TWO IRRIGATION SCHEDULING METHODS FOR CORN PRODUCTION

by 6408

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INTRODUCTION

According to Senator George McGovern (31), "the major problem in the 1940's was the atomic bomb, the major problem in the 1950's was the cold war, and the major problem in the 1960's and beyond is food". He also stated the world food supply has an annual growth rate of 1%, and the world population's annual growth rate is 2 %. Although great strides have been made in Thialand and Pakistan, Senator McGovern cautions against excessive optimism at this point. Although these statements seem remote and unrelated to Kansas, they are not. Dr. James A. McCain (30) stated that "America is now feeding 1 in 20 of the persons in free Asia, and Kansas is feeding 1 in 50".

Irrigated land in Kansas, although presently amounting to less than 10% of the cropland, is expanding rapidly. In 1968, the Division of Water Resources, Kansas Board of Agriculture approved the appropriation of 800,000 acre-feet of water from the state's ground water resources. Although not all of the appropriation was for irrigation water, a large percent of the increase was (23). Farmers in Kansas are now irrigating more than ten times the acreage of 10 years ago (23).

How can irrigation in Kansas make its maximum contribution towards reducing our world's food problem? Gulhati and Smith (10), in their remarks concerning irrigated agriculture history, state that the areas of soil reclamation and water management have not, in the past, received much attention. They add that the history of irrigation clearly points to the need for far greater attention to these phases.

In order to give greater attention to irrigation water management, a definition is required. The U.S. Soil Conservation Service defines irrigation water management as "the use and management of irrigation water, where the quantity of water used for each irrigation is determined by the water-holding capacity of the soil, and the need of the crop, where the water is applied at a rate and in such a manner that the crop can use it efficiently and significant erosion does not occur" (from Jensen, 21). This definition raises the question: what is the need of the crop? Jensen (21), suggests the need of the crop to be deliberate depletion of the soil moisture to a level which produces the most desirable product from a crop. It is this phase of irrigation water management that concerns the study reported herein.

OBJECTIVES OF THE STUDY

The objectives of the study were to:

1. Investigate two methods of scheduling irrigation on the basis of:

   (a) time of irrigation initiation

   (b) amount of water used

   (c) crop response

2. Obtain more knowledge through physical measurement of the properties of the soil, as they apply to irrigation, on the Kansas State University Irrigation Experiment Field.

3. Determine if the Jensen computer program could be adapted to schedule irrigations in Kansas.

REVIEW OF LITERATURE

As previously mentioned, Gulhati and Smith (10) indicated more attention needs to be given to water management. Robins (40) states that, "appropriate frequency of irrigation water application, in relation to crop needs and soil water conditions, is an additional management area subject to significant improvement." This statement is made in regard to reducing the amount of water required for irrigation.

Jensen (20), in his discussion of irrigation scheduling practices, indicated that the practices concerning timing and amount, have not changed significantly from those observed 27 years ago by Israelson (15). The potential for better irrigation water management has improved because of better water control and measurement facilities (44), increased knowledge of each crop's response to soil moisture levels (11), more reliable methods for estimating evapotranspiration (20), improved system design criteria (1), and commercially available soil moisture instrumentation for timing irrigation (11). Knowing the potential for better irrigation management has improved, a review of the literature on two techniques for timing irrigation was conducted.

Scheduling Methods

The criteria most suitable for scheduling irrigation varies. When water is scarce, irrigation should be scheduled to maximize crop production per unit of water applied. Where land is more scarce, irrigation should be scheduled to maximize crop production per unit of land. Other considerations may dominate in given situations. Irrigation may be scheduled to facilitate other farm operations, to control groundwater level, to accomplish leaching of salts, to overcome slow infiltration rates, or to accommodate the schedule of water delivery to the farm (11). Taylor (50) states that "irrigation should take place while the soil water potential is still high enough that the soil can and does supply water fast enough to meet the local atmospheric demands without placing the plants under a stress that would reduce yield or quality of the harvested crop."

There have been many proposals for irrigation scheduling techniques. A list of irrigation scheduling methods would include: 1) time interval (24), 2) date (46), 3) visual indicators such as foliage insulation and color, vegetative development, fruit growth, and color (2, 11), 4) plant temperature (2, 11), 5) measurement of plant water deficits such as infiltration rate of stomatal apertures and plant water potential (2, 11), 6) appearance of soil (11), 7) soil moisture blocks and tensiometers (5, 11, 12), and 8) the meterological approach (20, 6, 57).

Since the study being reported on in this thesis used several tensiometer levels and a meterological approach to schedule irrigation, the remainder of the review of literature will be devoted to these two scheduling methods.

Tensiometer

The tensiometer is a device for measuring the soil moisture tension when the soil is not too dry and when osmotic pressure is negligible (27). Kirkham and Powers (27) equate soil moisture tension, (cm), and capillary potential (erg/gm) of soil water. Rose (45) explains this relationship as follows: let pressure in the soil water, measured from the gas pressure acting on the soil water as datum, be denoted by P. Then:

$$p = gh\rho$$

where

p = External gas pressure, dyne/cm^2

ρ = Density of fluid, gm/cm^3

g = Gravitational force, cm/sec^2

h = Submerged depth, cm

Capillary potential is defined as "the work to pull a gram of water from under a soil water film at location A to location B at the same level where the curvature of the water is zero" (27). Then, assuming the transfer to take place through a tube of cross-sectional area, dA, the equation becomes:

$$W = pdAl \qquad (2)$$
$$= pdv$$

where

W = Work done in the transfer, dyne-cm or erg

l = Length of the tube, cm

dv = Infinitesimal volume of water transferred, cm^3

The capillary potential per unit volume is then:

$$\psi\ vol = p \qquad (3)$$
$$\psi\ mass = W/pdV \qquad (4)$$

and

$$= P/\rho$$

$$\psi\ weight = W/\rho gdV \qquad (5)$$
$$= P/\rho g$$
$$= h$$

ψ = The capillary potential on a volume, mass or weight basis, dyne/cm^2, erg/ gm, cm

Plate I shows a tensiometer placed in the soil. The small pores in the tensiometer make a connection between soil water held in soil pores and a tension column. The cup pores must be smaller than the soil pores in which the tension is measured or air may enter the cup. From Plate I, the tension height is given by (27):

$$h = 13.6\, d - H \qquad (6)$$

h = Tension height, cm

d = Height of mercury rise, cm

H = Height of water column from mercury to the porous cup, cm

Although water theoretically has a high tensile strength (52), gauge tension in a tensiometer will ordinarily not be more than .75 atmospheres because of dissolved air, and other impurities in the water (38).

From the comments of Taylor (50), and from the discussion of Richards (48), it is apparent that in order to maximize crop production, irrigation must be scheduled somewhere between the field capacity and the permanent wilting point. A program has been proposed by Richards (39) for scheduling irrigation based on tensiometer readings at two or more depths. Briefly, irrigation was scheduled by tensiometer readings reaching a prescribed value for a soil depth where feeder root concentration is greatest. The duration of the irrigation was judged by instruments reading soil tension at a deeper location. Taylor (50) proposed that the arithmetic integration of soil moisture tension, measured at various

EXPLANATION OF PLATE I

A schematic view of a tensiometer

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

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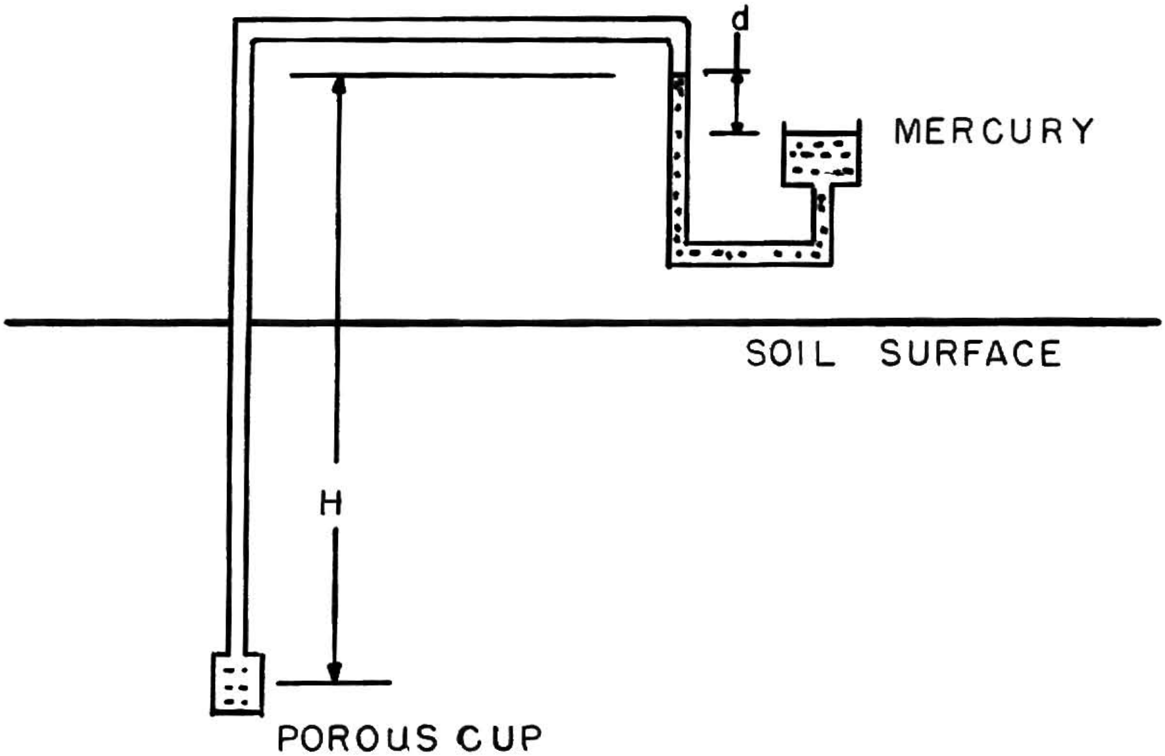


PLATE I

depths in the root zone, be used to obtain a single, integrated value, and that this integrated value be used to schedule irrigations. Taylor has compiled ranges in values of water tension required for optimum growth of many common crops. These ranges in values are based on instruments placed at the depth of maximum root activity for crops growing on soils low in salts and well-fertilized. His suggested range for vegetative corn is .50 bars, and for ripening corn is 8.00-12.00 bars.

Although tensiometers have been available for quite some time, and have improved since the first units were made by Dr. L.A. Richards and Dr. William Gardner at Utah State University (16), they have not received wide-spread acceptance. Duffin (5) lists two reasons for resistance to adoption of tensiometers: 1) the time involved in servicing, and 2) value of the instrument is questioned. He further states that less than 5% of California's irrigated acres are presently scheduled with tensiometers.

Meteorological Approach

Haise and Hagan (11), in their coverage of scheduling methods, list a number of investigators using meteorological approaches. Numerous correlations have been made between evapotranspiration and evaporation from pans or tanks and from atmometers (small, wet, porous surfaces). Tanner (49) states that over appropriate time periods there is a high correlation between evaporation from pans and atmometers and from water bodies, wetted soils, and vegetation amply supplied with water.

However, Pruitt and Angus (37) show that selection of pan site has a marked influence on measured evapotranspiration.

Pruitt (36) found that the regrowth and cutting of alfalfa surrounding a 10 m x 10 m weather station increased the average estimated evapotranspiration/actual evapotranspiration ratio from .95 to 1.20 It is apparent that the transfer of evaporation data and evapotranspiration relationships from project to project and even within a project can be done only with extreme caution. Various investigators reported a lack of success with this method due to extreme variability and indicated that the pans did not respond to different exposures in the same manner as the crop (11).

Another meteorological approach has been developed by Jensen. This approach uses a time-sharing computer program to estimate soil moisture depletion, the number of days prior to the next irrigation, and the amount of water that should be applied. The program was initially tried on plots in 1966 (20).

This predictive approach begins with an estimate of the daily potential evapotranspiration rates. Then, a crop coefficient which is a function primarily of surface soil moisture and stage of growth is applied to the potential evapotranspiration. Crop coefficients are based on experimental data and are adjusted automatically by the program to reflect changes in surface soil moisture caused by irrigation, precipitation, or evapotranspiration. The Jensen procedure is outlined in Plate II and is as follows (20, 22, 6, 18).

1. Estimate daily potential evapotranspiration, E_{t_p}. Either an approximate energy balance or a combination equation can be used. A combination equation developed by Penman was used to predict E_{t_p} for the program used in this research.

EXPLANATION OF PLATE II

Sequence of steps in the Jensen computer program.

START

↓

READ REGIONAL CONSTANTS
AND CURRENT CLIMATIC DATA
FOR EACH REGION

↓

READ LAST WEEK'S CLIMATIC DATA,
SOIL MOISTURE DEPLETION, CUMMULATIVE
RAIN, AND IRRIGATION

↓

PRINT DAILY CLIMATIC SUMMARY AND
POTENTIAL E.T. FOR EACH REGION

↓

FOR EACH REGION, FARM AND FIELD: READ
CONTROL AND PREVIOUS STATUS DATA, CALCULATE
DAILY E.T. , SOIL MOISTURE DEPLETION, AVERAGE
E.T., DAYS BEFORE NEXT IRRIGATION, AND AMOUNT
OF WATER TO APPLY

↓

WRITE COMPUTED DATA INTO FILE FOR LATER PRINTING

↓

WRITE LAST WEEK OF CLIMATIC DATA, SOIL MOISTURE
DEPLETION, CUMULATIVE RAIN, RAIN, AND IRRIGATION

↓

PRINT REGIONAL DATA AND DATA FOR EACH FARM AND FIELD

↓

STOP

PLATE II

The daily parameters required are:

a. Solar radiation

b. Daily maximum and minimum air temperatures

c. Windspeed or daily wind run at a height of two meters, or adjusted to two meters by the log-profile or the 1/7 power law

d. Mean daily dew point temperature

e. Solar radiation for the corresponding cloudless day for the area

The Penman equation is:

$$E_{tp} = \frac{\Delta}{\Delta+\gamma} (R_n - G) + \frac{\gamma}{\Delta+\gamma} (15.36)(1.0 + .01W)(e_s - e_d) \quad (7)$$

where,

Δ = Slope of the saturation vapor-pressure-temperature curve

γ = Psychrometric constant

e_s = Mean saturation vapor pressure, mb (mean at maximum and minimum daily air temperature)

e_d = Saturation vapor pressure at mean dew point temperature, mb

W = Total daily wind run, miles

R_n = Daily net radiation, cal/cm^2

G = Daily soil heat flux, cal/cm^2

The parameters $\Delta/(\Delta+\gamma)$ and $\gamma/(\Delta+\gamma)$ are mean air temperature weighing factors whose sum is 1.0 (20). Further explanation of this equation and its development is in Rose (45).

If windspeed and humidity data are not available, a two-parameter equation may be used if advective conditions are not severe (20). The equation, generally called the modified Jensen-Haise, is:

$$E_{tp} = C_t \ (T - T_x) \ R_s \quad (8)$$

where,

C_t = Air temperature coefficient, constant for a given area and derived from the long-term mean maximum and minimum temperatures for the month of highest mean air temperature

T = Mean daily air temperatures

T_x = Linear equation intercept on the temperature axis

R_s = Daily solar radiation expressed as the daily equivalent depth of evaporation

C_t and T_x may be determined by calibration when accurate evapotranspiration data are available for an area. When calibration data are not available, C_t may be calculated for aerodynamically rough crops at normal summer mean air temperatures and elevations less than 2000 feet by:

$$C_t = \frac{1}{48 + 13\, C_H} \quad (T \text{ in } {}^\circ F) \qquad (9)$$

where

C_H, a humidity index, is:

$$C_H = \frac{37.5\text{mm Hg}}{e_2 - e_1} + \frac{50\text{mb}}{e_2 - e_1} \qquad (10)$$

The mean saturation vapor pressure, e_2, is measured at the maximum air temperatures during the warmest month. The mean saturation vapor pressure, e_1, is measured at the minimum air temperatures during the same month (20). Daily solar radiation is usually reported in cal/cm (Langleys) and may be converted to equivalent depths of evaporation assuming 585 cal/g by:

Langleys x .0171 = mm (11)

2. Determine the crop coefficient based on the stage of growth, the time since an irrigation or rainfall, and the remaining available soil moisture. The crop coefficient can be estimated using the following energy balance components if experimental data are not involved (20):

$$K_t = \frac{1 + \beta_o}{1 + \beta} \quad \frac{(Rn + G)}{(Rn_o + G_o)} \tag{12}$$

where

β = (H/LE), the Bowen ratio

H = Sensible heat flux to or from the air

Rn= Net radiation

LE= Latent heat of evaporation multiplied by the evaporation rate

G = Sensible heat flux to or from the soil

The subscript "o" designates concurrent values for the reference crop in the immediate vicinity. The crop coefficient is approximated in the computer program using the equation:

$$K_c = K_{co} K_a + K_s \tag{13}$$

where

K_{co} = Mean crop coefficient based on experimental data where soil moisture was not limiting

K_a = Relative coefficient as available soil moisture becomes limiting (for this program K was assumed to be proportional to the logarithm of 1 plus the percentage of remaining available soil moisture)

K_s = Change in the coefficient at a given stage of growth when the soil surface is moist due to irrigation or rainfall

3. Estimate evapotranspiration. For each day since the previous computation using observed climatic data, estimate for the next three days, Et, based on forecasts of the climatic parameters by:

$$E_t = K_c \quad E_{tp} \tag{14}$$

4. Estimate the cumulative soil moisture depletion to the current day by the equation:

$$D = \sum_{i=1}^{n} (E_t - R_e - I + W_d) \tag{15}$$

where

D = Depletion of soil moisture

E_t = Evapotranspiration

R_e = Effective rainfall

I = Irrigation water applied

W_d = Drainage from the root zone, assumed zero in the present program

5. Estimate the number of days before the next irrigation using the average E_t for the three preceeding days and the three forecast days

$$N = \frac{D_o - D}{\bar{E}_t} \tag{16}$$

$N = 0$ for $D > D_o$

where

N = estimated number of days until another irrigation is needed if no additional rainfall is received

D_o = maximum depletion of soil moisture allowed for the present stage of growth

D = estimated depletion of soil moisture

$\overline{E_t}$ = mean rate of E_t for the three previous days and three forecast days.

6. Estimate the total amount of water to be delivered to the field per unit area

$$W_I = \frac{D_o}{E} \quad , \quad D_o > D \qquad (17)$$

$$W_I = \frac{D}{E} \quad , \quad D > D_o \qquad (18)$$

where

W_I = Amount of water to be delivered per unit area

E = System irrigation efficiency.

Rooting Depth for Corn

The computer program calculates percent depletions based on the assumption that the root zone depth increases linearly from planting to 100% at the day of full crop cover. In the program, a rooting depth of 4 feet was assumed at full crop cover. Robins (42) states that the primary root system for corn is relatively sparse and extends to depths of 1 to 1.5 m. MacGillivray, et.al., (28) state that a mature sweet corn plant will extract water from depths of 2 to 4 feet. A maximum corn root depth of 1.55m was reported by Kiesselbach and Weiling (26).

DESIGN OF EXPERIMENT

The area selected for the study is located near the Miller Canal on the north side of the Experiment Field. A randomized block design was employed with three replications (see Plate III). Individual plot size was 8-30 inch rows by 615 feet. The addition of borders made the total area of the study 340 feet by 615 feet. Average plot slopes were .37% for the first replication, .56% for the second, and .67% for the third. The soil has been classified as a Crete soil. This is a silty clay loam.

Alternate row irrigation was used. Water applied and tail-water were measured from the four irrigated rows in each plot. Water applied was measured by recording the head on siphon tubes with a chart recorder. Tailwater was measured by recording the upper head reading on a 1-inch, free-discharging Parshall flume with a chart recorder. Head readings on the Parshall flumes were recorded on the first replication. Flumes were installed on the second replication as a reference. Head readings on the siphon tubes were recorded for two replications.

Date of planting was May 5, and harvest date was October 6. The variety was Pioneer 3306 at a population of 24,500 plants per acre. Yield data were taken from an area in the center two rows, 30 feet long, near the upper end of each plot. Yield data areas were also planted near the lower end of the plots, but yield data were not taken due to incomplete germination.

EXPLANATION OF PLATE III

A map of the 1970 irrigation scheduling plots.

Scheduling plots are:

1. Jensen computer program
2. high moisture tensiometer-scheduled
3. medium moisture tensiometer-scheduled
4. low moisture tensiometer-scheduled
5. straw covered plots

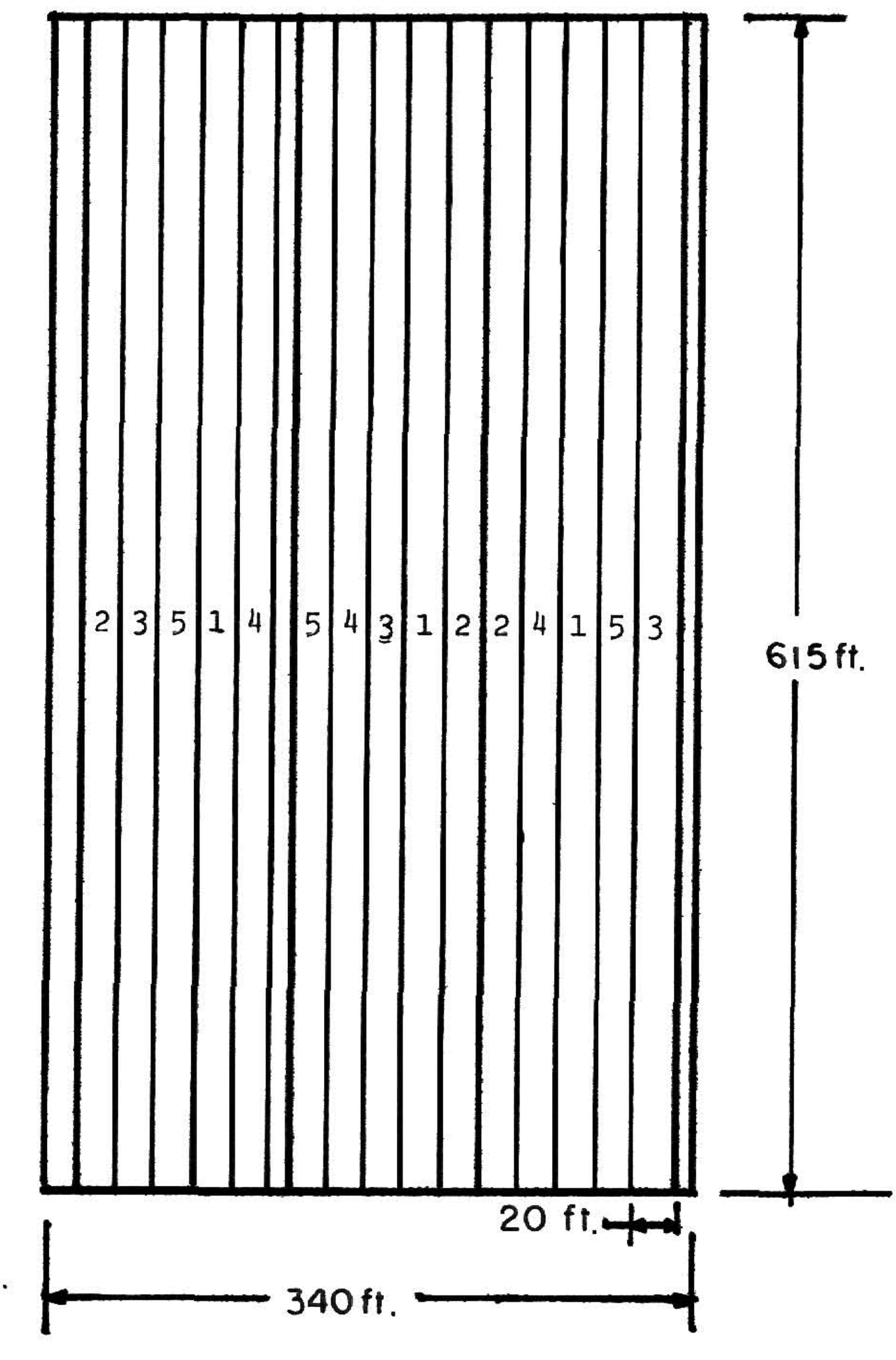


PLATE III

EQUIPMENT AND PROCEDURE

For each irrigation, the water applied and the tailwater were measured. As a check on the net water applied, neutron access tubes were placed at the upper, the center, and the lower portions of the plot.

Water onto the plots was measured by recording the head on new, 1-inch siphon tubes with a chart recorder, and calculated by assuming the head constant for one hour periods, using the equation (16):

$$Q = CA(2gh)^{1/2} \quad (19)$$

where,

Q = Flow, cfs

C = Frictional coefficient

A = Area of orfice, ft^2

g = Gravitational force, ft/sec^2

h = Orfice head, ft

The frictional coefficient used for the 1-inch siphon tubes was .52 from Manges (29).

Tailwater off the plots was measured by recording the upper head on 1-inch free discharging Parshal flumes with Stevens water level chart recorders. Water was gathered from the four furrows which were irrigated on each plot (see Plate IV). Calibration curves were run on each flume in the hydrology labratory in the Agricultural Engineering Department. Neutron access tubes were planned to be placed directly in the corn rows to measure the actual amount of water applied to the plants.

The neutron moisture probe used was a Troxler, Model 1255.

EXPLANATION OF PLATE IV

A cross-sectional view of a plot .

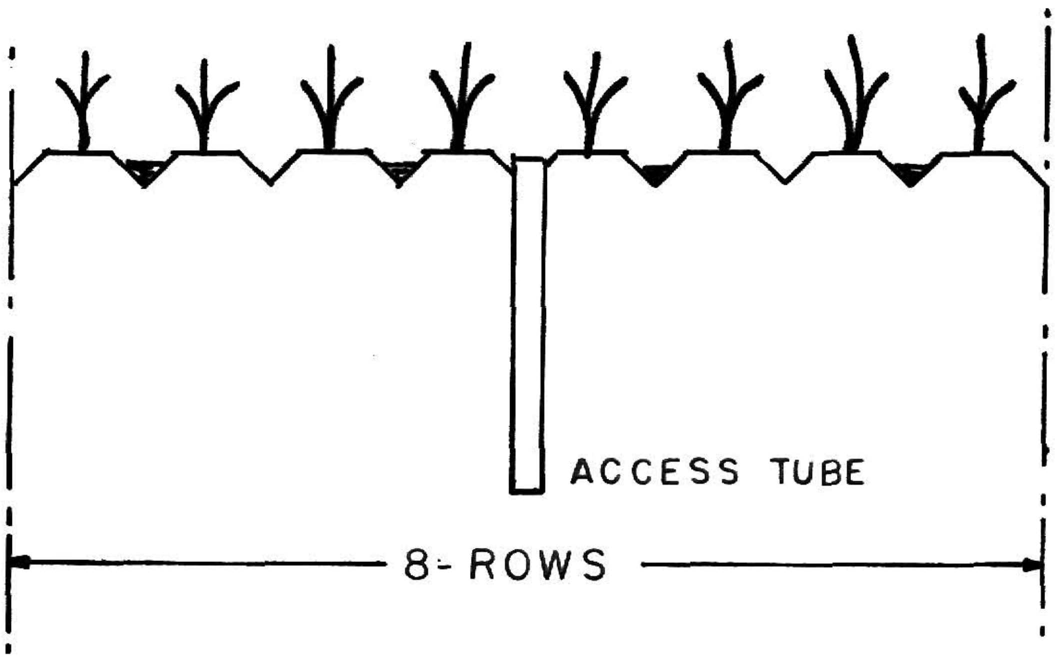


PLATE IV

The access tubes for this study were ordered along with other access tubes for the Evapotranspiration Laboratory. Unfortunately, the Evapotranspiration Laboratory and the Agricultural Engineering Department have different model Troxler neutron probes, and the two probes require different diameter access tubes. By the time that the proper tubing was located, the corn had grown too tall to maneuver a tractor with soil probe for placement of the access tubes over the row. Therefore, the tubes were placed in the center, non-irrigated row. (see plate IV) Probe readings were taken at 1,2,3, and 4-foot depths. A 6-inch radius of influence was assumed for the probe. This is near the radius reported by Holmes and Turner (14) for the water content range in this study. The tubes were placed assuming that, in the silty clay loam soil, alternate row irrigation brought about a somewhat uniform moisture distribution in the soil among the rows following a normal 3-inch to 5-inch irrigation.

Mercury tensiometers were placed near the neutron access tubes in the same furrows so that a partial calibration curve of soil moisture versus soil tension could be obtained. Since it was desired to have three moisture levels maintained by the tensiometers, and since calibration curves for tensiometers were not available for the soil, the following criteria were assumed:

1. Low moisture level to be maintained by scheduling irrigation when the soil moisture tension reached 1.0 atmosphere at a 18-inch depth.
2. Medium moisture level to be maintained by scheduling

irrigation when soil moisture tension reached 1.0 atmosphere at a 12-inch depth.

3. High moisture level to be maintained by scheduling irrigation when the soil moisture tension reached .5 atmosphere at a 12-inch depth.

From the literature review, it is apparent that the first two criteria could not be reached due to tension failure of the water column. In order to estimate the 1.0 atmosphere tension, a plot of tension height versus time was kept. After the water column pulled apart, the curve was extropolated visually to determine the time of irrigation initiation for each treatment. It was hoped that these criteria would result in the irrigation occurring at the following soil moisture levels: 1. 25% of the available soil moisture depleted, 2. 50% of the available soil moisture depleted, and 3. 75% of the soil moisture depleted.

The Jensen computer program was modified to print out the fixed depletion based on crop growth from the original program and the estimated 40%, 50%, and 60% of available water depletion for Crete soil. Input data required for the computer program were minimum temperature, maximum temperature, solar radiation, mean dewpoint temperature, daily wind run, irrigation water applied, and rainfall amount. Maximum and minimum temperatures were measured on a clock-driven hygrothermograph. Daily wind run was measured with a circular dial-type anemometer set 18 inches above the soil surface and was corrected to two meters by the 1/7 power law. Mean dewpoint temperature was estimated by determining the dew point temperature at 8:00 a.m. This was assumed representative of the mean condition. Solar radiation was measured with an integrating solar meter. Sample input data is shown in Table 1. In order to estimate the volume of water contained in the listed depletion amounts, field capacity was estimated to be 40% by volume, and permanent wilting point was estimated to be 19% by volume. The plot was irrigated following the recommendations of the 50% depletion level. A sample output of the computer program for the Irrigation Field is shown in Table 2.

A computer program was written to give hourly inflow of water based on the siphon tuve head. A second program computed the volume percent moisture at each level and the total amount of water in inches from the probe data. This information was then used to compute the total amount of water applied, and an estimate of the water applied.

Table 1. Sample input data for computer program

Month	Day	Min. Temp. TMN (F)	Max. Temp. TMX (F)	Solar Radiation RS (cal/cm day)	Dew Point Temp. TD (F)	Wind Run W (miles/ day)	Rainfall R inches
August	3	73	104	636.1	65	110.3	0.0

Table 2. Sample output from computer program

FARM: SCANDIA IRRIGATION DATE: AUG. 7, 1970

CROP-FLD	LAST IRR	RAIN	EST DEPLN
CORN	JUL 21	0.0	2.72

OPTIMUM DEPLETION				DAYS TO IRRIGATE				AMOUNT TO APPLY			
FIXED-D	40%D	50%D	60%D	FIXED-D	40%D	50%D	60%D	FIXED-D	40%D	50%D	60%D
3.0	3.9	4.9	5.9	4	4	7	11	6.7	6.6	8.2	9.9

RESULTS AND DISCUSSION

A summary of rainfall during the irrigation season is shown in Table 3. Between the days of June 21 and August 19, only .66 inches of rainfall occurred. No irrigation occurred exclusive of these dates, and rainfall amounts were not included in the following analysis.

The Initial Irrigation

Shortly after the installation of the tensiometers was completed, irrigation of the plots was initiated following the criteria previously mentioned. Irrigation continued until a uniform moisture level was reached near the neutron access tubes. Over-irrigation was necessary on all plots in order to bring the soil surrounding the access tubes to uniform moisture level.

A summary of the soil moisture properties of the Crete soil are shown in Table 4. Field capacity was determined with the neutron probe 24 hours after irrigation water application had ceased. Permanent wilting points were determined by the Evapotranspiration Laboratory. An attempt to obtain current density information with the Troxler gamma probe failed due to a faulty pulse height analyzer battery, so soil density data used to convert from percent by weight to volume percent were taken from Manges (29), since the same field was involved.

Soil moisture tension versus the volume percent moisture for a 1-foot tensiometer depth is plotted in Plate V. This is near the curve in Taylor (50) for a loam soil. From Plate V, it may be seen that irrigation of the high moisture plots probably occurred at less than 25% depletion, and that irrigation of the

Table 3. Precipitation-Summer 1970

Date of Precipitation	Amount (Inches)
May 9	.18
May 13	.29
May 23	3.22
May 25	.21
May 27	.34
June 1	1.15
June 4	.13
June 9	.07
June 10	.04
June 12	.57
June 14	.60
June 16	3.80
June 19	.03
June 20	.55
July 12	.19
July 13	.15
August 17	.32
August 20	1.45

Table 4. Soil physical properties determined for Crete soil

Depth of Sample (ft)	Relative Soil Density	Field (% by vol.)	Capacity (in. of water)	Permanent (% by vol.)	Wilting Point (in. of water)	Available Moisture
0.0-0.5	1.32	41.5	2.49	14.2	.85	1.64
0.5-1.5	1.35	41.5	4.98	14.2	1.70	3.28
1.5-2.5	1.45	43.7	5.24	27.5	3.30	1.94
2.5-3.5	1.55	41.2	4.96	24.2	2.91	2.05
3.5-4.5	1.43	42.9	5.14	20.7	2.49	2.65
Total or Average		42.2	22.81	20.2	11.25	11.56

EXPLANATION OF PLATE V

Soil moisture tension curve at a 1-foot depth for the Crete soil from 1970 data.

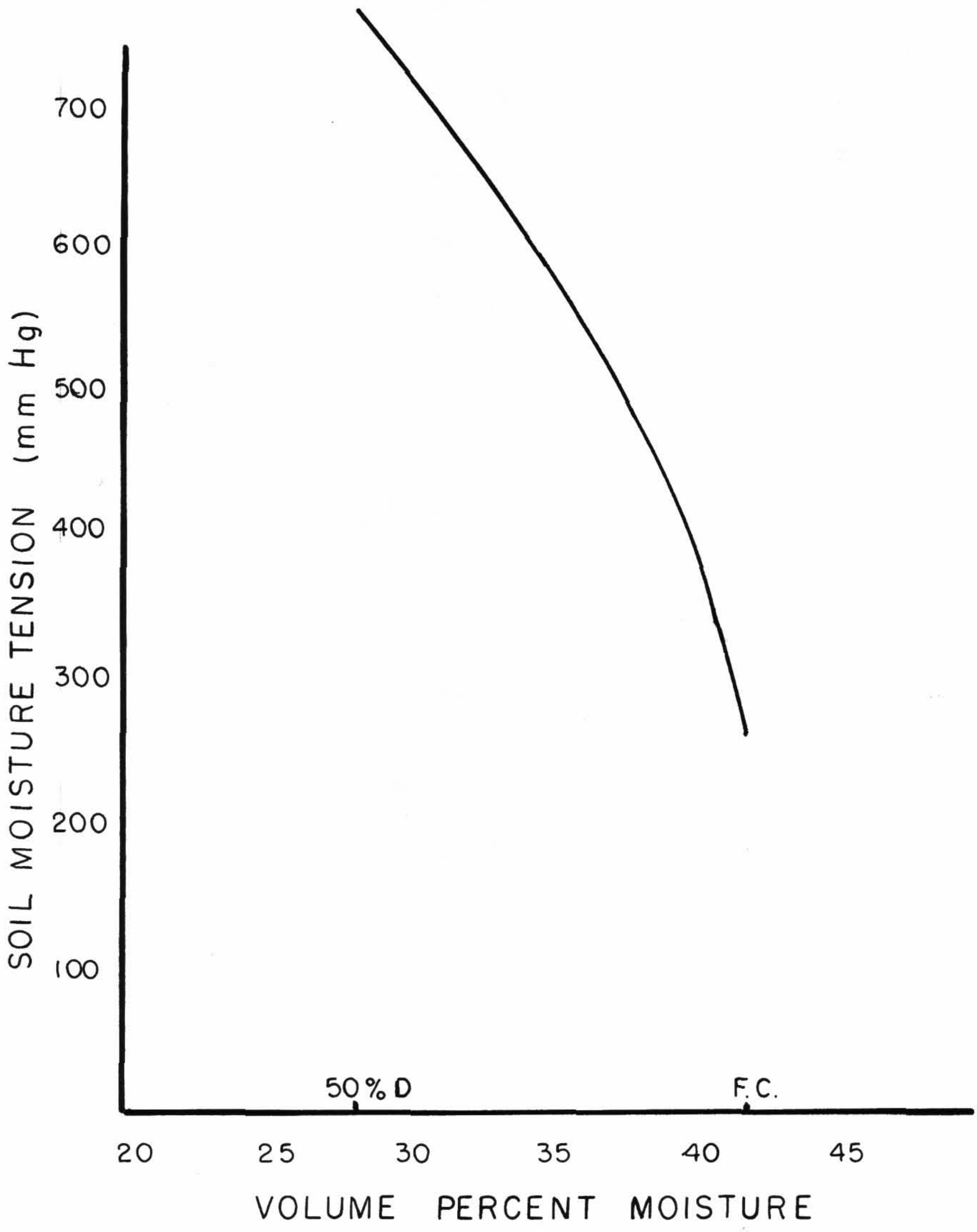

SOIL MOISTURE TENSION (mm Hg)
700
600
500
400
300
200
100
50% D
F.C.
20
25
30
35
40
45
VOLUME PERCENT MOISTURE

PLATE V

medium moisture plots occurred near the 50% depletion amount. Not enough data was obtained to plot a curve for the 18-inch depth. A soil moisture tension curve would have been desirable for the 18-inch depth in order to determine the actual tension for this depletion level.

Moisture Distribution

One of the first factors which could invalidate a soil moisture study is uneven initial moisture distribution among plots. As a check on this factor, probe readings were taken at the beginning of the season, and water distribution efficiency was calculated from the total moisture at each access tube to estimate the initial soil moisture uniformity.

The water distribution efficiency was calculated from the equation listed in Israelson and Hanson (16):

$$E_d = 100 \left[1 - \left(\frac{y}{d} \right)\right] \qquad (20)$$

where

E_d = Water distribution efficiency

y = Average numerical deviation in depth of water stored from average depth stored during the irrigation

d = Average depth of water stored during the irrigation

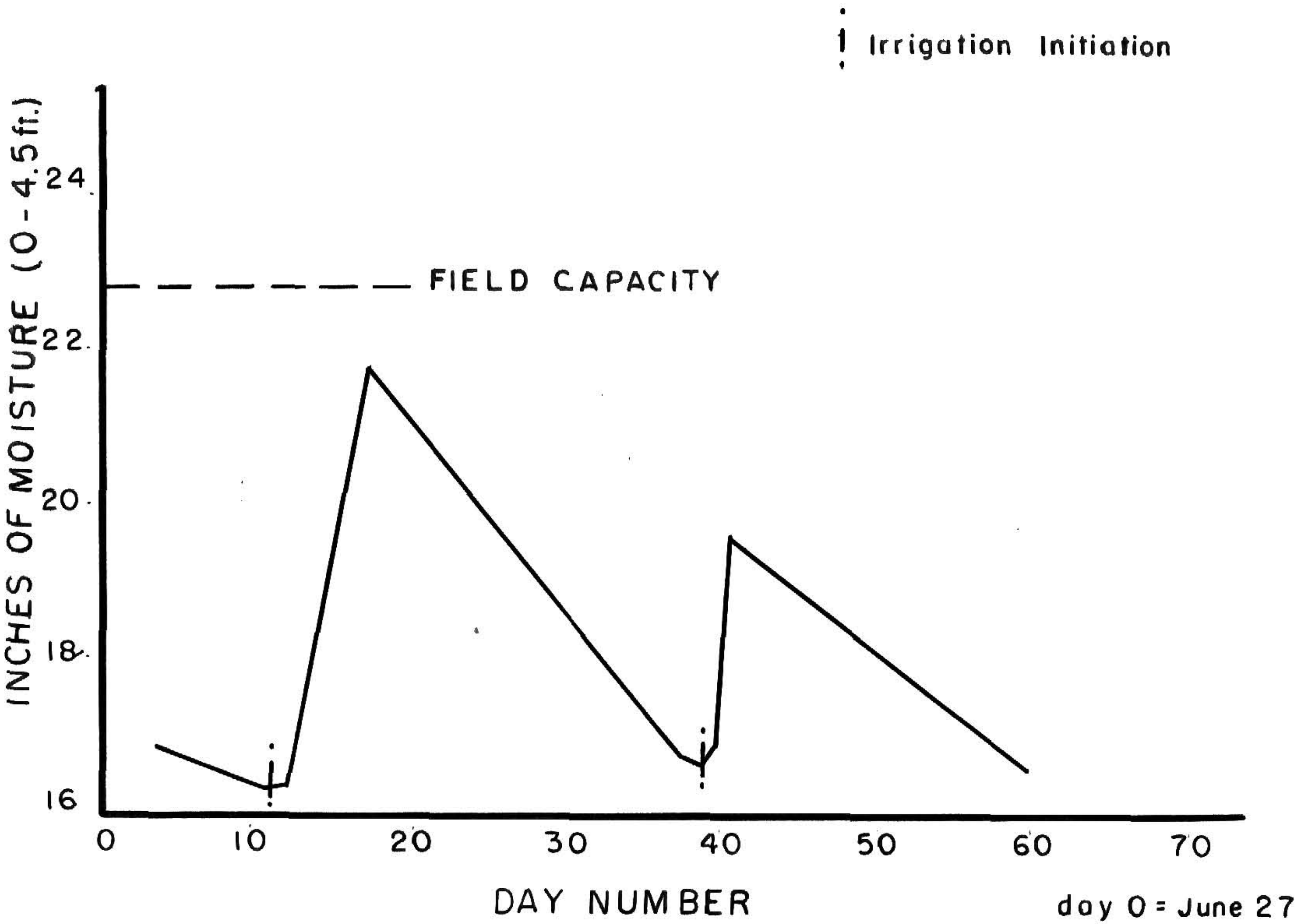
The initial water-distribution efficiency figure over all the plots was calculated to be 99% which illustrates that the initial moisture distribution was quite uniform among plots.

Plates VI, VII, VIII, and IX show the average moisture distribution surrounding the neutron access tubes throughout the irrigation season. The moisture amount shown includes the total

EXPLANATION OF PLATE VI

A plot of the average moisture distribution adjacent to the low moisture level access tubes during the irrigation season.

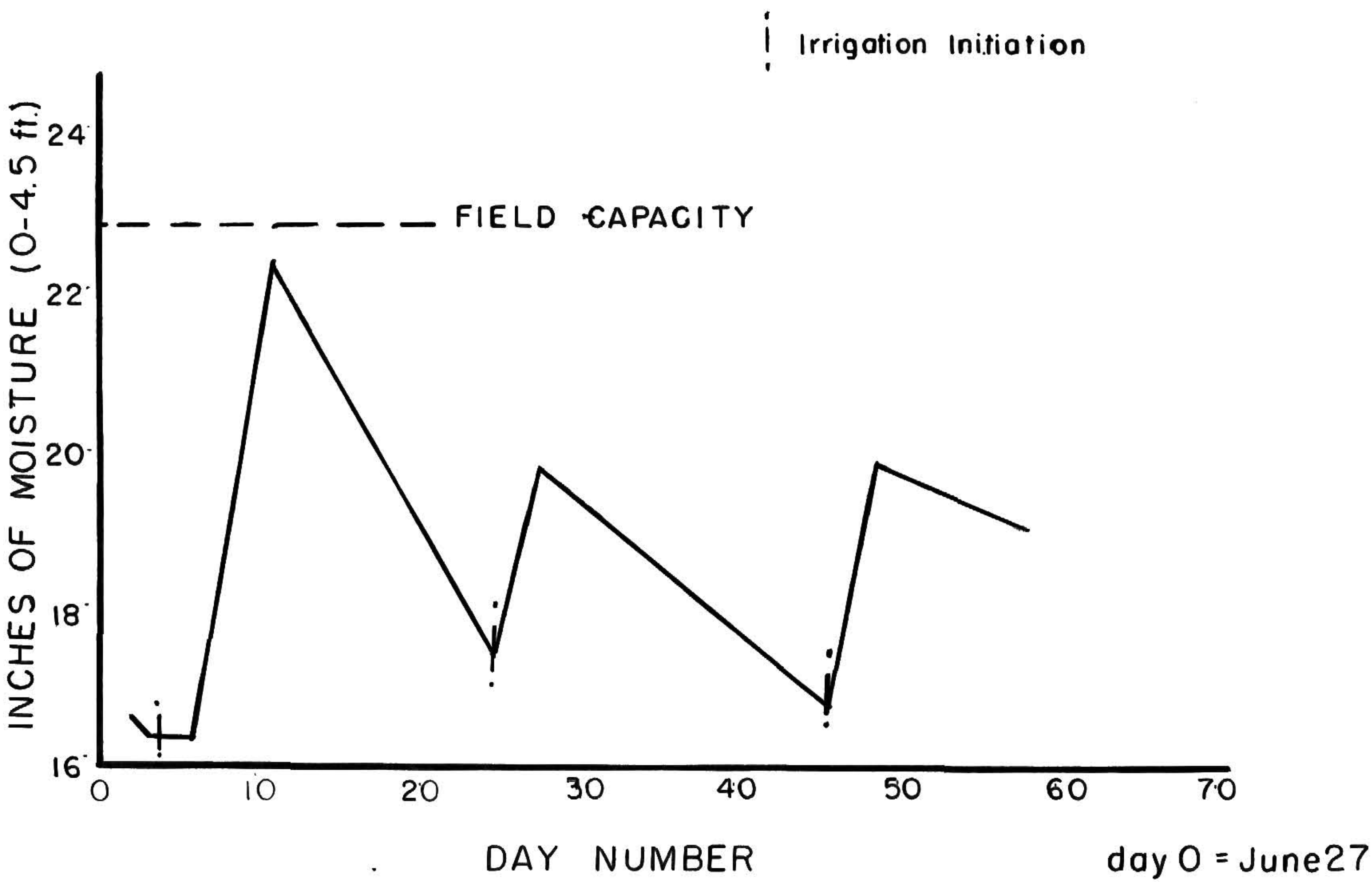
PLATE VI


Irrigation Initiation
INCHES OF MOISTURE (0-4.5ft.)
24
22
20
18
16
FIELD CAPACITY
0
10
20
30
40
50
60
70
DAY NUMBER
day 0 = June 27

EXPLANATION OF PLATE VII

A plot of the average moisture distribution adjacent to the medium moisture level access tubes during the irrigation season.

PLATE VII

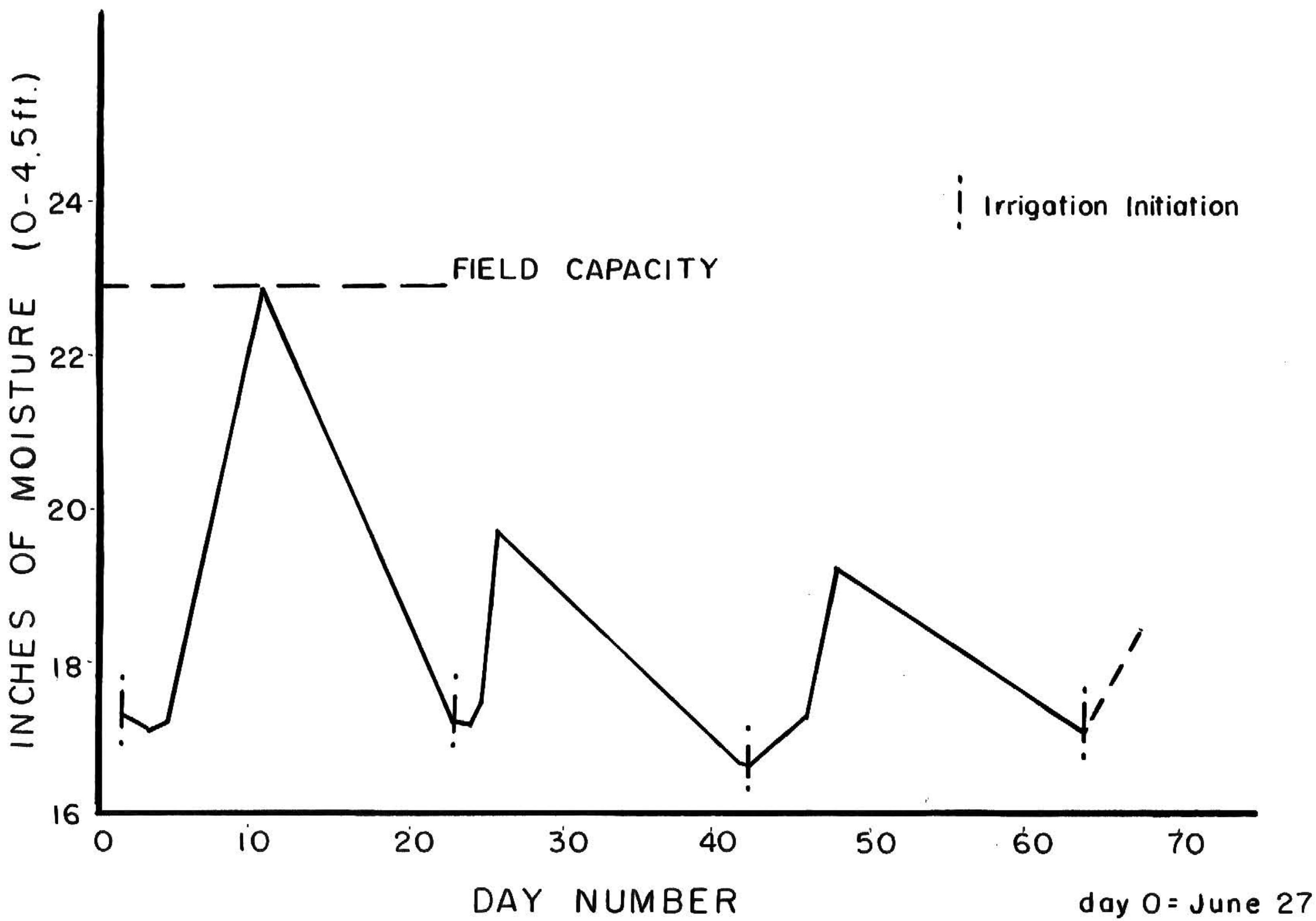


Irrigation Initiation
FIELD CAPACITY
INCHES OF MOISTURE (0-4.5 ft.)
24
22
20
18
16
0
10
20
30
40
50
60
70
DAY NUMBER
day 0 = June27

EXPLANATION OF PLATE VIII

A plot of the average moisture distribution adjacent to the high moisture level access tubes during the irrigation season.

PLATE VIII



INCHES OF MOISTURE (0-4.5ft.)
16
18
20
22
24
FIELD CAPACITY
Irrigation Initiation
0
10
20
30
40
50
60
70
DAY NUMBER
day 0 = June 27

moisture from 6 inches to 54 inches. The 0 to 6-inch depth moisture level could not be taken with the neutron depth probe, so some surface gravametric samples were taken, but not enough to keep complete track of the total soil moisture. For the analysis of this study, the 0 to 6-inch depth of soil was assumed to be at permanent wilting point just prior to irrigation, and at field capacity following irrigation.

From Plates VI, VII, VIII, and IX, it may be seen that the alternate rows did not approach field capacity following the first irrigation. The alternate rows did increase roughly 2 inches in moisture following each irrigation, and, therefore, may be used as an indication of the water amounts applied. It is interesting to note that, according to the alternate row moisture level, each treatment initiated irrigation within 1-inch of the depletion level of any other treatment which is misleading because the vertical moisture level distribution preceeding the irrigation is different for each treatment. An example of the difference in the vertical moisture distribution of the various plots is given in Table 5. The moisture in this table is the average of the three access tubes in each plot prior to the first irrigation. The main difference in moisture levels is the upper two readings. The moisture distribution of the two upper readings prior to the irrigation ranks them in the expected order.

Computer Plot

A plot of the computer program estimated soil moisture level and the neutron probe readings on the computer plot is shown in Plate IX. Again, the alternate row does not reach

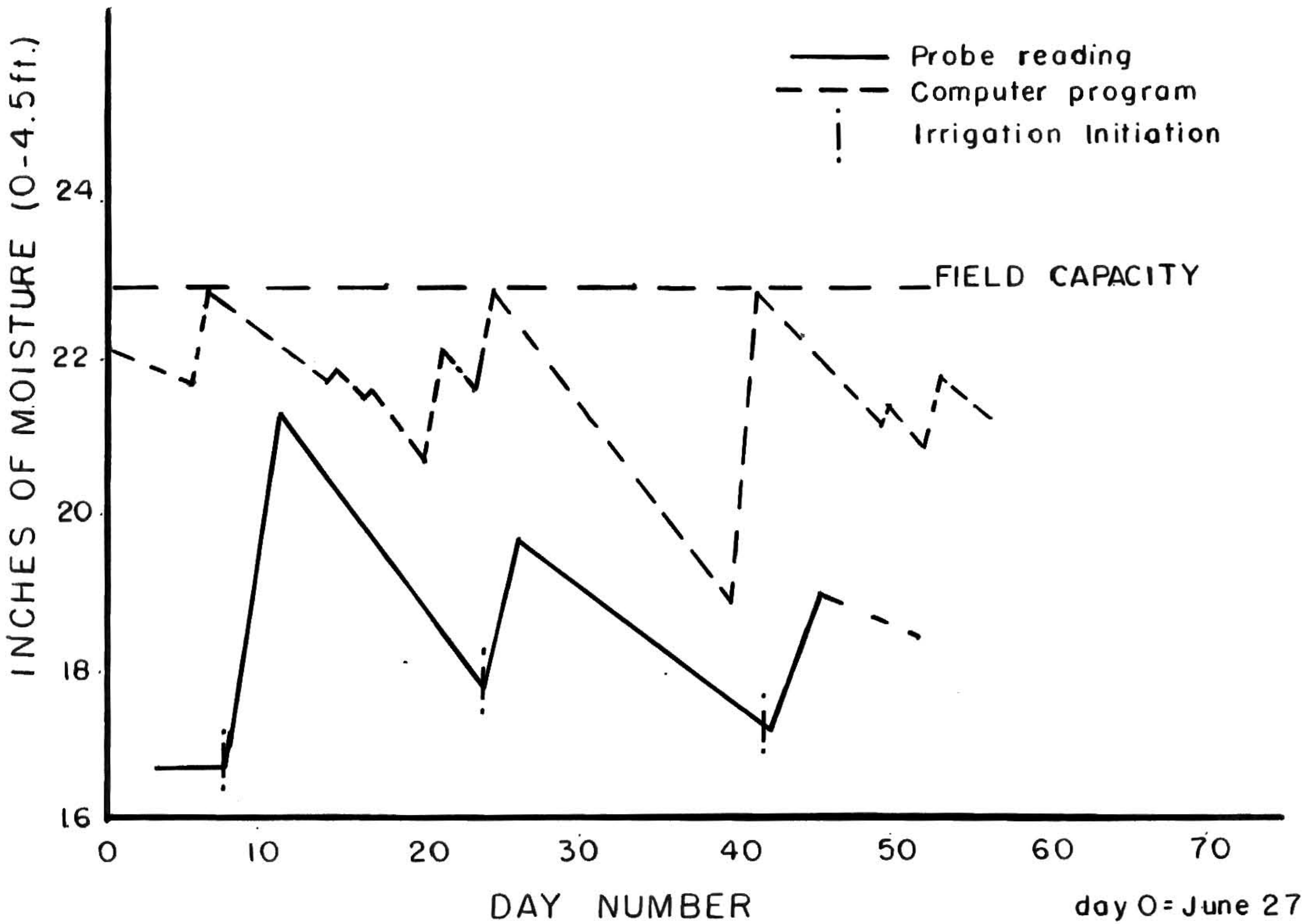
Table 5. Volume percent moisture distributation proceeding initial irrigation

Depth (ft.)	High Level	Treatment Medium Level	Computer	Low Level
.5-1.5	34.3	34.8	32.6	28.2
1.5-2.5	43.2	38.2	42.2	36.6
2.5-3.5	39.6	37.7	38.7	37.5
3.5-4.5	39.4	39.7	38.3	37.8

EXPLANATION OF PLATE IX

A plot of the average moisture distribution adjacent to the computer access tubes and the computer program's predicted soil moisture depletion for the irrigation season.

PLATE IX


Probe reading
Computer program
Irrigation Initiation
FIELD CAPACITY
INCHES OF MOISTURE (0-4.5ft.)
24
22
20
18
16
0
10
20
30
40
50
60
70
DAY NUMBER
day 0 = June 27

field capacity, but the row does follow in direction, not magnitude, the movement of the computer program. It cannot be stated fro a che available data that the computer program was either accurate or inaccurate in predicting the soil moisture depletion. A general observation may be made, however. Since the computer program assumed the entire plot reached field capacity following each irrigation, and since this obviously did not occur, the program may be over-estimating the actual evapotranspiration.

Determination of Total Water Applied

Due to the fact that several other new research projects were being conducted on the Irrigation Field, flow determination data were incomplete. Rather than use an average flow figure for the days missed, an infiltration curve was developed for each plot based on the available data. The data was in close agreement between irrigations. Maximum observed difference in net flow between irrigations was 20 cubic feet/hour for 5 hours between the first and second irrigation on the computer plot. The above difference in net flow amounts to .008 inches of water applied. This implies that the error resulting from assuming the same infiltration curve from irrigation to irrigation is not very large. Net flow was then determined by integration along the proper curve for the amount of hours required. Infiltration rates at 36 hours ranged from .14 inches/hour to .15 inches/hour. This is within the range of values previously reported by Manges (29). Irrigation dates and total amount of water applied at each irrigation are shown in Table 6.

Table 6. Irrigation treatment application dates and amounts

Irrigation Number	Treatment							
	High Level		Medium Level		Computer		Low Level	
	in. applied	date	in. applied	date	in. applied	date	in. applied	date
1	39.1	6/27	13.7	6/30	17.2	7/3	18.9	7/8
2	14.4	7/19	7.4	7/23	10.5	7/20	10.9	8/4
3	21.5	8/7	10.9	8/10	13.8	8/7		
4	3.8	8/29						
Total	78.8		32.0		41.5		29.8	

Estimation of Actual Water Applied

From Table 6, it is obvious that over-irrigation occurred on all plots, and some amount of the irrigation water applied was not stored where the plants could use it. In order to estimate from the available data the actual amount of water placed into the root zone for use by the plant, two assumptions were made. First, the vertical moisture distribution over the entire plot was the same as the vertical moisture distribution surrounding the access tubes. Second, the entire plot was brought to field capacity following irrigation.

Next, from Israelson and Hansen (16), the following equation during irrigation, neglecting evaporation, is used:

$$W_f = W_s + R_f + D_f \qquad (21)$$

where

W_f = Water delivered to the plot

W_s = Water stored in the soil root zone

R_f = Surface runoff

D_f = Deep percolation below the soil root zone

Replacing $W_f - R_f$ by the net amount of water applied, W_n, the equation becomes:

$$W_n = W_s + D_f \qquad (22)$$

From the two assumptions listed, and from equation 22 , an estimate of the amount of water applied and the amount of deep percolation may be obtained. The estimated amount of deep percolation, water stored in the soil, and water applied is shown in Table 7. The resulting estimated water stored in the soil will be higher than the amount actually stored due to the assumption of the entire plot being brought to field capacity, but it may be seen from Table 7 that the total amount of water stored in the soil during the irrigations is near the estimated consumptive use of corn in the area (54). A statistical analysis was made on the estimate of irrigation water stored and the corn yield. An analysis of variance for each is shown in Table 8. Table 9 is a summary of the results obtained. Those treatments which are underlined in the estimate of water applied and yield row refer to the l.s.d. test not being significant. As crop yield increased, the estimated amount of water applied increased. The medium moisture levels were significantly different from the other levels.

Table 7. Estimation of water balance

Treatment	Irrigation number	Amount of water applied (inches)	Estimated amount applied from probe reading (inches)	Estimated drainage (inches)
High Level	1	39.1	4.7	34.4
	2	14.4	4.9	9.5
	3	21.5	5.4	16.1
	4	3.8	4.3	-0.5
	Total	78.8	19.3	60.0
Medium Level	1	13.7	4.9	8.8
	2	7.4	4.2	3.2
	3	10.9	5.3	5.6
	Total	32.0	14.4	17.6
Computer Program	1	17.2	5.2	12.0
	2	10.5	4.3	6.2
	3	13.8	5.4	8.4
	Total	41.5	14.9	26.6
Low Level	1	18.9	5.6	13.3
	2	10.9	5.2	5.7
	Total	29.8	10.8	19.0

Table 8. Analysis of variance tables for probe estimate of water applied to plots and yield from plots

A.N.O.V. table for probe estimate of water applied to plots

	d.f.	S.S.	M.S.	F
Blocks	r-1=1	5.92	2.96	
Treatments	t-1=3	109.42	36.47	57.9**
Error	(r-1)(t-1)=6	3.79	.63	
Total	rt-1=11	119.13		

A.N.O.V. table for yield from plots

	d.f.	S.S.	M.S.	F
Blocks	r-1=1	872.1	872.1	
Treatments	t-1=3	12,431.7	4143.9	136.3*
Error	(r-1)(t-1)=3	91.2	30.4	
Total	rt-1=7	13,395		

**Significant at the 1% level
*Significant at the 5% level

Table 9. Summary of results
1970 Irrigation Scheduling

Variable	Treatment			
	High level	Medium level	Computer	Low level
Total water applied (in)	78.8	32.0	41.5	29.8
Estimate of irrigation water stored (in) l.s.d. (.01) = 1.22	19.3	14.4	14.9	10.9
Plant height (in)	95	99	91	84
Yield (bu/acre) l.s.d. (.05) = 15.4	185.0	157.0	160.0	79.8
Average delay from high tensiometer for scheduling irrigation (days)	0.0	3.3	2.7	14.0
Irrigation water efficiency (bu/in)	9.6	11.1	10.7	7.3

The items above the same horizontal line are not significantly different for the levels listed in the parentheses.

SUMMARY AND CONCLUSION

Two methods were used to schedule irrigations for corn production. The high soil moisture level tensiometer-scheduled treatment resulted in significantly better yield than any other treatment, but also resulted in significantly more water used to reach this yield. The medium soil moisture level tensiometer-scheduled treatment and the computer scheduled treatment gave almost identical water application amounts, time of scheduling, and crop yield. The low soil moisture tensiometer-scheduled treatment resulted in a much delayed irrigation, reduced water application amounts, and inferior yields. The computer treatment and the medium level treatment gave the best yield per inch of water applied, implying that these moisture levels were the most efficient production levels of those evaluated.

The following are some of the conclusions which may be drawn from the results of this study:

1. Alternate row irrigation does not result in uniform soil moisture distribution in the Crete soil.
2. The Jensen computer program will schedule irrigation as well as a tensiometer.
3. There exists an optimum range of moisture conditions for the maximum production of corn.
4. For the range of moisture levels covered in this study, a higher moisture level resulted in a higher yield.
5. Highest water use efficiency (yield per unit of water) was obtained at the medium moisture levels.

6. For the Crete soil, field capacity is 42% by volume, and permanent wilting point is 20% by volume.

SUGGESTIONS FOR FUTURE RESEARCH

Since much of the difficulty in determining the soil moisture changes due to irrigation was due to alternate row irrigation, it is suggested that the soil moisture distribution under every and alternate row irrigation be investigated for the Crete soil.

Continued investigation of irrigation scheduling is encouraged with increased water measurement replications for each treatment. Use of the Jensen computer program with the addition of precipitation probabilities to improve accuracy of predicted irrigation dates would be desirable. Amounts of water applied should follow the recommendations of the program.

If plant turgor could be easily and accurately measured, this could be the best means of scheduling irrigations. Future research measuring plant turgor easily and accurately should be pursued.

Although the neutron probe worked satisfactorily for this study, an investigation of the temperature effects on count stabilization would be a prerequisite to a very precise moisture study.

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TWO IRRIGATION SCHEDULING METHODS FOR CORN PRODUCTION

by

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B.S., Agricultural Engineering
Kansas State University, 1967

AN ABSTRACT OF A MASTER'S THESIS

Submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1971

ABSTRACT

The purpose of this study was to investigate two methods of scheduling irrigations on the basis of time of irrigation initiation, amount of water used, and corn response in furrow irrigation.

The Jensen computer program was used to schedule one treatment using a predicted 50% allowable depletion. Three tensiometer criteria were used to schedule irrigations: .5 atmosphere at 12 inches, 1 atmosphere at 12 inches, and 1 atmosphere at 18 inches. These criteria resulted in irrigation being initiated at approximately a 25% depletion for the .5 atmosphere treatment, and a 50% depletion for the 1.0 atmosphere at 12 inches during the first 60 growing days. Although a soil tension curve was not available, irrigation of the 1.0 atmosphere at 18 inches treatment occurred at a level considerable above the 50% depletion level. Field capacity for the Crete soil (a silty clay loam) was determine to be 42% by volume. Permanent wilting point was determined to be 20% by volume.

Alternate row irrigation was used, based on the assumption that a uniform moisture distribution between rows would ensue following a normal 3 to 5-inch irrigation. Water applied was measured by recording the head on 1-inch siphon tubes. Surface runoff was measured by recording the upper head on a 1-inch Parshall flume. Vertical moisture distribution along the 600 foot by 20 foot plots was taken at the upper, middle, and lower ends with a neutron probe. Readings were taken at 1, 2, 3, and 4 foot depths. Access tubes were located in the center of the plot in the dry rows. A randomized block design

using three replications was employed. Very little rainfall occurred inclusive of the irrigation season dates of June 21 to August 19, and rainfall amounts were not included in the analysis.

Alternate row irrigation does not result in uniform moisture distribution in the Crete soil. The dry rows did not reach field capacity unless extreme over-irrigation occurred. In order to estimate the actual amount of water which was available for use by the plants, two assumptions were made. First, the vertical moisture distribution over the entire plot was the same as the vertical moisture distribution surrounding the neutron access tubes. Second, the entire plot was brought to field capacity following irrigation. Then, a water balance, neglecting evaporation from the water surface, gave an estimate of the drainage and the actual water applied for plant use.

Corn yields were 185, 157, 160, and 80 bu/acre with irrigation water amounts applied of 19, 14, 15, and 11 inches for the .5 atmosphere, 1.0 atmosphere at 12 inches, computer program, and 1.0 atmosphere at 18 inches, respectively. The .5 atmosphere tensiometer treatment had a significantly higher yield than the other treatments and used significantly more water. The 1 atmosphere tensiometer at an 18-inch depth criteria had a significantly lower yield than the other treatments and used significantly less water. The third tensiometer treatment and the computer treatment gave almost identical water use, irrigation timing, and yield. These two treatments gave the most efficient water use level.