1.851	2.810

TABLE XIX

SOIL MOISTURE DETERMINATION BY OVEN DRY METHOD FOR LOCATION W-4

	DEPTH OF WATER STORED IN SOIL PROFILE (INCHES)				TOTAL	TOTAL	TOTAL	TOTAL
DATE	0-6	6-12	12-18	18-24	0-9	0-12	0-15	0-21
7-20	0.232	0.462	0.892	1.104	0.463	0.694	1.140	2.138
7-23	1.066	1.068	0.878	1.073	1.600	2.134	2.573	3.548
7-26	0.666	0.934	1.003	1.019	1.133	1.600	2.101	3.112
7-30	0.668	0.415	0.732	0.961	0.875	1.083	1.449	2.296
8-08	0.536	0.363	0.662	0.782	0.717	0.899	1.229	1.951
8-22	0.750	0.408	0.616	0.702	0.954	1.158	1.466	2.125
10-06	0.866	1.068	1.087	1.091	1.400	1.934	2.477	3.566
10-18	0.644	0.854	0.944	1.003	1.071	1.498	1.970	2.943

TABLE XX

SOIL MOISTURE DETERMINATION BY OVEN DRY METHOD FOR LOCATION NE-1

	DEPTH OF WATER STORED IN SOIL PROFILE (INCHES)				TOTAL	TOTAL	TOTAL	TOTAL
DATE	0-6	6-12	12-18	18-24	0-9	0-12	0-15	0-21
7-11	0.746	0.739	0.664	1.147	1.115	1.485	1.816	2.721
8-15	0.464	0.174	0.109	0.171	0.551	0.638	0.692	0.831
8-16	0.585	0.205	0.212	0.315	0.689	0.790	0.899	1.162
8-17	0.621	0.604	0.224	0.270	0.923	1.225	1.337	1.584
8-19	0.278	0.197	0.179	0.242	0.376	0.475	0.563	0.773
8-21	0.698	0.336	0.219	0.316	0.866	1.034	1.143	1.410
8-23	0.297	0.178	0.181	0.242	0.386	0.475	0.565	0.776
8-24	0.159	0.142	0.180	0.173	0.230	0.301	0.391	0.576
10-06	0.649	0.703	0.756	0.666	1.000	1.352	1.729	2.440
10-18	0.545	0.539	0.744	0.735	0.814	1.084	1.455	2.194

TABLE XXI

SOIL MOISTURE DETERMINATION BY OVEN DRY METHOD FOR LOCATION NE-2

	DEPTH OF WATER STORED IN SOIL PROFILE (INCHES)				TOTAL	TOTAL	TOTAL	TOTAL
DATE	0-6	6-12	12-18	18-24	0-9	0-12	0-15	0-21
7-11	0.624	0.796	0.736	0.616	1.022	1.420	1.788	2.464
8-13	0.246	0.219	0.431	0.376	0.355	0.465	0.681	1.085
8-15	0.411	0.210	0.332	0.310	0.516	0.621	0.787	1.108
8-16	0.604	0.215	0.361	0.326	0.711	0.819	0.999	1.343
8-17	0.592	0.322	0.318	0.314	0.753	0.914	0.953	1.389
8-19	0.348	0.350	0.236	0.229	0.523	0.698	0.816	1.048
8-21	0.598	0.216	0.403	0.392	0.706	0.814	1.015	1.412
8-23	0.239	0.185	0.182	0.239	0.331	0.424	0.514	0.725
8-24	0.164	0.148	0.222	0.281	0.238	0.312	0.423	0.674
10-06	0.614	0.339	0.733	0.673	0.783	0.953	1.319	2.022
10-18	0.398	0.517	0.609	0.587	0.656	0.915	1.219	1.817

TABLE XXII

SOIL MOISTURE DETERMINATION BY OVEN DRY METHOD FOR LOCATION NE-3

	DEPTH OF WATER STORED IN SOIL PROFILE (INCHES)				TOTAL	TOTAL	TOTAL	TOTAL
DATE	0-6	6-12	12-18	18-24	0-9	0-12	0-15	0-21
8-13	0.529	0.449	0.663	0.863	0.753	0.978	1.309	2.072
8-15	0.519	0.368	0.585	0.710	0.703	0.887	1.179	1.826
8-16	0.738	0.408	0.598	0.601	0.942	1.146	1.445	2.044
8-17	0.790	0.729	0.509	0.540	1.154	1.519	1.773	2.298
8-19	0.599	0.610	0.515	0.511	0.904	1.209	1.466	1.978
8-21	0.947	0.685	0.625	0.803	1.289	1.632	1.944	2.658
8-23	0.449	0.508	0.575	0.692	0.703	0.957	1.244	1.877
10-06	0.897	1.082	1.350	1.370	1.438	1.979	2.654	4.014
10-18	0.676	0.986	1.351	1.501	1.169	1.662	2.337	3.763

TABLE XXIII

SOIL MOISTURE DETERMINATION BY OVEN DRY METHOD FOR LOCATION NE-4

	DEPTH OF WATER STORED IN SOIL PROFILE (INCHES)				TOTAL	TOTAL	TOTAL	TOTAL
DATE	0-6	6-12	12-18	18-24	0-9	0-12	0-15	0-21
8-13	0.528	0.485	0.398	0.515	0.770	1.013	1.210	1.665
8-15	0.468	0.258	0.442	0.528	0.597	0.726	0.947	1.432
8-17	0.798	0.636	0.488	0.557	1.116	1.434	1.678	2.200
8-19	0.477	0.493	0.394	0.386	0.723	0.970	1.166	1.556
8-21	0.787	0.522	0.519	0.415	1.048	1.309	1.568	2.035
8-23	0.962	0.608	0.556	0.622	1.266	1.570	1.848	2.437
10-06	0.766	0.899	1.277	1.206	1.215	1.665	2.303	3.695
10-18	0.605	0.880	1.054	0.984	1.045	1.485	2.012	3.031

APPENDIX C

METEORLOGICAL DATA

TABLE XXIV

RAINFALL DATA

DATE	AMOUNT (INCHES)
7-14	2.20
7-20	0.55
7-21	0.65
7-28	0.05
7-30	0.65
8-09	0.20
8-15	0.25
9-01	0.09
9-08	3.25
9-13	0.76
9-17	1.04
9-27	2.23
10 04	1.14
10-12	1.45

TABLE XXV

DAILY TEMPERATURES FOR MONTH OF JULY

STATION		DAY OF MONTH 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
CLOUD CHIEF	MAX	98	99	100	104	97	102	102	101	97	89	90	91	90	90	84	88
	MIN	72	73	71	70	68	68	69	61	68	66	63	64	68	69	62	60
WEATHERFORD	MAX	96	96	97	101	100	100	99	98	96	96	89	90	89	99	82	87
	MIN	75	75	73	73	72	71	73	71	71	69	66	67	70	70	63	61
CARNEGIE	MAX	97	97	99	102	100	97	98	94	97	91	88	89	91	90	61	86
	MIN	74	76	72	70	69	71	72	72	70	70	61	67	69	70	65	62

STATION		17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
CLOUD CHIEF	MAX	96	96	99	103	90	90	92	94	88	91	95	87	83	90	90
	MIN	63	73	70	72	63	63	65	72	65	65	62	65	67	63	65
WEATHERFORD	MAX	94	94	96	102	102	91	92	94	94	92	95	94	86	94	91
	MIN	68	73	72	77	65	66	66	73	66	68	67	68	67	70	67
CARNEGIE	MAX	94	96	96	103	99	91	92	93	91	91	94	92	92	88	85
	MIN	66	73	73	80	64	66	68	73	67	68	63	70	70	70	67

TABLE XXVI

DAILY TEMPERATURES FOR MONTH OF AUGUST

STATION		DAY OF MONTH 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CLOUD CHIEF	MAX	88	86	87	84	91	94	97	95	98	99	100	100	97	99	103
	MIN	61	60	60	61	61	65	72	67	69	70	65	65	69	68	69
WEATHERFORD	MAX	87	86	87	88	89	93	96	95	97	97	99	99	97	97	102
	MIN	62	63	63	66	65	66	72	72	70	71	68	70	74	70	73
CARNEGIE	MAX	85	85	85	85	88	92	95	94	98	97	96	100	95	96	101
	MIN	64	62	60	61	64	65	72	69	71	72	68	67	69	69	72

STATION		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
CLOUD CHIEF	MAX	91	96	94	97	97	100	104	102	104	100	97	95	91	89	92	92
	MIN	63	69	65	64	67	66	70	73	67	76	65	64	64	68	63	71
WEATHERFORD	MAX	100	97	93	96	96	99	101	101	104	103	98	93	94	93	91	90
	MIN	67	71	70	68	72	71	72	74	73	73	70	69	69	69	69	70
CARNEGIE	MAX	91	93	92	96	96	98	103	100	106	100	95	93	92	89	91	92
	MIN	66	70	68	68	69	65	72	71	74	71	70	72	74	67	69	74

APPENDIX D

APPARENT SPECIFIC GRAVITIES

TABLE XXVII

APPARENT SPECIFIC GRAVITY OF SOIL SAMPLES
FOR NORTH-EAST TEST LINE

SAMPLE LOCATION	DEPTH IN (INCHES)	APPARENT SPECIFIC GRAVITY
NE-1	1.5-4.5	1.53
NE-1	7.5-10.5	1.54
NE-1	13.5-16-5	1.54
NE-1	19.5-22.5	1.49
NE-2	1.5-4.5	1.48
NE-2	7.5-10.5	1.51
NE-2	13.5-16.5	1.57
NE-2	19.5-22.5	1.49
NE-3	1.5-4.5	1.46
NE-3	7.5-10.5	1.58
NE-3	13.5-16.5	1.64
NE-3	19.5-22.5	1.56
NE-4	1.5-4.5	1.61
NE-4	7.5-10.5	1.60
NE-4	13.5-16.5	1.55
NE-4	19.5-22.5	1.53

TABLE XXVIII

APPARENT SPECIFIC GRAVITY OF SOIL SAMPLES
FOR WEST TEST LINE

SAMPLE LOCATION	DEPTH IN (INCHES)	APPARENT SPECIFIC GRAVITY
W-1	1.5-4.5	1.61
W-1	7.5-10.5	1.63
W-1	13.5-16.5	1.58
W-1	19.5-22.5	1.55
W-2	1.5-4.5	1.71
W-2	7.5-10.5	1.72
W-2	13.5-16.5	1.72
W-2	19.5-22.5	1.59
W-3	1.5-4.5	1.57
W-3	7.5-10.5	1.58
W-3	13.5-16.5	1.59
W-3	19.5-22.5	1.49
W-4	1.5-4.5	1.63
W-4	7.5-10.5	1.70
W-4	13.5-16.5	1.64
W-4	19.5-22.5	1.62

APPENDIX E

IRRIGATION LIST

TABLE XXIX

LIST OF IRRIGATION FOR SEASON

LOCATION	DATE OF IRRIGATION	SPEED SETTING (%)
WEST	7-27	40
WEST	8-04	40
NE	8-04	40
WEST	8-07	35
NNW	8-09	35
NORTH	8-09	35
NE	8-10	35
NE	8-14	95
WEST	8-15	95
WEST	8-15	40
NE	8-16	40
NE	8-20	40
NORTH	8-21	40
NNW	8-21	40
WEST	8-22	40
WEST	8-24	40
NNW	8-24	40
NORTH	8-24	40
NE	8-25	40
NORTH	8-30	45
WEST	8-30	45
NE	8-30	45
NNW	8-30	45

VITA

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