ESTIMATING CROP WATER REQUIREMENTS IN SOUTH-CENTRAL KANSAS

by

HOSSEIN V. KAZEMI

B.S., Oklahoma State University, 1983

A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

in

Agricultural Mechanization

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1985

Approved by:

Harry L. Manges

Major Professor

AKNOWLEDGEMENTS

This study was made possible by the guidance of my major professor, Dr. Harry L. Manges. I thank him for his time, patience, and willingness to assist whenever it was necessary. I thank Phil Barnes, irrigation engineer at the Kansas River Valley Experiment Field, for helping with the computer programs and providing wind velocity data. I also thank Dr. Richard D. Black, Associate Professor of Agricultural Engineering, for his advice and help during a trip to McPherson County.

I thank Dr. Laureston V. Withee and Dr. James M. Steichen for serving on my graduate committee.

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

Irrigation has become one of the most important factors of agriculture in arid and semi-arid regions. It is essential that the consumptive use and irrigation requirement of crops be known in irrigation planning by each individual farmer and irrigation district. A reason is the low and variable precipitation in many parts of the world. Farmers choose different methods of irrigation for different reasons. Availability of water, economy of the system, climatological conditions, and soil characteristics are among the important reasons. In addition a knowledge of consumptive use of crops is necessary in planning farm irrigation system layout and improving irrigation practices.

With increasing labor costs and diminishing groundwater supplies, the efficient use of water for irrigation and obtaining the optimum yield are becoming more important. How much water to apply for a given crop and when to apply it depends on many factors. Some factors are type of crop, climate, location, management, and soil characteristics.

Lack of knowledge about the irrigation requirement of each crop in a specific location is one of the reasons for yield reduction. Among the more popular grain crops, corn has the highest water requirement. Grain sorghum and soybeans, which are usually used as alternative crops for corn, have lower water requirements.

The main objectives of this study were to estimate the consumptive use and irrigation requirement of crops in south central Kansas. The knowledge of consumptive use of crops should be available in order to estimate the irrigation requirement. Consumptive use is the amount of water required to meet the evaporation and transpiration needs of vegetative areas so plant production is not limited by lack of water. This water is supplied by precipitation and irrigation. Therefore, the difference between consumptive use and precipitation is *irrigation requirement*.

Blaney-Criddle (USDA-SCS, 1967), Penman (USDA-ARS, 1974), and ET Lab (Kanemasu et al., 1979) are different methods for estimating the consumptive use and irrigation requirement of crops. Each of these methods requires knowledge of factors influencing the water requirements of each crop.

REVIEW OF LITERATURE

The problem concerning the amount of irrigation water required and the time of application is becoming more involved, especially in arid and semi-arid regions. The methods for estimating the water requirements of crops in use today are generally based on the correlation of estimated consumptive use, water loss from soil and plant surfaces, with one or more climatic factor. Field measurements of seasonal consumptive use were started in the western USA as early as 1887. Extensive studies of seasonal consumptive use have been conducted since 1900. Attempts to relate seasonal consumptive use to common climatic factors were underway in the 1920's. In recent years there has been more emphasis on doing comprehensive research on the seasonal water use and soil water depletion of individual crops. Corn has been one of the more extensively researched crops.

Blaney and coworkers made numerous measurements of consumptive use during the 1920's and 1930's using primarily soil sampling techniques. Blaney and Morin (1942) developed an empirical relationship between consumptive use and mean air temperature, mean relative humidity, and possible daylight hours. Blaney and Criddle (Pair et al., 1975) modified this relationship to exclude the humidity term. This method was initially used for seasonal estimates of consumptive use. The principle assumption is that consumptive use varies directly with the sum of the products of mean monthly air temperature and monthly percent of annual daylight hours when adequate soil moisture is present. The formula for seasonal estimates of consumptive use is as follows:

$$U = (KF) = \text{sum of } (kf) \tag{1}$$

where: U = Estimated seasonal consumptive use in inches

K = Empirical seasonal consumptive use coefficient

F = The sum of monthly consumptive use factors

k = Monthly consumptive use coefficient

f = Monthly consumptive use factor

The monthly consumptive use factor, f, is calculated by the following equation:

$$f = (tp) / 100 \tag{2}$$

where: t = Mean monthly air temperature

p = Monthly percent of annual daylight hours

The monthly percent of annual daylight hours is constant and air temperature is the only climatic variable involved when the Blaney-Criddle method is used in a given location and for a given month and year. The Blaney-Criddle method should not be used in climatic zones significantly different from those in the western USA until it is calibrated for the area.

Consumptive use is a function of many variables including air temperature, relative humidity, wind velocity and sunshine. In the Blaney-Criddle formula, air temperature and possible daylight hours represent these climatic variables.

The Blaney-Criddle model was modified by the Soil Conservation Service for estimating monthly consumptive use in arid and semi-arid areas (Pair et al., 1975). The monthly crop coefficient is multiplied by a temperature coefficient that is directly related to the mean monthly air temperature. The modified formula is:

$$u = (k_c)(k_t)f \qquad (3)$$

where: u = Monthly consumptive use

k_c = Crop coefficient

k_t = Climatic coefficient

Crop coefficient, k_c, reflects the influence of the crop growth stage on consumptive use rate. The climatic coefficient, k_t, is related to mean air temperature by the following equation:

$$k_t = 0.0173\ T - 0.314 \qquad (4)$$

where: T = Mean monthly air temperature in degrees Farenheit

(For mean air temperatures less than 36 degrees

Farenheit, k_t becomes 0.300)

Penman (Pair et al., 1975) combined the energy balance equation with Dalton's aerodynamic equation which was derived experimentally. The resulting equation gives an estimate of evaporation from open water. These values are multiplied by a coefficient to give an estimate of the potential transpiration rate from an extensive short grass cover completely shading the ground and adequately supplied with water.

The climatic data required by the Penman model to estimate consumptive use are air temperature, dew point temperature, windrun (measured at 2 meters height), and solar radiation. Wind speed is normally not measured at 2 meters above a grassed surface at most weather stations in the USA. Although measured wind velocity is desirable at 2 meters height, it may be estimated from readings at other heights (Doorenbos and Pruitt, 1977). The Penman's model has not been used extensively in the USA, except by researchers, because of the need for many parameters. However, it gives the most reliable results for short period estimates.

Thornthwaite and Mather (Pair et al., 1975) developed an empirical equation for estimating potential evapotranspiration. Evapotranspiration is another term used for consumptive use. They defined potential evapotranspiration as "the amount of water which will be lost from the surface completely covered with vegetation if there is sufficient water in the soil at all times for the use of vegetation".

Thornthwaite and Mather (1955) added an additional condition for potential evapotranspiration. The size of area has to be large enough so the evapotranspiration from the area is not affected by external forces under high moisture conditions. Some of these external forces are the advection of moist or dry air masses and their modifications by local conditions. Since these conditions do not exist in arid and semi-arid regions, the Thornthwaite method would not be expected to give accurate estimates.

Holt and Van Doren (1961) showed the depth of water extraction and peak water use were related to growth stage of corn. Their results indicated corn extracted water from the upper 2 feet of soil until tasselling occured. After tasselling, water extraction was also from the 3 to 5 feet layer of soil. Their second year of data showed corn extracted water from the 4 to 5 feet layer by the time tasselling occured. Their results indicated the depth of water extraction was dependent on soil moisture and climatic conditions. Highest rates of water use occured from tasselling to kernel formation.

Other researchers have related soil moisture stress to crop yield. Denmead and Shaw (1960) found water stress at the silking stage of corn caused a yield reduction of 50%, and a yield reduction of only 25% with water stress before or after silking stage. Denmead and Shaw (1959) also related consumptive use of corn to crop development and found that highest consumptive use rates occured during silking stage. The two studies by Denmead and Shaw demonstrated a relationship between maximum water use and the most water stress sensitive period of crop growth.

Porter et al. (1960) found that grain sorghum had the highest rate of water use from the booting stage to soft dough stage. They also found that rate of water use was not significantly affected by row width or planting rate.

Hay (1980) showed the optimal time for irrigating grain sorghum was from boot stage to half bloom stage. He also showed water use rates of grain sorghum peaked during the reproductive stage. Soybeans were found to have the highest rate of consumptive use in the late flowering period, when small pods were beginning to appear.

Musick and Dusek (1976) showed grain sorghum had a greater ability to extract water below -15 bars of soil moisture tension than soybeans. Stone et al. (1973) showed that 99.9% of sorghum roots were in the upper 4.3 feet of the soil profile.

Eavis and Taylor (1979) studied the relationship of soybean's transpiration to leaf area and soil water content. The result of this study indicated that transpiration was controlled primarily by leaf area when soil water is not limiting.

Jensen and Haise (1963) reevaluated about 3000 short period measurements of consumptive use by soil sampling procedures during a 35-year period in the western USA. Approximately 1000 measurements for 15 different crops met the standards established. These data were correlated with air temperature and solar radiation, RS, the main component of the energy balance equation.

Approximately 100 selected measurements were used to evaluate the potential evapotranspiration, PET, which may occur in irrigated fields located in arid and semi-arid areas. The results showed a linear increase in ET/RS, as the mean air temperature increased. This relationship resulted in a simple empirical equation for estimating evapotranspiration, which can occur in well-watered irrigated fields located in arid and semi-arid areas, where an effective full crop canopy exists, (Jensen and Haise, 1963).

They developed the following equation:

$$PET = (0.014\ T - 0.37)\ RS \qquad (5)$$

where: PET = Potential evapotranspiration in inches per day

T = Mean daily air temperature in degrees Farenheit

RS = Solar radiation expressed as evaporation equivalent in inches per day

Jensen (1968) used percent of growing season as a basis for indicating crop development in relation to a crop coefficient, K_c. Crop coefficient is the ratio of measured or actual evapotranspiration to potential evapotranspiration. There are different methods for measuring actual evapotranspiration like lysimeter and neutron method. The value of crop coefficient varies with crop and development stage of the crop. Evapotranspiration is estimated for various stages of growth by first estimating the potential evapotranspiration for a reference crop like alfalfa under given climatic conditions, and then applying the crop coefficient:

$$ET = (K_c)\ (PET) \qquad (6)$$

PET, in equation 6, represents the upper limit or maximum ET under given climatic conditions which occurs within a field having a well-watered agricultural crop, such as alfalfa, with about 12 to 18 inches of top growth.

Jensen (1974) defined the potential evapotranspiration as the rate at which water if available would be removed from the soil and plant surface.

Kanemasu et al. (1979) developed a model for estimating daily consumptive use and available soil moisture. Since this model was developed in the ET Laboratory of Kansas State University, it is also known as the ET Lab model. This model was developed for estimating the consumptive use of corn, but it can be modified for soybeans, sorghum, and some other crops.

The climatic data required by the ET Lab model to estimate consumptive use are solar radiation, maximum air temperature, and minimum air temperature. These climatic data should be in daily values in order for consumptive use to be estimated daily.

The Penman, ET Lab, and Blaney-Criddle consumptive use models may also be used to estimate the irrigation requirement of crops. These models require some additional data such as effective precipitation to estimate the crop irrigation requirement. Irrigation requirement may be estimated by irrigation models which combine consumptive use model with precipitation data. This combination is shown in equation 7:

$$IR = ET - EP \qquad (7)$$

where: IR = Irrigation requirement

ET = Evapotranspiration

EP = Effective precipitation

METHOD AND PROCEDURE

Estimating the Consumptive Use

Any irrigator should know when to irrigate and how much water to apply to each specific crop during the growing season. The knowledge of seasonal water requirements by crops is essential in planning and scheduling for an irrigation system. There are different methods available for estimating daily, weekly, monthly, or seasonal consumptive use of crops. These methods depend on different factors such as type of crop, location, climate, and soil characteristics.

Irrigations are usually either based on guesswork or rigid scheduling. This is because the farmers do not have enough information about consumptive use of the crops. In order to increase the irrigation efficiency there should be some reliable information available about water requirements of crops. As mentioned earlier, there are different methods for estimating the water requirements of crops and the relation between available soil moisture, soil moisture depletion, and consumptive use of crops. It was also mentioned that input is needed for these methods in order to estimate the crop consumptive use.

This study was based on using three models for estimating the consumptive use and irrigation requirement of three crops. These models were the Penman, ET Lab, and Blaney-Criddle. They were implemented in the form of computer programs for simplicity and accuracy of the results. The programs for each of the models are attached in Appendices B, C, and D. The three crops used in this study were corn, sorghum, and soybeans.

Following is a description of the factors and variables of each model used for estimating the crop consumptive use:

Penman Model (USDA-ARS, 1974)

The factors and variables used in the Penman model are:

1. Climate

   a - Maximum daily air temperature in degrees Farenheit

   b - Minimum daily air temperature in degrees Farenheit

   c - Daily dew point temperature in degrees Farenheit

   d - Daily windrun in miles per day

   e - Daily solar radiation in Langleys

2. Crop

   a - Coefficient, K_c

   b - Depth of root zone in feet

3. Others

   a - Number of days to effective cover

   b - Length of growing season in days

Daily average relative humidity and daily average air temperature were used to calculate daily dew point temperature. For simplicity dew point temperature was read from a psychrometric chart.

The Penman model requires wind velocity measured at a height of 2 meters. Wind velocity is normally not measured at 2 meters above a grassed surface at most weather stations in the USA. In this particular case, the wind velocity was measured at 3 meters. Wind velocity was corrected so it could be used in the Penman model. Doorenbos and Pruitt (1977) showed that wind velocity measured at 2 meters was 7% lower than measured at 3 meters. Therefore, the values of wind velocity at 3 meters were reduced by 7%. This was done by a separate statement in the program.

Windrun is the total distance of wind travel during a day. Windrun may be calculated by two methods. One is simply to multiply the average daily wind velocity, in miles per hour, by 24. The other method is to sum the 24 average hourly wind velocities.

The crop coefficient, K_c, is the ratio of measured or actual evapotranspiration to potential evapotranspiration. The value of K_c varies with crops and development stages of the crops. K_c values increase from a low value at the time of crop emergence to a maximum value during the period when the crop reaches full development and declines as the crop matures (Doorenbos and Pruitt, 1977). K_c was calculated by equations given in the program, Appendix B.

The information which is required on crops for calculating the crop coefficient are date of sowing and length of growing season. The length of growing season includes the duration of initial stage, duration of crop development, duration of mid-season stage, and duration of late season stage. These four stages are simply different stages of crop growth.

Number of days to effective cover of the crop is dependent on several factors. Location, crop variety, and temperature are some of the factors influencing the effective cover date. The sooner a crop reaches the effective cover, the lower is the annual water requirement for that crop.

ET Lab Model (Kanemasu et al., 1979)

The factors and variables used in the ET Lab model are:

1. Climate

a - Maximum daily air temperature in degrees Farenheit

b - Minimum daily air temperature in degrees Farenheit

c - Daily solar radiation in Langleys

2. Crop

a - Daily Leaf Area Index, LAI

3. Others

a - Length of growing season in days

Leaf Area Index, LAI, is one of the most important factors considered by the ET Lab model. LAI is the green leaf area per unit of soil area. It can be calculated by measuring the area of each leaf on a plant and counting the number of plants per unit ground area. Because the LAI may vary widely over a field, samples should be selected subjectively that represent the field. The LAI values vary from crop to crop and they even vary within the varieties of a given crop. For this study, LAI was determined from the curves in Agronomy Journals, (Mayaki et al., 1976, Rosenthal et al., 1977 and Kaigama et al., 1977).

Blaney-Criddle Model (USDA-SCS, 1967)

The factors and variables used in the Blaney-Criddle model are:

1. Climate

a - Mean monthly air temperature in degrees Farenheit

2. Crop

a - Coefficient reflecting the effect of the crop growth stage on consumptive use rate, K_c

3. Others

a - Length of growing season in month or fractions of month

b - Latitude

c - Mean monthly percent of annual daylight hours

Mean monthly air temperature is the mean of average daily temperatures during one month.

Latitude of the location is used in finding the values for mean monthly percent of annual daylight hours. The mean monthly percent of annual daylight hours reflects the influence of sunshine and solar radiation on plant growth. As an example, the length of the daytime at the equator varies little throughout the year, whereas at 50 degrees north latitude, the length of the day in the summer is much longer than in winter. Thus, at equal temperatures, photosynthesis can take place for several hours longer each June day at the northern latitude than the equator. Crop growth and water consumption vary with photosynthetic activities. For this study, crop coefficients were taken from curves presented by the USDA-Soil Conservation Service (1967).

Irrigation Requirement

The irrigation requirement of each crop is influenced by development stage of the crop and available soil moisture. The effect of development stage is summarized in the form of a coefficient and was used in estimating the consumptive use. The moisture content of the soil depends on irrigation water or precipitation, and extraction of moisture by crops. It should be mentioned that as the soil moisture content goes lower than 50 percent of available, there is the possibility of yield reduction.

The pattern of irrigation based on the Penman and the ET Lab models is to irrigate when the soil moisture is depleted by 50%. The Blaney-Criddle model indicates that there should be a range of moisture available to the crops depending on soil water holding capacity. In this study it is estimated to be 1.13 inches of water, (Bruce and Louie, 1974). The procedure for estimating irrigation requirement of the crops based on the Penman and the ET Lab models is included with procedure for estimating consumptive use. The Blaney-Criddle model has a different procedure for estimating irrigation requirement. A sample of this procedure is shown in Appendix E.

The Penman, ET Lab, and Blaney-Criddle models require data for estimating irrigation requirement other than those used for estimating the consumptive use. The consumptive use is certainly the main factor influencing irrigation requirement. The rest of the data required for estimating irrigation requirement are related to the soil characteristics and precipitation.

Following is a discussion of the factors and variables of each model used for estimating the irrigation requirement of crops:

Penman Model (USDA-ARS, 1974)

The factors and variables used in the Penman model are:

1. Daily precipitation in inches
2. Type of soil
3. Available water holding capacity
4. Initial moisture condition

The Penman model assumes that all of rainfall is effective and does not consider runoff losses.

Water holding capacity of the soil is usually measured in the laboratory. A specific type of soil is put under different pressures and the water content is measured. Soil water holding capacity and water content are directly related to the soil texture. Soil water holding capacity may be obtained from the soil survey reports if the soil series name is known. It may also be estimated from the soil texture. In general total available soil moisture, inches of water per foot of soil depth, for different soil textures is shown in table 5 (Appendix A). Total available soil moisture for this study was estimated to be 4.53 inches for crops with a rooting depth of three feet.

Initial soil moisture is the amount of water in the soil at planting. Soil moisture at the beginning of the growing season was assumed to be equal to the soil moisture content at field capacity. Field capacity is the amount of water a soil profile will hold against drainage by gravity at a specified time usually from 24 to 48 hours, after a thorough wetting, (Pair et al., 1975). The initial moisture content for this study was assumed to be 9.50 inches.

ET Lab Model (Kanemasu et al., 1979)

The factors and variables used in the ET Lab model are:

1. Daily precipitation in inches
2. Type of soil
3. Available water holding capacity
4. Initial moisture condition

The ET Lab model considers the effective rainfall to be the amount of rainfall infiltrating into the soil. This does not include the runoff water. The ET Lab model considers there is runoff when more than one inch of rainfall occurs at one time. Therefore, when the rainfall is one inch or less, all of it is considered effective. And whenever the rainfall is more than one inch, the amount of effective rainfall is calculated by the following equation:

$$ER = R^{0.75} \qquad (8)$$

where: ER = Effective precipitation

R = Net amount of rainfall

The amount of runoff, RO, is calculated by equation 9:

$$RO = R - ER \qquad (9)$$

Available moisture content and initial moisture content used in the ET Lab model were the same as those in the Penman model.

Blaney-Criddle Model (USDA-SCS, 1967)

The factors and variables used in the Blaney-Criddle model are:

1. Mean monthly rainfall in inches
2. Type of soil
3. Initial soil moisture condition

Monthly rainfall is simply the total rainfall during the month. The initial moisture condition used in the Blaney-Criddle model was the same as for the Penman and the ET Lab models. A sample calculation of irrigation requirement based on the Blaney-Criddle model is shown in Appendix E.

The location of this study was Equus Beds Groundwater Management District. Type of soil used in the study was a fine sandy loam which is commonly found in the area.

The data used in the programs for estimating the consumptive use and irrigation requirement of the crops were from the year 1983. The data were collected at the Hesston Experiment Field located in Harvey County. This site was selected because it is within the Equus Beds Groundwater Management District. The data were made available for this study by the weather data library of the Agricultural Experiment Station at Kansas State University.

Data for the Hesston Experiment Field were not complete for the whole growing season. The data for the first 15 days of July were not available because of technical problems in recording instruments. Therefore, the data from the Sandyland Experiment Field, located about 80 air miles west of Hesston, were used to replace the missing data from Hesston.

Wind velocity data recorded at the Hesston Experiment Field were significantly high for the periods of June 15 to 30th and July 16 to 31th. Inaccurate weather readings were due to technical problems in the station's weather recording equipments. The wind velocity data, for the periods mentioned above, were replaced by the data collected at the Kansas River Valley Experiment Field. This station is located about 105 air miles northeast of Hesston.

RESULTS

Crop water use is influenced by climate, crop species, available soil moisture, and soil characteristics. Most of the consumptive use models require these parameters as input for estimating the consumptive use and irrigation requirement of crops. Estimated consumptive use of corn, soybeans, and sorghum are given in Tables 1, 2, and 3. The cumulative consumptive use of the crops based on different methods are shown in the Figures 1, 2, and 3.

The consumptive use of corn was higher than soybeans and sorghum by the Penman and the Blaney-Criddle models. The consumptive use of corn according to the ET Lab model was slightly lower than sorghum, but higher than soybeans. The reason for this can be the Leaf Area Index which is one of the factors used in estimating consumptive use by ET Lab model. LAI can vary depending on varieties of a crop and location.

The Penman model over-estimated the consumptive use in the beginning and end of the season compared to the other two models. This may be due to the fact the Penman model estimated the potential water use. Crop water use in the beginning and end of the season is normally not as near potential as during the middle of the season. As shown in the tables and figures, the rate of consumptive use based on the Penman model during the middle of the season was similar to the other models. The crop coefficient is another factor influencing the consumptive use. The crop coefficient varies with time depending upon the type of crop, planting date, and effective cover date or expected date of peak water use (USDA-ARS, 1974).

Table 1. Corn Monthly and Seasonal Estimated Consumptive Use by Three Models.

Month	Penman (inches)	ET Lab (inches)	B-C* (inches)
May	3.720	1.651	2.240
June	5.093	4.366	5.460
July	9.012	10.545	10.140
August	9.221	7.502	8.780
Total(Seasonal)	27.046	24.064	26.620

* B-C is the Blaney-Criddle model.

(Growing season for corn was from May 1 to August 31.)

(Length of growing season = 123 days)

Table 2. Sorghum Monthly and Seasonal Estimated Consumptive Use by Three Models.

	Models		
Month	Penman (inches)	ET Lab (inches)	B-C* (inches)
May 20	1.574	0.857	0.550
June	4.100	3.438	4.050
July	7.366	9.479	10.130
August	7.484	8.488	7.940
September 20	2.497	1.204	2.580
Total(Seasonal)	23.021	23.466	25.250

* B-C is the Blaney-Criddle model.

(Growing season for sorghum was from May 20 to September 20.)

(Length of growing season = 124 days)

Table 3. Soybeans Monthly and Seasonal Estimated Consumptive Use by Three Models.

Month	Models Penman (inches)	 ET Lab (inches)	 B-C* (inches)
May 20	0.984	0.871	0.360
June	3.154	2.592	3.210
July	9.476	9.096	7.360**
August	7.603	8.127	9.780
September 20	4.098	3.808	3.050
Total(Seasonal)	25.315	24.494	23.760

* B-C is the Blaney-Criddle model.

** Used in sample calculation shown in Appendix E.

(Growing season for soybeans was from May 20 to September 20.)

(Length of growing season = 124 days)

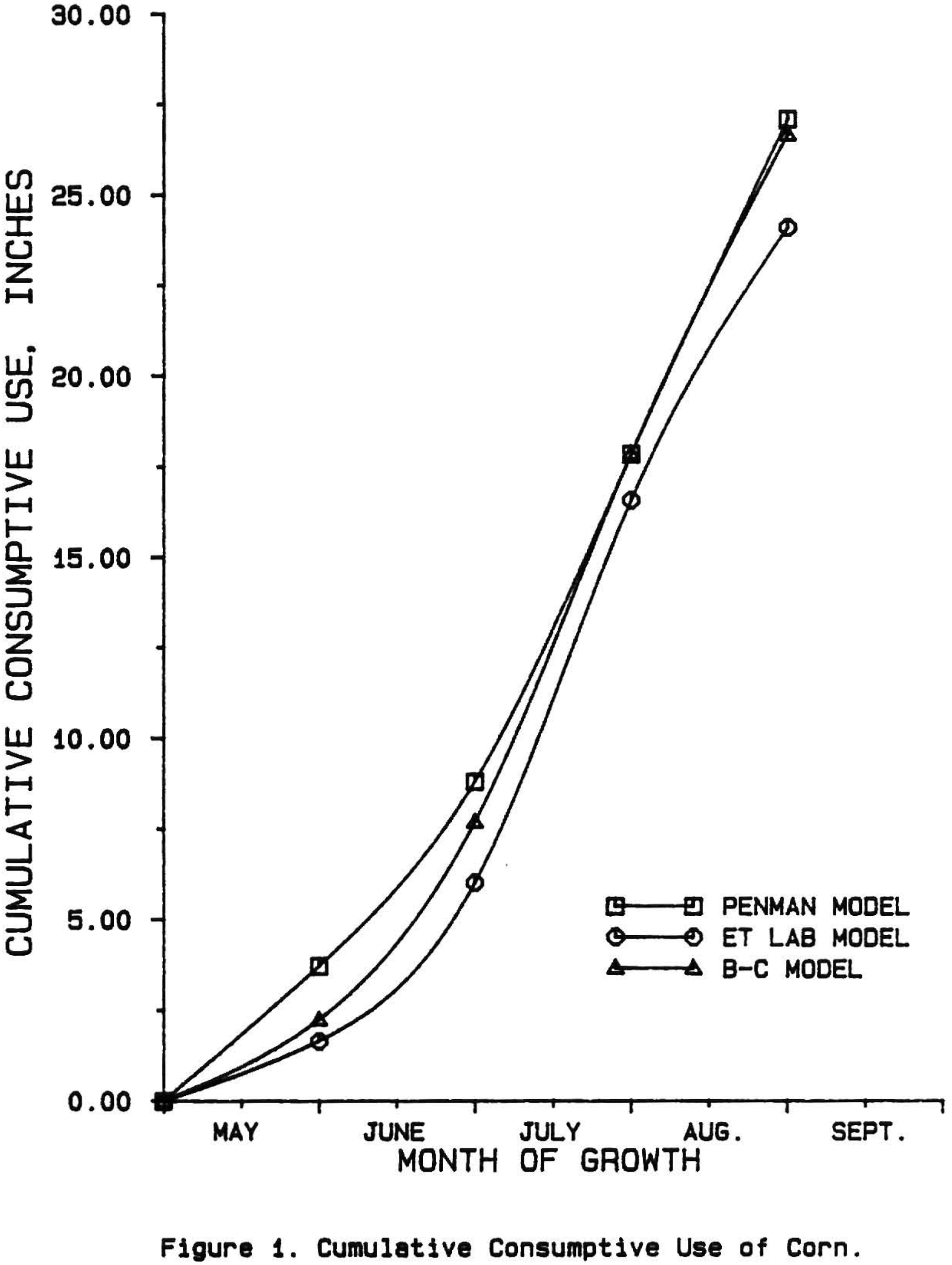

Figure 1. Cumulative Consumptive Use of Corn.

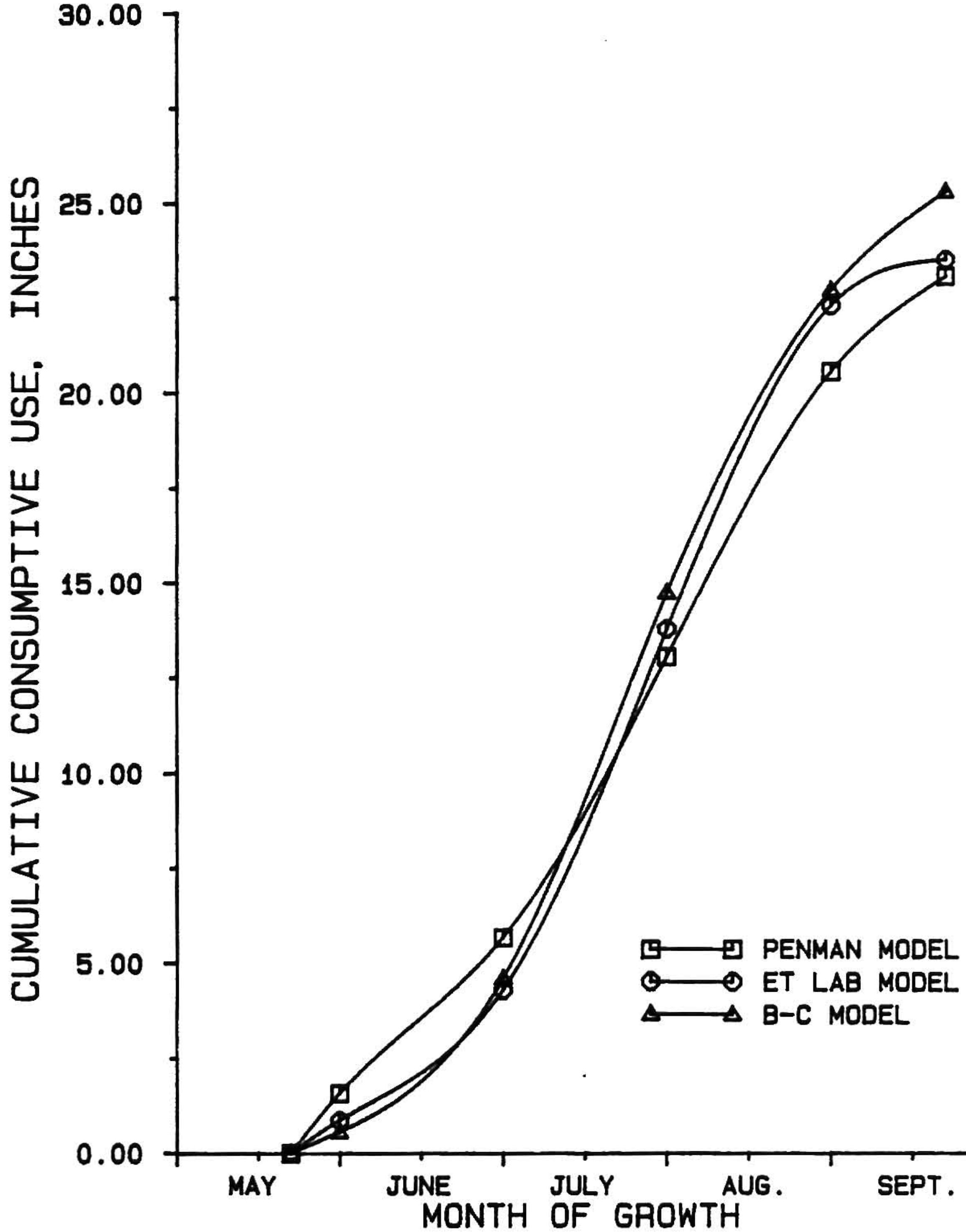

Figure 2. Cumulative Consumptive Use of Sorghum.

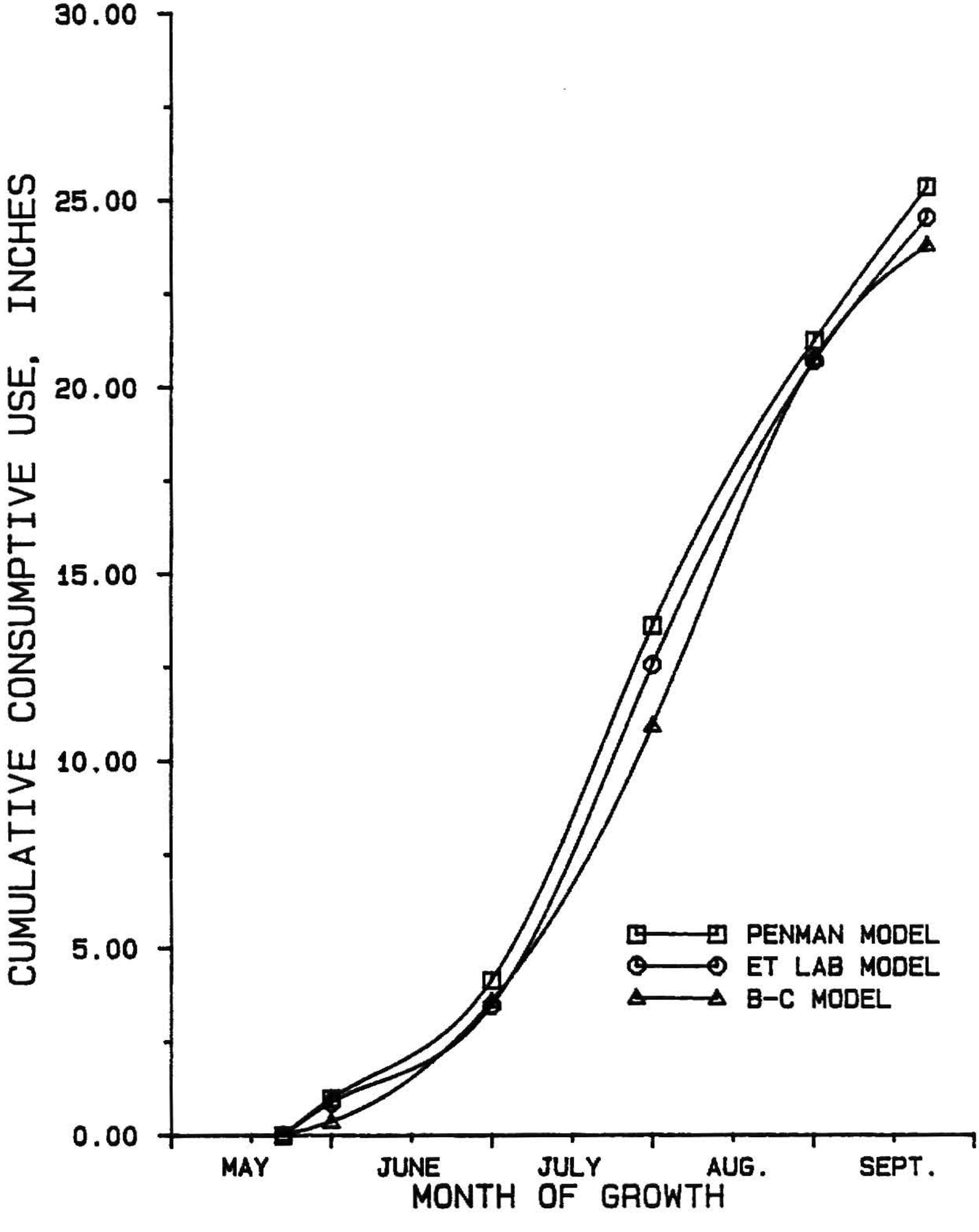

Figure 3. Cumulative Consumptive Use of Soybeans.

Cumulative consumptive use is another way to compare different methods of estimating the consumptive use. Cumulative consumptive use of corn and sorghum by the Blaney-Criddle model is higher than cumulative consumptive use of soybeans.

The irrigation requirement of the crops was estimated by the three models. The estimated irrigation requirement of each crop is summarized in Table 4. Corn required slightly less water than soybeans and sorghum according to the ET Lab model. Planting date was the most effective reason for this event. Corn was planted 20 days earlier than soybeans and sorghum. There were 2 inches of rainfall during this period available to corn, which reduced the irrigation requirement of corn relative to soybeans and sorghum. Irrigation requirement of corn was slightly less than soybeans but greater than sorghum according to the Blaney-Criddle model.

The irrigation requirement, based on this study, for corn and sorghum was 14 to 17 inches and for soybeans 12 to 18 inches assuming a water application efficiency of 100 percent. This is not a true assumption and normally the efficiency is 70 to 85 percent which increases the amount of irrigation application.

Kirkeeng (1984) investigated the irrigation practices of farmers in the Equus Beds Groundwater Management District #2 in south central Kansas. A summary of the farmers reported yield and depth of irrigation is presented in Appendix F. Results of statistical analyses of these data are shown in Table 5. Figures 4, 5, and 6 show graphs of yield as a function of irrigation depth for each crop and the lines of best fit and equations as determined by the method of least squares.

Table 4. Seasonal Net Irrigation Requirement of Crops by Three Models*.

Crop	Models		
	Penman (inches)	ET Lab (inches)	B-C** (inches)
Corn	14	14	17.68
Sorghum	14	16	15.25
Soybeans	12	16	17.80

* Assumption: This irrigation requirement is based on net irrigations of 2 inches.

** B-C is the Blaney-Criddle model.

Table 5. Statistical Analyses of Crop Yield as a Function of Irrigation Depth.

Soybeans

Source of Variation	DF	SS	MS	F
Linear Regression	1	139.00	139.00	1.79NS
Deviation	32	2491.00	77.84	
Total	33	2630.00		

Sorghum

Source of Variation	DF	SS	MS	F
Linear Regression	1	749.24	749.24	1.48NS
Deviation	39	19760.76	506.67	
Total	40	20510.00		

Corn

Source of Variation	DF	SS	MS	F
Linear Regression	1	73.39	73.39	0.33NS
Deviation	28	6308.61	225.31	
Total	29	6382.00		

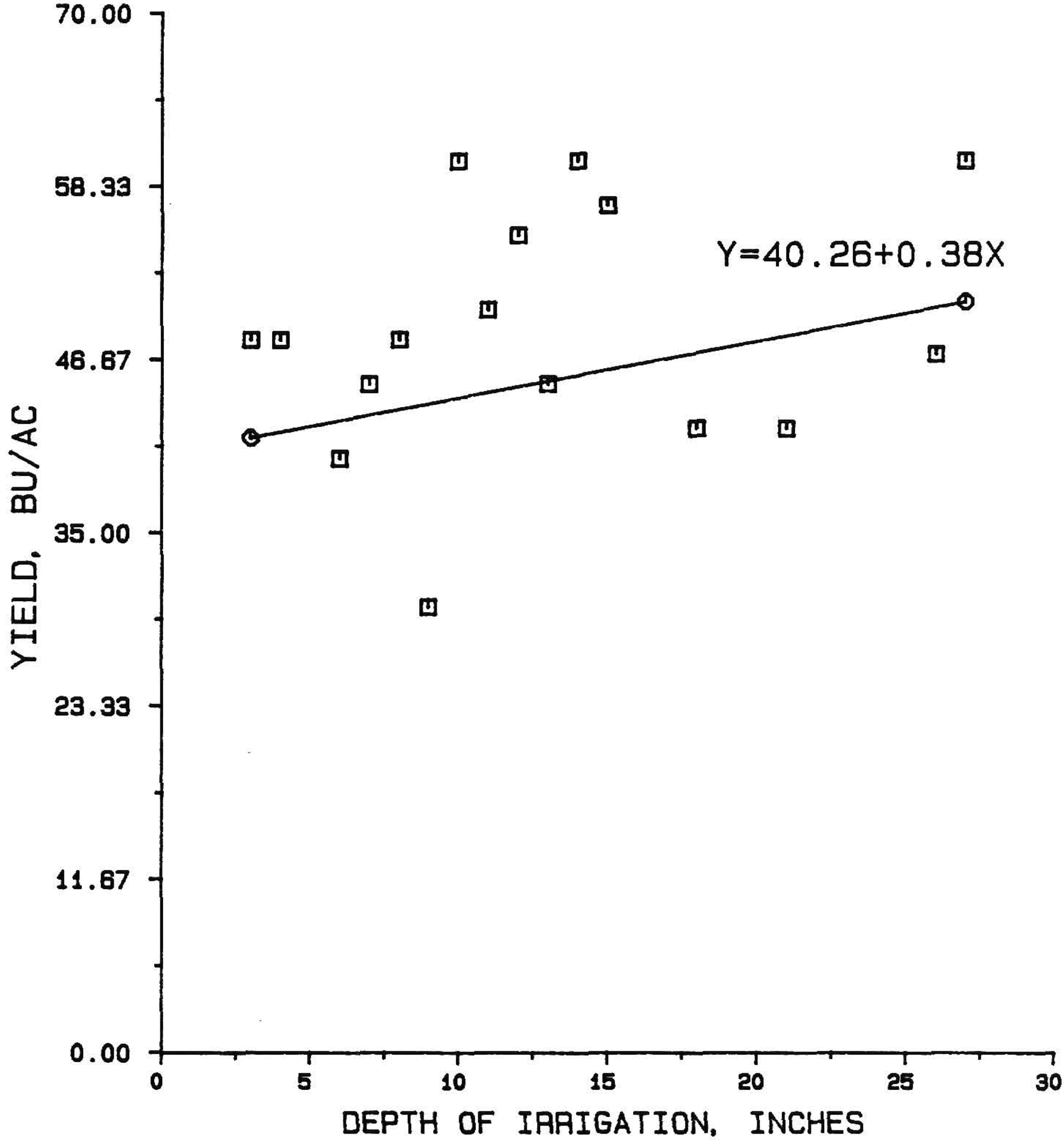

Figure 4. Effect of Irrigation on Soybeans Yield.

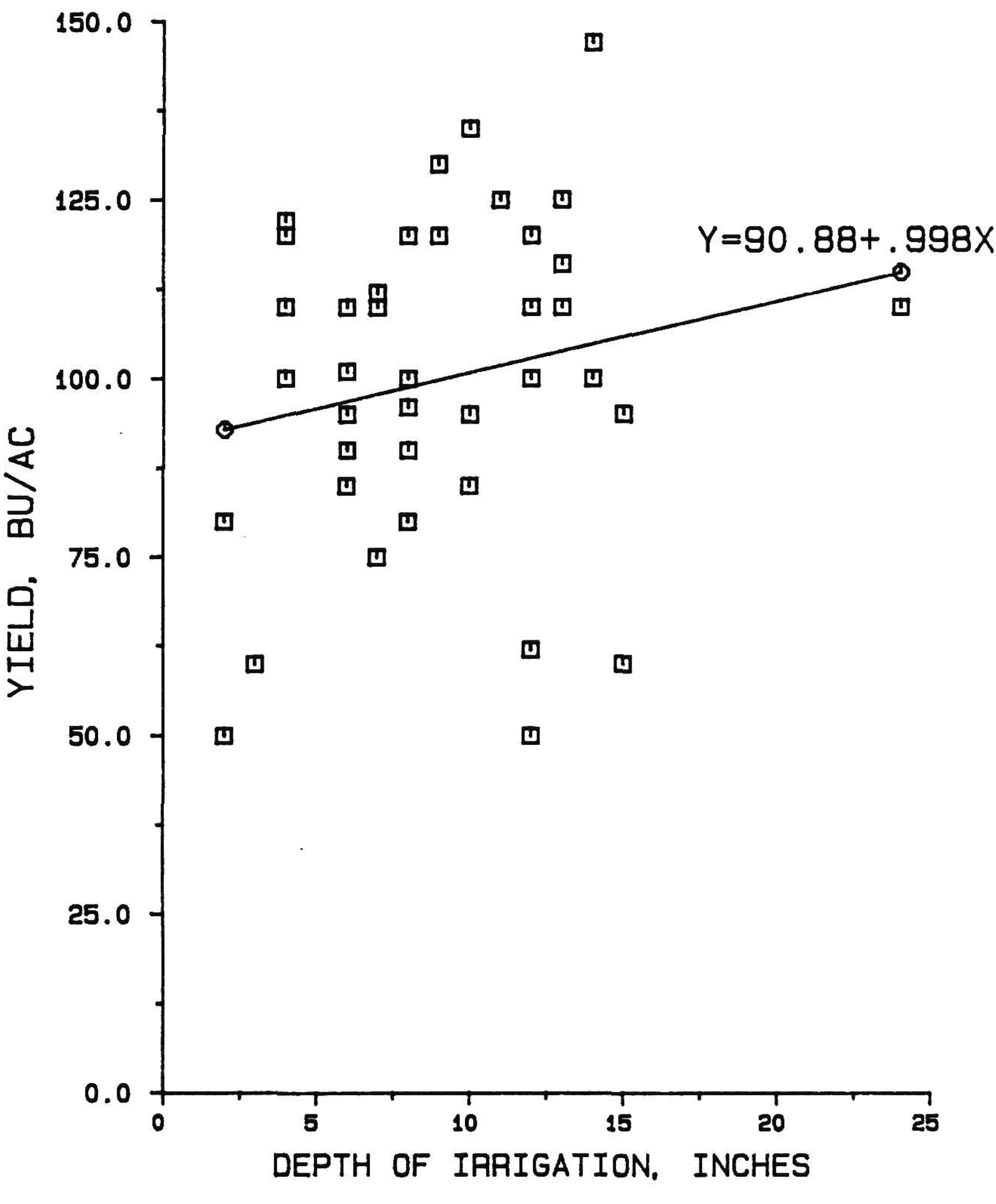

Figure 5. Effect of Irrigation on Sorghum Yield.

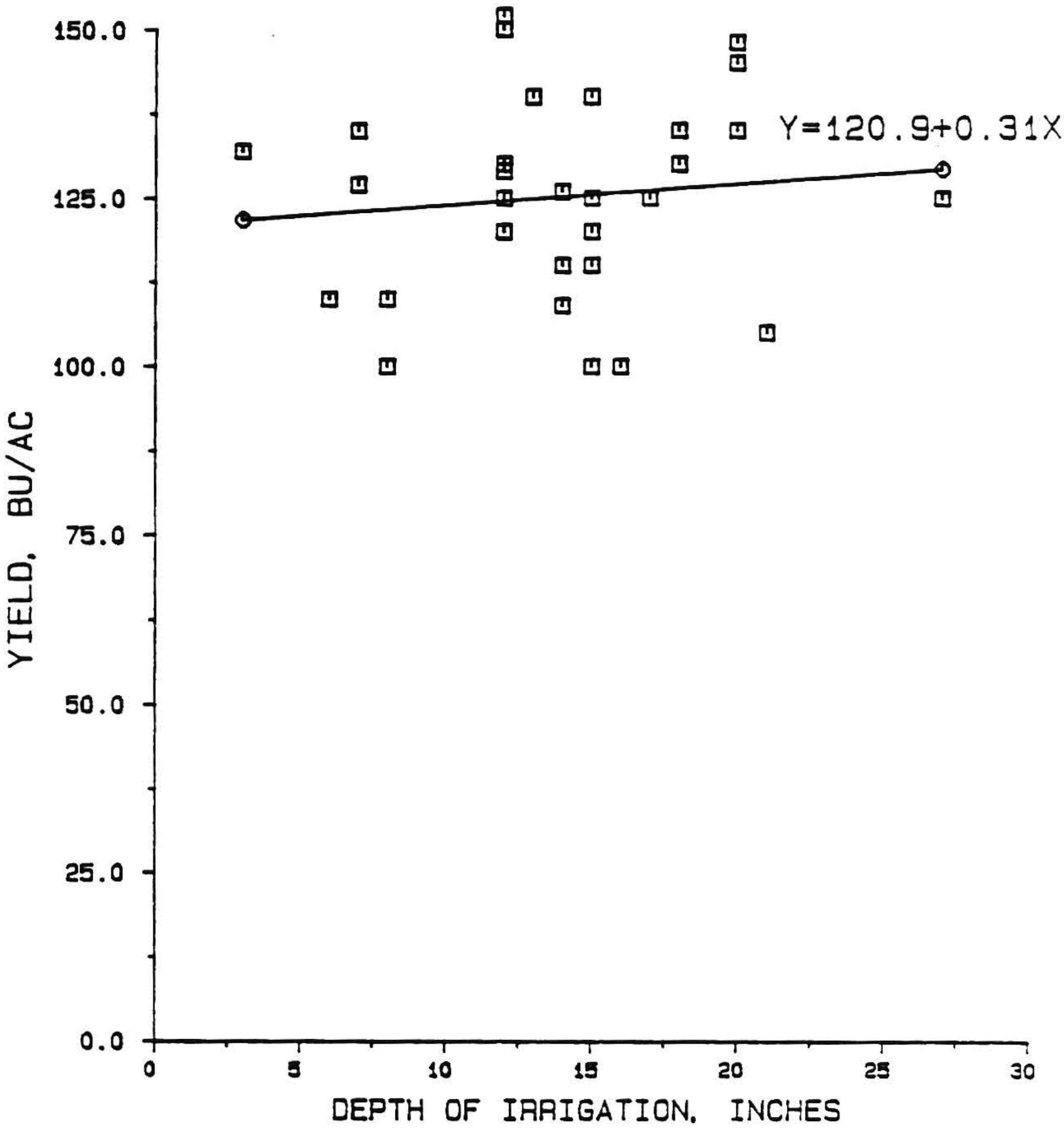

Figure 6. Effect of Irrigation on Corn Yield.

The analyses of yield-irrigation, as reported by farmers, reveals that amount of irrigation is not an influencing factor on yield. The first 2 or 3 inches of irrigation water may have most of the irrigation influence on yield. Therefore, application of more water would be an extra cost. There are other factors influencing the yield. These factors include soil physical and chemical properties, management, weed control, planting date, and plant population.

DISCUSSION

There are some limitations and advantages for using each of the models to estimate the consumptive use and irrigation requirement of crops. The principle limitation of the Penman model is the lack of sufficient weather measurements in most localities. It should also be mentioned that the Penman model assumes all of the rainfall is infiltrated into the soil and does not consider runoff. However, the model could be modified to consider the effective rainfall. At the same time, the most important advantage of the Penman model is that it gives the most reliable short period estimates.

The ET Lab model was another method for estimating the consumptive use of crops. The main difference between the ET Lab model and the others is that it uses the Leaf Area Index of crops rather than a crop coefficient. Leaf Area Index, LAI, is the main crop factor influencing the consumptive use in the ET Lab model. LAI changes by location and crop species. Therefore, at each location the new LAI should be determined for each crop. Although LAI information is not readily available, it does give the ET Lab model an advantage over the other models. LAI is a current information about the crop and increases the accuracy of estimating the consumptive use and the irrigation requirement.

The Blaney-Criddle model estimates the monthly consumptive use of crops. The factors and variables which are used in this model are the mean of daily values. This is a limitation because the estimated consumptive use is not accurate for periods of less than one month. An advantage of the Penman and the ET Lab models is estimating the daily consumptive use. This information is helpful in scheduling the irrigation application. A limitation of the Penman model is not having a function for estimating the surface runoff.

Factors and variables could be a limitation for using each of the models for estimating consumptive use. The Penman model has not been used extensively in the USA because of the need for many parameters. The Blaney-Criddle model requires fewer data. This is an advantage for the Blaney-Criddle model because it can be used in regions with limited weather information.

The Penman and the ET Lab models have an advantage over Blaney-Criddle model in calculating the irrigation requirement by crops. Penman and ET Lab models give daily values of consumptive use and soil moisture content. Therefore, it will be easier to schedule irrigation. The Blaney-Criddle model only estimates the monthly amount of irrigation requirement. For this reason the Blaney-Criddle model can not be used for real time scheduling of irrigation.

Primarily the choice of method must be based on the type of climatic data available and on the accuracy required in determining the water requirement. The climatic conditions of each specific location are somewhat different from those of other locations. Each one of these methods can be used for estimating the consumptive use. However they should be calibrated to match the available conditions in that location, (Doorenbos and Kassam, 1979).

Concerning accuracy, only approximate possible errors can be given since no base-line type of climate exists. Doorenbos and Pruitt (1977) investigated the accuracy of Penman and Blaney-Criddle models. The modified Penman model would offer the best results in estimating the consumptive use and irrigation requirement. This has a minimum possible error of plus or minus 10 percent in summer, and up to 20 percent under low evaporative conditions. The Blaney-

Criddle model should only be applied for periods of one month or longer. This model gives an over and under prediction of up to 25 percent in humid, windy, and mid-latitude winter conditions.

REFERENCES

Blaney, H. F. and K. V. Morin. 1942. Evaporation and consumptive use of water empirical formulas. Amer. Geophys. Union Trans., pp. 76-83.

Bruce, R. H. and W. D. Louie. 1974. Soil survey of Harvey county, Kansas. USDA-Soil Conservation Service., pp. 30-95.

Denmead, O. T. and R. H. Shaw. 1959. Evapotranspiration in relation to the development of the corn crop. Agronomy Journal. 51:725-726.

Denmead, O. T. and R. H. Shaw. 1960. The effects of soil moisture stress at different stages of growth on the development and yield of corn. Agronomy Journal. 52:272-274.

Doorenbos, J. and A. H. Kassam. 1979. Yield response to water. FAO, Irrigation and Drainage Paper., pp. 1-34.

Doorenbos, J. and W. O. Pruitt. 1977. Crop water requirements. FAO, Irrigation and Drainage Paper., pp. 1-65.

Eavis, B. W. and H. M. Taylor. 1979. Transpiration of soybeans as related to leaf area, root length, and soil water content. Agronomy Journal. 58:9-12.

Hay, Delynn. 1980. Irrigate properly. In: Grain Sorghum Handbook. Cooperative Extension Service. Kansas State University. C-494., pp. 13-15.

Holt, O. W. and C. A. Van Doren. 1961. Water utilization by field corn in western Minnesota. Agronomy Journal. 53:43-45.

Jensen, M. E. 1968. Water consumption by agricultural plants. Water Deficits and Plant Growth, Vol. II, Chapter 1, pp. 1-22.

Jensen, M. E. 1974. Consumptive use of water and irrigation water requirements. A report prepared by the Tech. Comm. on Irrigation Water Requirement, Irri. Drain Div., Amer. Soc. of Civil Engin., pp. 210-215.

Jensen, M. E. and H. R. Haise. 1963. Estimating evapotranspiration from solar radiation. Amer. Soc. of Civil Engin. Proc. 89(IR 4):15-41.

Kaigama, B. K., I. D. Teare, L. R. Stone and W. L. Powers. 1977. Root and top growth of irrigated and nonirrigated grain sorghum. Agronomy Journal. 17:555-559.

Kanemasu, E. T., J. L. Steiner, V. P. Rasmussen and J. Bagley. 1979. Estimating water requirements of corn with a programmable calculator. Kansas Agricultural Experiment Station. Bulletin 615., pp. 1-10.

Kirkeeng, T. A. 1984. Sample size determination for an irrigation baseline study. Unpublished M.S. Thesis. Kansas State University Library. Manhattan, Kansas.

Mayaki, W. C., I. D. Teare and L. R. Stone. 1976. Top and root growth of irrigated and nonirrigated soybeans. Agronomy Journal. 16:92-94.

Musick, J. T. and D. A. Dusek. 1976. Soil water depletion relation of irrigated grain sorghum, wheat, soybeans. TRANSACTIONS of the ASAE. 19:489-493.

Pair, C. H., W. W. Hinz, C. Reid and K. R. Frost. 1975. Sprinkler irrigation. 4th edition. Silver Spring, Maryland. The Irrigation Association.

Porter, K. B., M. E. Jensen and W. H. Sletten. 1960. The effect of row spacing, fertilizer and planting rate on the yield and water use of irrigated grain sorghum. Agronomy Journal. 52:431-434.

Rosenthal, W. D., E. T. Kanemasu, R. J. Raney and L. R. Stone. 1977. Evaluation of an evapotranspiration model for corn. Agronomy Journal. 69:461-464.

Stone, L. R., M. L. Horton, and T. C. Olson. 1973. Water loss from an irrigated sorghum field: II. Evapotranspiration and root extraction. Agronomy Journal. 65:495-497.

Thornthwaite, C. W. and J. R. Mather. 1955. The water balance. Publication in climatology. Volume 8. Laboratory of Climatology. Centerton, N.J.

USDA-Agricultural Research Service. 1974. Scheduling irrigations using a programmable calculator. ARS-NC-12:1-5.

USDA-Soil Conservation Service. 1967. Irrigation water requirement Technical Release Number 21. USDA-SCS., pp. 1-40.

APPENDIX

Appendix A

Table 6. Total Available Soil Moisture for Different Soil Textures*.

Type of Soil	Moisture Content (in/ft)
Fine Textured	2.40
Medium Textured	1.68
Coarse Textured	0.72

* Table produced from:

Doorenbos and Pruitt, 1977.

Appendix B

```
c      This computer program was written by Hossein V. Kazemi
c      to estimate the Water Consumptive Use of crops based on
c      Penman Model.
       dimension TMAX(200), TMIN(200), RAIN(200), RS(200),
        WIND(200), D1AY8(200), D2AY(200), TDEW(200)
       Real KCO, KS, IRR (200), KR(3), KP
       Read (5, *) FA, AA, T1MIN, T2MIN, T3MIN
       Read (5, *) A1, B1, CT, DT, EC
       Read (5, *) A2, B2, CR, DX
       Write (6, 100)
100    Format ("Input Starting Moisture")
       Write (6, 120)
120    Format ("Input DA")
       Read (5, *) DA
       DP = DA
       Write (6, 140)
140    Format ("Input M=1 if RAIN 3 day before start and
        4 if no RAIN")
       Read (5, *) M
       Write (6, 160)
160    Format ("Input number of days of data")
       Read (5, *) KR(1), KR(2), KR(3)
       Read (5, *) N
       Read (5, *) ( TMAX(I), TMIN(I), RAIN(I), IRR(I), RS(I),
        WIND(I), D1AY(I), D2AY(I), TDEW(I), I=1, N)
       R = 1
       Write (6, 180)
180    Format ("   DAY  ETP     KCO       KS       EVAP     CROP
        ET     RAIN    IRR      DP    $DP      USE      DRAIN")
       Do 500 I=1, N
       TAVE=(TMAX(I)+TMIN(I))/2
       C2=0.959-0.0125*TAVE+0.00004534*TAVE**2
       C1=1-C2
       E1S=-0.6959+0.2946*TMIN(I)-0.005195*TMIN(I)**2+
        89*0.000001*TMIN(I)**3
       E2S=-0.6959+0.2946*TMAX(I)-0.005195*TMAX(I)**2+
        89*0.000001*IMAX(I)**3
       ES=(E1S+E2S)/2
       ED=-0.6959+0.2946*TDEW(I)-0.005195*TDEW(I)**2+
        89*0.000001*TDEW(I)**3
       G=5*(TAVE-(T1MIN+T2MIN+T3MIN)/3)
       T3MIN=T2MIN
       T2MIN=T1MIN
       T1MIN=TAVE
       RSO=760*exp(-(((D2AY(I)-107)/157)**2))
       TK1=(5./9.)*(TMAX(I)-32)
       TA=TK1+273
       TL1=(5./9.)*(TMIN(I)-32)
       TB=TL1+273
```

```
      RBO=(0.37-0.0442)sqrt(ED))*(11.71*0.00000001)*
       ((TA**4+TB**4)/2)
      RN=0.77*RS(I)-(0.9*RS(I)/RSO+0.1)*RBO
      WIND(I)=0.93*WIND(I)
      W=(1.1+0.017*WIND(I))
      ETP=0.000673*(C1*(RN-G)+15.36*C2*W*(ES-ED))
      IF (ETP.LE.0.) ETP=0
      IF (D1AY(I).GT.EC) GO TO 250
      R=(D1AY(I)/EC)
      KCO=A1*R**3.+B1*R**2.+CT*R+DT
      GO TO 260
250   R=R+1
      KCO=A2*R**3.+B2*R**2.+CR*R+DX
260   IF (KCO.GT.1.) KCO=1
      TT=(1+100*(1-(FA-DP)/FA))
      KS=LOG(TT)/LOG(101.0)
      IF (KS.GT.1.) KS=1
      KP=KCO*KS
      IF (RAIN(I).GT.0.) GO TO 300
      IF (IRR(I).GT.0.) GO TO 300
      IF (M.LE.3.) GO TO 320
      GO TO 340
300   M = 1
320   ERT=KR(M)*(0.9-KP)*ETP
340   M = M + 1
      GO TO 360
360   IF (KP.GE.0.9) ERT=0
      IF (M.GT.3.) ERT=0
      DR = DA - FA
      IF (DR.LE.0.) DR=0
      D1PT=DA-KP*ETP-ERT+RAIN(I)+IRR(I)-DR
      BB = KP * ETP
      CC = BB + ERT
      WUS = DA - D1PT
      DA = D1PT
      D2PP = (FA - DA)/AA
      IF (D2PP.LT.0.) D2PP=0
      Write (6, 400) I, ETP, KCO, KS, ERT, BB, CC, RAIN(I),
       IRR(I), DA, D2PP, WUS, DR
400   Format (" ", I3, 2(3x, F5.3), (3x, F7.3), 3(3x, F5.3),
       2(3x, F4.2), (3x, F6.2), (3x, F5.3), 2(3x, F5.2))
      DP = DA
500   Continue
      STOP
      END
```

Appendix C

```
c     This computer program was written by Hossein V. Kazemi
c     to estimate the Water Consumptive Use of crops based on
c     ET Lab Model.
      dimension ET(200), SIM(200), DR(200), DIP(200),
       PET(200), TZ(200)
      dimension EE(200), TMAX(200), TMIN(200), RS(200), RAIN(200)
      Real IRR(200), LAI(200)
      write (6, 100)
100   Format ("Initial soil data")
      Read (5, *) S3MI1, A1M, F1C, C, U
      Write (6, 110)
110   Format ("Number of days of data")
      Read (5, *) N
      Do 500 I=1, N
      Read (5, *) TMAX(I), TMIN(I), RS(I), LAI(I), RAIN(I), IRR(I)
500   Continue
      T = 1
      SUM = 0
      Z1 = 1
      Write (6, 170)
170   Format ("   DAY  ETP    EVA{    CROP    ET       RAIN
       IRR  DP        %DP     USE     DRAIN")
      Do 1000 I = 1, N
      TAVE=(TMAX(I)+TMIN(I))/2
      TAVE=(5./9.)*(TAVE-32)
      S1=(0.016*TAVE)-(0.000005*TAVE**3)+(0.0000001*TAVE**4)+0.4
      IF (LAI(I).LE.3.0) GO TO 200
      RN=0.848*RS(I)-144.5
      GO TO 220
200   RN=0.86*RS(I)-103.9
220   Z2=S1*RN/59
      P = 1.35
      PV = 1.51
      PET(I)=P*Z2
      IF (PET(I).LT.0.) PET(I)=0
      TAU=exp(-0.39*LAI(I))
      IF (TAU.GT.1.) TAU=1
      IF (LAI(I).LT.3.) GO TO 250
      TR=(P-TAU)*Z2
      GO TO 270
250   TR=PV*(1-TAU)*Z2
270   IF (TMAX(I).LT.93.) GO TO 350
      IF (TMAX(I).GT.97.) A=TR*0.3
      IF (TMAX(I).GT.93.) GO TO 280
280   IF (TMAX(I).LT.97.) GO TO 340
340   A=(TR*0.1)*((5./9.)*(TMAX(I)-32)-33)
      GO TO 360
350   A = 0
360   IF (PET(I).LE.0.) TR = 0
```

```
      IF (PET(I).LE.0.) A = 0
      TZ(I)=TR+A
      Z1 = Z1 + 1
      IF (Z1.GT.7.) Z1 = 0
      IF (RAIN(I).LE.1.) GO TO 380
      IF (RAIN(I).GT.1.) GO TO 370
370   RAIN(I)=RAIN(I)**0.75
      GO TO 390
380   RAIN(I)=RAIN(I)
390   RAIN(I)=RAIN(I)*25.4
      IRR(I)=IRR(I)*25.4
      W=IRR(I)+RAIN(I)
      IF (W.GT.6.) GO TO 501
      IF (SUM.GT.0.) GO TO 501
      E2=C*((T**0.5)-((T-1)**0.5))
      IF (PET(I).LE.0.) GO TO 550
      T = T + 1
      E1=TAU*Z2
      IF (E2.GT.E1) E2 = E1
      E1 = 0
      GO TO 560
501   E1=TAU*Z2
      SUM=SUM+E1
      E2 = 0
      IF (SUM.GE.U) GO TO 520
      GO TO 560
520   SUM=0
      T = 1
550   E1=0
      E2=0
560   EE(I)=E1+E2
      IF (EE(I).LT.0.) EE(I) = 0
      DR(I)=S3MI1-F1C
      IF (DR(I).LT.0.) DR(I)=0
      ET(I)=TZ(I)+EE(I)
      SIM(I)=S3MI1-EE(I)-TZ(I)+W-DR(I)
      WUS=(S3MI1-SIM(I))/25.4
      S3MI1=SIM(I)
      DIP(I)=(F1C-S3MI1)/A1M
      IF (DIP(I).LT.0.) DIP(I)=0
      PET(I)=PET(I)/25.4
      EE(I)=EE(I)/25.4
      TZ(I)=TZ(I)/25.4
      ET(I)=ET(I)/25.4
      RAIN(I)=RAIN(I)/25.4
      IRR(I)=IRR(I)/25.4
      SIM(I)=SIM(I)/25.4
      DR(I)=DR(I)/25.4
      Write (6, 600) I, PET(I), EE(I), TZ(I), ET(I), RAIN(I),
       IRR(I), SIM(I), DIP(I), WUS, DR(I)
600   Format (" ", I3, 4(3x, F5.3), 2(3x, F4.2), (3x, F6.2),
       (3x, F7.3), (3x, F7.3), (3x, F5.3))
1000  Continue
```

```
STOP
END
```

Appendix D

```
c     This computer program was written by Hossein V. Kazemi
c     to estimate the Water Consumptive Use of crops based on
c     Blaney-Criddle Model.
      dimension f(5), kc(5), kt(5), t(5), p(5), k(5), U(5)
      Real kc, kt, p, k, sum
      Write (6, 100)
100   Format (" ", "Estimating Consumptive Use of Water")
      Read (5, *) N
      Read (5, *) (kc(I), t(I), p(I), I=1, N)
      Write (6, 150)
150   Format (" ", "Input number of months, N")
      sum = 0
      Do 200 I=1, N
      kt(I)=0.0173*t(I)-0.314
      Write (6, 160) kt(I)
160   Format (" ", F7.3)
      k(I)=kt(I)*kc(I)
      Write (6, 165) k(I)
165   Format (" ", F7.3)
      f(I)=(p(I)*t(I))/100
      Write (6, 175) f(I)
175   Format (" ", F7.3)
      U(I)=sum+(f(I)*k(I))
      Write (6, 180) U(I)
180   Format (" ", F7.3)
      sum = U(I)
200   Continue
      Write (6, 300) U(5)
300   Format (" ", (3x, F7.3))
      STOP
      END
```

Appendix E

Following is a sample calculation of net irrigation requirement for soybeans during July of 1983.

1- Consumptive use during July = 7.36 in.
   is calculated in the previous section of the study, Table 3.
2- Monthly rainfall during July = 1.36 in.
   obtained from weather record.
3- Monthly effective rainfall = 1.00 in.
   is calculated based on values in number 1 and 2.
   The results of this calculation for different ranges of monthly consumptive use and monthly rainfall has been collected in the form of table. Therefore by knowing the values of monthly consumptive use and monthly rainfall, the value for monthly effective rainfall can be taken directly from the table, (USDA-SCS, 1974).
4- Available soil moisture = 3.05 in.
   Initial soil moisture = 2.05 in. moisture carried over from the previous period.
   2.05 in. + 1.00 in. = 3.05 in.
5- Net irrigation requirement = 5.44 in.
   3.05 in. - 7.36 in. = -4.31 in.*
   It is assumed there should always be 1.13 in. of water available, (USDA-SCS, 1974). Then:
   -4.31 - 1.13 = -5.44 in.*

(* negative sign indicates lack of moisture.)

Appendix F

Table 7. Farmers Reports of Yield and Seasonal Water Application*.

CROP					
Soybeans		Sorghum		Corn	
Irrigation/Yield in.	bu/ac	Irrigation/Yield in.	bu/ac	Irrigation/Yield in.	bu/ac
3	48	2	50	3	132
4	48	2	80	6	110
6	35	3	60	7	127
6	37	4	100	7	135
6	40	4	110	8	100
7	45	4	120	8	110
8	35	4	122	12	120
8	37	6	85	12	125
8	40	6	90	12	129
8	42	6	95	12	130
8	47	6	101	12	150
8	48	6	110	12	152
9	30	7	75	13	140
10	54	7	97	14	109
10	55	7	110	14	115
10	60	8	80	14	126
11	43	8	90	15	100
11	50	8	96	15	115
12	39	8	100	15	120
12	40	8	120	15	125
12	45	9	120	15	140
12	55	9	130	16	100
13	22	10	85	17	125
13	40	10	95	18	130
13	45	10	135	18	135
14	40	11	125	20	135
14	55	12	50	20	145
14	60	12	62	20	148
15	35	12	100	21	105
15	57	12	110	27	125
18	42	12	120		
21	42	13	110		
26	47	13	116		
27	60	13	125		
		14	100		
		14	147		
		15	60		
		15	95		
		24	110		

* Table produced from: Kirkeeng, 1984.

ESTIMATING CROP WATER REQUIREMENTS IN SOUTH-CENTRAL KANSAS

by

HOSSEIN V. KAZEMI

B.S., Oklahoma State University, 1983

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

in

Agricultural Mechanization

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1985

ABSTRACT

Irrigation has become one of the most important factors of agriculture in arid and semi-arid regions. It is essential that the consumptive use and irrigation requirement of crops be known in irrigation planning for each individual farmer and irrigation district. A reason is the low and variable precipitation in many parts of the world.

This study was conducted to estimate the consumptive use and the irrigation requirement of three crops based on three methods in south central Kansas. The location of the study was the Equus Beds Groundwater Management District. The methods used to estimate consumptive use and irrigation requirement were Penman, ET Lab, and Blaney-Criddle. The three crops were corn, sorghum, and soybeans.

This study was also concerned with a comparison of different methods for estimating the consumptive use and irrigation requirement. The report includes the computer programs of each method to estimate the crop consumptive use and irrigation requirement. The estimated irrigation requirement was also compared with farmers reported water application.

The weather data used in this study were obtained from the weather data library of the Agricultural Experiment Station at Kansas State University. These data were for the year 1983 and were collected from Hesston Experiment Field located in south central Kansas. The Hesston Field was selected because it is within the Equus Beds Groundwater Management District.

The seasonal consumptive use of corn was 24 to 27 inches, and of sorghum

and soybeans was 23 to 25 inches. The Penman method over-estimated consumptive use in the beginning and end of the season when compared with the other two methods. The average irrigation requirement of corn and sorghum varied from 14 to 17 inches. Soybeans required 12 to 18 inches of water. Corn required less irrigation water than sorghum and soybeans based on the ET Lab method.

The analyses of yield-irrigation reported by farmers reveals that yield is not dependent on irrigation. The first 2 or 3 inches of irrigation water had the major influence. Additional irrigation water did not increase the yield because of other controlling factors. These factors include soil physical and chemical properties, management, fertilizer, weed control, planting date, and plant population.