205

Crop Coefficient Curves for Corn (*Zea mays* L.) and Soybean (*Glycine max* (L.) Merr.) Based on Fraction of Growing Season

by

Brigid Amos

B.A., Wellesley College, 1981

A MASTER'S THESIS

Submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

Kansas State University
Manhattan, Kansas

1985

Approved by:

Loyd R. Stone

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS

This thesis was made possible by the mentorship and financial support of my major professor, Dr. Loyd R. Stone. I have greatly appreciated his insight and enthusiasm for this project. Special thanks are due to Dr. L. Dean Bark for his assistance with the weather data and for allowing me to "camp out" in the climatological data library for several months. I also thank Dr. Bark and Dr. Mary Beth Kirkham for kindly serving on my graduate committee.

I thank Alison Meyer Peck for "showing me the ropes" at the ET Lab and in the field, and for her warm friendship as well. Larry Boxum deserves a great deal of credit for countless hours of meticulous calculations.

I feel I must list my dearest friends in these acknowledgements. They have made my stay in Manhattan, Kansas an integral part of my life, rather than a mere academic sojourn. In alphabetical order they are as follows: Tonja Berggren, Lolit Corpuz, Kelly Gregg, Renee Hart, Carolyn Jackson, Sharon Johnston, Steve Maxham, Linda Rudeen, Doug Varney, and Lou Young.

I thank my beloved parents, William and Agnes Amos, for their emotional and financial support during my graduate program. Finally, I thank the Lord for giving me intelligence, as well as the motivation to use it.

LIST OF FIGURES

LIST OF TABLES

APPENDIX TABLES

Introduction

The decline in the water tables of the Great Plains, coupled with the rapid increase of irrigated area in this region, has made conservative use of water on agricultural lands an imperative. High investment costs for water and energy have also made modern irrigation scheduling techniques attractive to today's farmer. The soil-water reservoir of the Great Plains is primarily depleted by evapotranspiration (Et) (Kanemasu et al., 1976), defined as the evaporation of water from soil and plant surfaces combined with the transpiration of water through plant tissues. Accurate predictions of crop Et throughout the growing season can provide the irrigator with the timing and amount of water which must be applied to prevent yield-reducing stress.

Basal crop coefficient curves for corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) were developed from water use and climatological data collected at sites at Manhattan and Tribune, Kansas from 1974 through 1982. A crop coefficient is defined as the ratio of crop evapotranspiration (Etc) to some reference crop Et (Etr). In this study, Etr values were calculated by using equations requiring meteorological input data. Since rainfall events increase the evaporation component of Etc, and soil water depletion tends to decrease the transpiration component, time periods with precipitation amounts less than 3 mm were used in the model development and the crop coefficients were corrected for available soil water.

A plot of crop coefficients for a particular crop as a function of time is called a crop coefficient curve. The time scale commonly used is days post emergence. Such curves must be adjusted for different planting dates, locations, years, and cultivars of different growing season lengths. This is due to the fact that climate and cultivar differences result in differences in crop development, thus causing shifts in days post emergence-based crop coefficient curves. Therefore, one goal of this project was to develop curves for corn and soybean which could be applied to a variety of cropping situations without the need to adjust the curves for crop development.

The basal crop coefficients described above were plotted against fraction of growing season calculated by using heat unit methods. This is the heat units accumulated from emergence to the time in question, divided by total heat units accumulated from emergence to physiological maturity. A photothermal unit equation was used to calculate fraction of growing season for soybean. The predictive ability of these basal crop coefficient curves was tested by using data collected at the Manhattan site in 1983 and 1984.

In addition to evaluating the validity of expressing crop coefficient curves based on fraction of growing season (calculated by using heat units), other goals of the project were to evaluate various heat unit methods, develop curves of maximum depth of depletion vs. fraction of growing season as a means of estimating effective rooting depth, and to develop and test curves of relative leaf area index vs. fraction of growing season for use in net radiation equations.

LITERATURE REVIEW

Crop Coefficient Curves

Crop coefficients are ratios of actual crop evapotranspiration (Et) to the potential Et of a well watered reference crop. A common form of the crop coefficient is:

$$Kc = Etc/Etr$$

in which Kc is the dimensionless crop coefficient for a particular soil moisture condition, Etc is crop Et, and Etr is the daily reference Et. Theoretically, Etr represents the evaporative demand imposed by the climate and Kc is a measure of the ability of the crop-soil system to meet the demand (Wright, 1981). A plot of crop coefficients for a particular crop as a function of time is called a crop coefficient curve. The purpose of the curve is to obtain an estimate of crop Et by selecting the Kc specific to the time period in question, and then multiplying it by an estimate of Etr calculated from meteorological data. The time base and method of calculating Etr must be compatible with the methods used to develop the particular curve being used. Such estimates of crop evapotranspiration are essential for accurate irrigation scheduling.

Denmead and Shaw (1959) discussed a method of estimating water use by crops which was originally suggested by Penman (1956). The method involves multiplying estimated free water evaporation by an empirical factor. This factor can only be applied to a green crop, which is actively growing, completely shading the ground, never short of water, and of uniform height. In an attempt to determine the period during the Iowa growing season when these conditions are met, they plotted ratios of measured corn (Zea mays L.) Et to open pan evaporation against time. After planting, their curve assumed the form of a sigmoid growth curve as leaf area developed and more bare soil was shaded. At silking, leaf expansion was complete and the curve remained flat for 16 days at a ratio of 0.81. They concluded that this is the period when Penman's method can be applied to corn in Iowa. Shaw (1963) later used this curve in a technique for predicting soil moisture changes under corn. Weekly averages of daily pan evaporation were multiplied by the appropriate ratio to obtain an estimate of corn Et. Doss et. al. (1962) also plotted ratios of Et to open pan evaporation as a function of time, thus developing a curve for irrigated corn in Alabama. The Et/pan evaporation ratio was 0.38 at emergence and increased to a maximum of 1.12 during early dough stage. It then dropped to 0.95 at grain maturity. This contrasts with the Denmead and Shaw curve, in which the Et/pan evaporation ratio began to decline after silking and commencement of ear growth, and ultimately reached its original low level as physiological activity of the plant stopped.

Jensen et al. (1970) recommended a crop coefficient which was not based solely on stage of growth. This crop coefficient was also based on time since an irrigation or rainfall and on the remaining available soil moisture. Doss et al. (1962) reported that the Et rate of corn decreased with decreasing available soil water. Zur et al. (1983) found that linear relationships between the transpiration rate of soybean [*Glycine max* (L.) Merr.] and both radiation flux and vapor pressure deficit existed only in well watered plants having low stomatal resistances. However, the transpiration rate quickly decreased following stomatal closure and remained essentially constant at high stomatal resistances. Conversely, Et rate will increase after rain or irrigation due to increased evaporation from the soil surface (Wright, 1981). Wright (1982) published a crop coefficient curve for snap beans (*Phaseolus vulgaris* L.) in which the Kc values calculated from lysimeter data and computed reference Et were plotted against time. This curve is so erratic that it would hardly be useful; the Kc values rise and drop sharply after each irrigation and rainfall. Wright remedied this situation by developing a "generalized basal crop coefficient curve". This was accomplished by manually fitting a curve to the time distribution of Kc representing conditions when the soil surface was dry and the availability of soil water did not limit plant growth or transpiration. The basal crop coefficient, designated as Kcb, was usually set equal to Kc after full cover. When ripening began, wet soil effects were again considered. Wright found that the maximum values of Kcb, corresponding to effective full cover, usually occurred shortly after the rows closed for most of the crops. This was when LAI reached 2.5 to 3.0. The Kcb then usually declined with time because of plant lodging and natural senescence.

The USDA - Agricultural Research Service Irrigation Scheduling Program described by Jensen et al. (1971) contains equations for estimating Kc from a basal crop coefficient and correction factors for available soil water and surface wetting. The equation given is:

$$Kc = KcoKa + Ks$$

in which Kco is the mean crop coefficient based on experimental data where soil moisture was not limiting and normal irrigation stands were used (it is therefore identical to Kcb described by Wright, 1982). Ka is a coefficient related to a natural logarithmic function of available water, and is calculated as $Ka = \ln(AM+1)/\ln 101$ in which AM is the percentage of remaining available soil water. Ka is therefore equal to 1 when AM is 100% and goes to 0 as AM goes to 0. Ks corrects for the increase in the coefficient when the soil surface is wetted by irrigation or rainfall. It is calculated as $Ks = (K1 - Kci)e^{-t}$, in which K1 is usually equal to 0.9, Kci is the basal crop coefficient at the time of irrigation or rainfall, t is the number of days after irrigation or rainfall, and e represents the combined effects of soil characteristics and evaporative demand. Wright (1981) suggested the following formula for correcting the Kcb value for surface evaporation:

$$Kc = Kcb + (1 - Kcb)(1 - (t/td)^{1/2})(fw)$$

in which t is the number of days after rain or irrigation, td is the usual number of days for the soil suface to dry, and fw is the relative portion of the soil surface originally wetted.

Shaw (1963) corrected Denmead and Shaw's (1959) crop coefficients by multiplying them by a stress factor. These stress factors were obtained from curves of Etc/pan evaporation ratios as a function of percent available soil water. Three separate curves were derived for low, average, and high stress conditions. These stress conditions represented the evaporative demand imposed by atmospheric conditions and were defined by various levels of pan evaporation. A separate set of curves was used after 31 July since root penetration had presumably stopped and atmospheric stress would therefore result in greater reductions in evapotranspiration. The results of a lysimeter study of evaporation from a corn canopy, conducted by Ritchie (1973), indicated that the amount of available soil water did not influence evaporation ratea nearly as much as Shaw's curves imply. Ritchie found instead that evaporation rates were independent of soil water status until soil water was depleted beyond a critical threshold. From that point, water was extracted at a decreasing rate before evaporation practically stopped.

The available soil water percentage used to calculate Ka should apply to the zone of active root development. Several attempts to describe the depth progression of corn and soybean roots have been made, some with the purpose of defining available soil water holding capacity.

Foth (1962) reported the results of root dry weight measurements of vertical soil samples of corn taken at various growth stages. He found that root growth below 38 cm largely occurred during the stages of rapid stem elongation, tasseling, silking, and pollination. By early milk stage, the increase in root weight between 38 and 91 cm had virtually stopped. Shaw (1963) presented a method of estimating soil moisture under corn in Iowa in which rooting depth was considered to be as follows: to 27 June, 61 cm; to 4 July, 76 cm; to 11 July, 91 cm; to 18 July, 107 cm; to 25 July, 122 cm; to 1 August, 152 cm. Shaw, therefore, considered root zone development to be a linear function of time with the deepest root depth reached on 1 August. Shaw used a plot of the ratios of corn Et to open pan evaporation as a source for estimating Et. This curve, as reported in an earlier article by Denmead and Shaw (1959), indicated that the average date of silking in Iowa is 20 July. The date of 1 August would therefore be approximately 12 days after silking. Stegman et al. (1977) computed Et/Etp ratios for successive 15-cm increments of profile depth under various crops in an attempt to estimate approximate rooting depth with time. The curve thus derived for corn appears to level off at 70 days post emergence. According to their crop coefficient curve for corn, this is approximately 8 days past silking. Allmaras et al. (1975) suggested that determinations of water sink alone cannot predict rooting depth, since in their study, the rooting depth of corn was almost always greater than the maximum depth of water uptake. However, since the available soil water correction discussed above applies to the effective root zone, maximum depth of water uptake would be an adequate estimate of rooting depth for this purpose.

Mitchell and Russell (1971) reported the dry weights for roots contained in soil monoliths taken from soybean rows at various times during the growing season. They divided root development into three general phases related to top growth. During phase 2, which included flowering and the beginning of pod formation, lateral roots penetrated the soil to a depth of 122 cm and root dry weight in the 92 to 122 cm layer was 0.06 grams/plant. During the third phase, which included seed set and maturity, major lateral roots elongated rapidly to a depth of 122 to 183 cm and root dry weight in the 122 to 183 cm layer was 0.03 grams/plant. These results are similar to those of Winter and Pendleton (1968). Their excavation of two soybean plants grown on a fairly dry silt loam revealed 11% of total roots in the 91 to 122 cm layer and 2% in the 122 to 152 cm layer. Mayaki et al. (1976) also studied soybean root development using field samples of soybean root systems. They found that the soybean roots in both irrigated and non-irrigated plots reached 160 cm by stage R9 (full size green beans in one of the four uppermost pods). However, there was a decrease in the rate of root depth increase near stage R5.5 (beginning of pod development). The soybean root zone depth vs. days post emergence curve , derived by Stegman et al. (1977) as described previously for corn, seems to level off at

80 days post emergence which they report as upper pod fill. However, the slope of the curve up to this point is quite low, and only 5 to 8 cm in soil depth are gained between 60 and 80 days post emergence. This seems to agree with the conclusion of Mayaki et al. (1976) that the growth of soybean roots slows down considerably after beginning pod development. Likewise, Mitchell and Russell (1971) found only half the accumulated dry weight at the next lower depth after beginning pod development (during phase 3).

The pattern described above is not evident in a rhizotron study of 7 soybean cultivars conducted by Kaspar et al. (1978). They found that the cultivars differed in the rates at which their roots extended downward during the various stages of reproduction and in the pattern of depth increases displayed by their root systems. The roots of all seven cultivars reached the bottom of the 217 cm deep compartment, one by the end of pod development, four by the time of beginning bean fill, and two reached 217 cm after bean development was nearly completed.

Several predictive simulations of soybean rooting depth have been developed. Stone et al. (1983) developed a simulation based on equations requiring time in days and soil temperature. These equations were derived from data obtained from a greenhouse study of the root growth of four cultivars grown at four temperatures (Stone and Taylor, 1983). Narda and Curry (1981) developed a model of soybean root growth and water uptake based on root growth attributes and the amount of carbohydrate available for root growth. The calculated water uptake rates were modified by accounting for decreased rates of water use due to diminishing soil water content, as well as aging and death of roots.

Various time scales have been used for crop coefficient curves and their disadvantages have been noted by researchers. Stegman et al. (1977) presented curves for six crops based on days post emergence. They pointed out that the position of these curves can shift from year to year due to different rates of crop development. They suggested that technicians visit fields periodically to carefully observe phenologic stages. If needed, curve adjustments could be made by comparing growth stages in particular seasons with the average phenology vs. days post emergence relationships shown on their curves. In an earlier paper outlining the use of crop coefficient curves for irrigation scheduling, Stegman and Valer (1972) said that the time scale, days post emergence, was chosen to purposely specialize the curves for east-central North Dakota. Wright and Jensen (1978) published a crop coefficient curve for beans in which Kc is a function of percentage of time from planting until full cover. After full cover, Kc is a function of elapsed days. This was done because large differences in planting dates usually have little effect on the date full cover is reached. Wright and Jensen (1978) suggested that service groups use some key growth stages to adjust crop development to this curve.

Dylla et al. (1980) recommended that crop coefficients be developed from data in climates similar to those in which they are to be used. They warned users that even if this rule is followed, year to year climate aberrations, crop varietal and maturity differences, and any other factors that inhibit crop growth could cause shifts in the calculated Kc curve. Wright (1982) commented that it would be desirable to have a means of relating crop coefficients more directly to crop development with an index such as accumulated growing degree days. In 1976, Stegman and Olson developed a crop coefficient curve for pinto beans (*Phaseolus vulgaris* L.) based on accumulated growing degree units. They felt that since this parameter is more specific to the temperature of a given season, its use would reduce the seasonal variation of the curve. Sammis et al. (1985) calculated crop coefficients on a monthly time period and regressed these against monthly cumulative modified growing degree days (see next section). They called this the G method. Their crop curves for corn were statistically the same over 2 years and locations. They reported that corn required 1680 growing degree days to mature at both locations, so varieties of different growing season lengths were not used in their analysis. They also reported that some variability between years occurred that could not be accounted for, showing the "inadequacy of the G method to account for all the variability between years."

Reference Crop Evapotranspiration

As many as 50 methods or variations have been advanced for estimating potential Et (Hill et al. 1983). Due to the ambiguities in describing potential Et, the term "reference crop Et" (Etr) is now used by most researchers, and the reference crop is specifically noted. Etr cannot be simply described for all climate and crop situations. Relative leaf area and the morphological and physiological aspects of the crop canopy affect the energy exchange and the aerodynamic diffusion process occurring above a field (Wright, 1981).

Two theoretical approaches to evaporation from saturated surfaces are incorporated into the equations discussed here. In the energy balance approach, evaporation is considered to be a change of state demanding a supply of energy as heat of vaporization (Penman, 1956). The aerodynamic approach assumes that evaporation is due to turbulent transfer of vapor by a process of eddy diffussion (Penman, 1948). Penman developed an equation combining both of these principles to predict "the amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short of water" (Penman, 1956).

Jensen et al. (1971) described a form of the Penman equation which they used in the USDA - Agricultural Research Service Irrigation Scheduling Program. The equation is as follows:

$$E^* = [\Delta/(\Delta+\gamma)]\ (Rn - G) + [\gamma/(\Delta+\gamma)]\ (15.36)(1.0 + 0.01W)(es-ed)$$

in which E^* represents the daily potential evaporative flux from a well watered reference crop like alfalfa (*Medicago* *sativa* L.) with 30 to 46 cm of top growth. Rn is daily net radiation in calories per square cm, G is the daily soil heat flux in cal per square cm, Δ is the slope of the saturation vapor pressure - temperature curve (de/dT), γ is the psychrometric constant, es is the mean saturation vapor pressure in mb (mean of the saturation vapor pressures at the maximum and minimum daily air temperature), ed is the saturation vapor pressure at mean dew point temperature (or dew point temperature near 0800 h) in mb, and W is total daily wind run in miles. The parameters $\Delta/(\Delta+\gamma)$ and $\gamma/(\Delta+\gamma)$ are mean air temperature weighting factors whose sum is 1.0.

In their study of peak water requirements for crops in southern Idaho, Wright and Jensen (1972) realized that the equation above greatly underestimated alfalfa Et. These low estimates occurred primarily when a high proportion of the energy used for Et came from the advection of sensible heat to the irrigated area from the surrounding desert lands. They therefore calibrated the wind function using 2 years of lysimeter data from well watered, actively growing alfalfa with 20 cm or more of growth. The new wind function is as follows:

$Wf = (0.75 + 0.0185W)$ For W in miles/day at 2 meters.

This modification yields values considerably greater than the equation given previously when $W > 50$ miles per day.

While the Penman equation is favored by such researchers as Wright and Jensen (mentioned above) and Shaw (1963), who found it to be the most accurate of the methods he tested, it has some drawbacks. Humidity and windspeed data are not widely available. Also, Hill et al. (1983) warned that judgement should be used when using any wind term coefficients if there is a different advective energy condition at night than during the day. Also, they noted that field checks have indicated that field crop depletion does not follow the equation under extremely windy conditions. An arbitrary limit of 100 miles per day for W at 2m is imposed in some regions.

In addition to humidity and windspeed, net radiation data are not widely available. Fortunately, there are various equations available for estimating this input of the Penman equation. Net radiation flux (Rn) may be calculated from the radiation balance equation:

$$Rn = (1.0 - \alpha)Rs - Rln$$

in which α is albedo, Rs is the global solar radiation flux, and Rln is the longwave radiation flux (de Jong et al., 1980). In addition to equations for estimating solar radiation (Rs), which is readily available in the areas in which this research was done, de Jong et al. (1980) presented two equations for estimating Rln. The first was an equation developed by Linacre (1968), as presented by de Jong et al. (1980):

$$Rln = 32 * 10^{-5} (1 + 4n/N)(100 - T)$$

in which T is air temperature in degrees celsius and n is the number of recorded hours of bright sunshine in a daylength of N hours. The second equation, which they found led to an overestimation of Rln due to its lack of a cloud adjustment factor, was developed by Idso and Jackson (1969), (as reported by de Jong et al., 1980):

$$Rln = \sigma T_K^4 \{0.261 \exp(-7.77 * 10^{-4} (273 - T_K)^2)\}.$$

In the above equation, σ is the Stefan - Boltzmann constant and T_K is the air temperature in degrees kelvin.

Wright (1982) presented an equation for net outgoing longwave radiation (Rb) as an input of the radiation balance equation to calculate Rn. The equation is:

$$Rb = (a(Rs/Rso) + b)Rbo$$

in which Rs is the incident solar radiation, Rso is the clear day solar radiation, Rbo is the net clear day outgoing longwave radiation, and the coefficients are dependent upon the ratio of Rs to Rso. An equation for Rbo, with the inputs of saturation vapor pressure at mean dewpoint temperature (ed) and average daily temperature, is also contained in Wright's article.

Locally calibrated Rn equations resulted from work done at the Evapotranspiration Research Field 14 km southwest of Manhattan, KS. Rosenthal et al. (1977) reported a relationship between Rn and Rs specifically for corn:

$$Rn = 0.861Rs - 103.92 \quad \text{For LAI} < 3.0$$
$$Rn = 0.848Rs - 144.49 \quad \text{For LAI} > 3.0$$
$$Rn = 0.766Rs - 99.89 \quad \text{For LAI} < 3.0 \text{ and after blister stage}$$

where Rn and Rs are in langleys/day and LAI is the leaf area index. Likewise, such a relationship for soybean was reported by Kanemasu et al. (1976):

$$Rn = 0.725Rs - 0.86 \quad \text{For } LAI < 3$$
$$Rn = 0.805Rs - 2.332 \quad \text{For } LAI > 3.$$

In the above equations, Rn and Rs are in mm/day.

The above net radiation equations require either the measurement or estimation of leaf area index. Various methods of estimating soybean LAI have been proposed. Wiersma and Bailey (1975) suggested that total leaf area (TLA) could be predicted by a linear equation having the sum of the products of the lengths and widths of all the terminal leaflets as the independent variable:

$$TLA = 6.532 + 2.045\ (\Sigma\ L_iW_i \text{ terminal leaflets}).$$

Sivaknmar (1978) regressed leaf dry weight and leaflet number against measured leaf area per plant (LA) to derive the prediction equation:

$$LA = -286.7 + 80.3(LDW) + 31.5(LN)$$

As Ogbnehi and Brandle (1981) pointed out, no independent test of this equation was reported. They too found significant linear regressions of leaf area on leaf dry weight and leaf number. While these equations were accurate in predicting LA of independent samples taken from the same treatment and season, they were inaccurate in predicting LA of plants grown in a different treatment or season. Koller (1972) reported that the leaf area to leaf dry weight ratio changes over the growing season of the soybean plant and suggested that models for the prediction of soybean leaf area from leaf weight should include time as a variable. A different approach by Sinclair

(1984) produced a model of total plant leaf area (L) based on plastochron index (PI), defined as an integer count of the number of emerged leaves plus a decimal fraction representing the progress of the emerging leaf toward full emergence. The relationship is as follows:

$$L = A * PI + B * (exp(C * PI^{(3/2)}) - 1)$$

in which the coefficients differ among cultivars.

Leaf area index development is very dependent on temperature variations among different environments. Goldsworthy (1975) compared the LAI vs. days after sowing curves of a highland corn hybrid grown at an elevation of 2,250 m above sea level and a lowland variety grown at 60 m. The growing season at the high elevation site was 193 days while at the low elevation site it was 112 days. Maximum LAI was attained at 60 days after sowing in the lowland site and at 91 days after sowing in the highland site. While LAI declined rapidly after silking at the lowland site, at the highland site its near - maximum value was maintained for an additional 45 days after silking. Likewise, Eik and Hanway (1965) reported that not only did longer season corn hybrids produce larger total leaf area per plant, but they also tended to maintain green leaf areas for longer periods than the shorter season hybrids.

The frequent lack of available data for the Penman equation was dealt with by Merva and Fernandez (1982). The results of their sensitivity analysis showed that extraterrestrial radiation has the greatest influence of any parameter on the Et calculation. Conversely, a variation in either the dewpoint temperature or wind velocity makes a relatively small contribution to the predicted evapotranspiration. They found that a 20% variation in either of these two parameters does little to alter the predicted Et, with wind contributing the least to the variation.

The Jensen-Haise equation for estimating potential Et relies on the following basic principles of the energy balance concept: "When an evaporating surface, such as an actively growing crop, is supplied with adequate water, the rate of Et is controlled by the available heat energy" (Jensen and Haise, 1963). Using data from crops with adequate soil moisture as well as evaporating and transpiring surfaces which were not limiting the vaporization of water, Jensen and Haise developed the following linear relationship:

$$(Et/Rs)_p = (0.014)T - 0.37$$

In the above equation, $(Et/Rs)_p$ is the potential ratio of Et to short wave solar and sky radiation flux and T is the mean air temperature in degrees F. The equation can be rewritten to estimate potential Et, which the authors define as the Et which can occur in irrigated fields located in arid and semi-arid areas. They further explain that Etp does not imply a homogeneous or unlimited boundary area of well watered actively growing vegetation. Jensen et al. (1970) presented a modified version of the Jensen-Haise equation containing an air temperature coefficient, C_T, which is constant for a given area and derived from long-term mean maximum and minimum temperatures for the month of highest mean air temperature. Due to the large changes in the air temperature-net radiation relationships at high elevations, one of the constants used to calculate C_T is adjusted for elevation. The modified Jensen-Haise equation takes the form:

$$Etp = C_T(T - T_x)Rs$$

in which T is the mean daily air temperature, T_x is a constant for a given area and is the linear equation intercept on the temperature axis, and Rs is the daily solar radiation expressed as equivalent depth of evaporation. Etp represents the maximum Et that can occur under given climatic conditions from a well watered, aerodynamically rough crop, such as alfalfa with about 30 cm to 46 cm of top growth.

C_T and T_x can be determined by local calibration. They can also be calculated from the following equations listed conveniently by Hill et al. (1983):

$$C_T = 1/(C_1 + C_2 C_H)$$

$$C_1 = 68 - (3.6)(\text{elev.}/1000)$$

$$C_2 = 13$$

$$C_H = 50(e_2 - e_1)$$

$$T_x = 27.5 - 0.25(e_2 - e_1) - (\text{elev.}/1000)$$

In the above equations, e_2 and e_1 are saturation vapor pressures (mb) of water at the long term mean maximum and minimum temperatures, respectively, for the warmest month of the year for the study area. Elev. is elevation in feet above sea level. Hill et al. suggested that caution be used when applying C_T and T_x with full elevation correction for areas of 4500 feet and above, depending on the surroundings. They regressed correction factors, defined as the attainable Et divided by the calculated Et, against elevation, thus obtaining the following linear equation:

$$CF_{JHE} = 1.653 - 0.1640\ El./1000.$$

The above equation relates a correction factor for the modified Jensen-Haise method to elevation in feet above sea level.

Hill et al. (1983) defined the Priestley - Taylor equation as essentially the Penman equation with both of the wind term coefficients equal to 0. It takes the form:

$$Etmax = \alpha\ [s/(s + \gamma)]Rn$$

in which Etmax is daily maximum evapotranspiration during predominantly nonadvective conditions, s is the slope of the saturation vapor pressure curve at a weighted average temperature 3[(Tmax + Tmin)/4], γ is the psychrometric constant, and Rn is net radiation in ly/day (Rosenthal et al. 1977). The coefficient α is dependent on climate and crop type.

Various values for α exist in the literature. Using lysimeter, fluxatron, and open water data, Priestley and Taylor (1972) found an overall mean α of 1.26. (The lysimeter data alone produced an α of 1.32.) Davies and Allen (1973) calculated values of α which ranged between 1.16 and 1.36 and had an overall mean of 1.27. Mukammal and Neuman (1977) found that near field capacity, α has a value of 1.29. De Bruin

(1983) found an α of 1.3 for well watered surfaces. Work done at the Evapotranspiration Research Field near Manhattan resulted in an α of 1.35 for corn and 1.45 for soybean (Kanemasu et al. 1976: Rosenthal et al., 1977).

Heat Units

Scientists have long known that any attempt to measure plant development using calendar days alone is subject to environmental variation. As early as 1735, Reaumur discovered that plant development is more closely related to the temperature accumulated to a given stage than with time alone (Neild and Seeley, 1977). While the majority of researchers agree that using "accumulated heat units" or "growing degree days" to predict phenological events is a great improvement over calender days, there is still much controversy regarding the appropriate method of measuring heat units.

The oldest method was used successfully by Neild and Seeley (1977). The equation, $GDD = [(Max + Min)/2] - 50$, says that the growing degree days for a given day are equal to the daily temperature average in °F minus 50 °F (Neild and Seeley, 1977). The base temperature of 50 °F is used because Lehenbauer (1914) discovered that growth of corn is extremely slow below 50 °F (Newman, 1971). A linear regression of Hanway's numerical stages of development for corn (Ritchie and Hanway, 1982) against growing degree days accumulated from planting to each stage resulted in coefficients of determination (r^2) of 0.98 - 0.99 and standard errors of 0.34

to 0.40. This compared favorably with standard errors of 0.60 - 0.83 when the regression was done using days from planting (Neild and Seeley, 1977).

The method described above has been criticized on both biological and statistical grounds. Gilmore and Rogers (1958) pointed out that this method does not represent the effective heat units when temperatures fall below the minimum for growth or rise above the optimum. Temperatures below 50 °F may not further reduce growth and may cause unreasonably low GDD accumulations. Relying on the parabolic nature of Lehenbauer's growth curve for corn seedlings, they asserted that temperatures above the optimum retard growth, and therefore cause unreasonably high GDD accumulations. In addition, of the 15 methods of calculating heat units tested, they found the [(Max + Min)/2] - 50 method to have the highest coefficient of variation (CV) (Gilmore and Rogers, 1958). Likewise, Mederski et al. (1973) found this method to have the highest CV of the 6 methods they tested. Cross and Zuber (1972) found that when a regression of number of days to pollen shed against accumulated thermal units was performed, this method yielded an r^2 of only 0.208. In contrast, of five models tested by Daughtry et al. (1984) , including the "heat stress" method favored by both the teams of Gilmore and Rogers and that of Cross and Zuber, the daily average minus 50 °F method produced the lowest CV when used for the period from planting to silking.

The limitations of the standard GDD formula are dealt with in the modified growing degree day method (MGDD) used by the National Weather Service. As far as the calculations are concerned, any temperature below 50 °F is set to 50 °F and any temperature above 86 °F is set to 86 °F. Otherwise, the calculation is the same as the standard GDD formula (Newman, 1971). A similar method called the "Daily Adjusted Average System" had an r^2 of 0.966 when the regression method of Cross and Zuber (as described previously) was performed. This method differs from the MGDD method in that the base temperature is not subtracted each day (Cross and Zuber, 1972).

Another method, commonly called the Heat Stess Method, assumes that temperatures above the optimum retard growth and should consequently result in reduction in heat units. Gilmore and Rogers (1958) make this correction by subtracting from the daily mean the number of degrees by which the maximum daily temperature exceeds the optimum. As in the MGDD method, temperatures below 50 °F are considered to be 50 °F and a base temperature of 50 °F is subtracted from each daily average. Of the 15 methods tested, they found this one to have the lowest CV (Gilmore and Rogers, 1958). Of the daily methods tested, Cross and Zuber (1972) found their daily heat stress method to be the best, but it was only slightly better than the daily adjusted average system. Their version differs from the method of Gilmore and Rogers (1958) in that no base temperature is subtracted and the high temperature corrections are made by subtracting from 86 °F the amount by which the maximum temperature exceeds 86 °F and then computing the average (Cross and Zuber, 1972).

The heat unit method commonly used in Canada is the Ontario System. Mederski et al. (1973) found this system to be the best among those they tested and describe it as follows: Daily HU total = (day + night)/2 in which day = 1.85(max - 10 °C) - 0.026(max - 10 °C) and night = min - 4.4 °C. A later version described by Coelho and Dale (1980) was found to be less effective than the MGDD method.

Several researchers have attempted to devise a system based on Lehenbauer's growth curves. Gilmore and Rogers (1958) calculated "optimum days" from a freehand curve based on Lehenbauer's data for corn seedlings grown at constant temperatures for 6-hour periods. They fitted a scale to the curve so that the optimum temperature had a rating of 1.00 and other temperatures had a rating of a fraction until the zero point was reached when no growth occurred. They achieved a low CV of 1.24% by using the mean of the maximum and minimum temperature ratings. Coelho and Dale (1980), using a similar technique, derived function of temperature equations:

$$
\begin{aligned}
FT &= 0.027T - 0.162:\ 6C <= T < 21C \\
FT &= 0.086T - 1.410:\ 21C <= T < 28C \\
FT &= 1.0:\ 28C <= T < 32C \\
FT &= -0.083T + 3.67:\ 32C <= T < 44C \\
FT &= 0 \text{ for } 6C > T => 44C
\end{aligned}
$$

Daughtry et al. (1984) found that differences in CV among the thermal models tested were very small for planting to physiological maturity. However, for the silking to physiological maturity interval, CV for calendar days was much smaller than CV for the thermal models. They suggested the use of a "mixed" model in which a thermal model is used to predict silking date and then the mean interval in days from silking to physiological maturity is added to predict date of physiological maturity. They found that the accuracies of these mixed models are better than the accuracies of the conventional thermal models for predicting physiological maturity of corn.

Stapper and Arkin (1980) presented a method of calculating heat units for corn which was used in their CORNF growth and development model. The CORNF growing degree day calculation is identical to the modified growing degree day method when the minimum daily temperature is 10 °C or above. However, when the minimum daily temperature drops below 10 °C, a sine curve is used to approximate the diurnal change in temperature between maximum and minimum. The CORNF growing degree days are multiplied by a daylength correction factor, since the actual average temperature is higher than the average of the maximum and minimum when days are longer than nights.

In comparison with corn, there is little research in the use of thermal units for predicting soybean development. This is most likely due to the difficulty of accounting for the photoperiodic response of soybean in thermal models. Brown (1960) grew soybean in growth chambers at different combinations of temperature and daylength, finding that nearly the same number of night hours were required to reach flowering for all photoperiods at any one temperature. Defining rate of development as the reciprocal of night hours from planting to flowering, he plotted the rate of development for each average temperature. The curves thus derived were quadratic expressions, intersecting the x axis at 50 °F and having an optimum temperature between 85 °F and 87 °F (similar to the temperature responses of corn).

Major et al. (1975a) tested two thermal unit methods based on Brown's quadratic equation along with 9 other thermal unit methods similar to those previously discussed for corn. Brown's method, and thermal unit methods having a base temperature of 10 °C subtracted daily, performed better than calendar days and methods with no base temperature. However, no method tested adequately predicted post-flowering events, showing the need to incorporate daylength into a development model.

In a companion paper, Major et al. (1975b) described a mathematical equation for soybean development based on an iterative regression analysis (IRA) technique. The functions were chosen so that the rate of development was curvilinear with respect to daylength and temperature. The equation for maturity (M) is:

$$M = \sum_{S_1}^{S_2} [a_1(L - a_o) + a_2(L - a_o)^2] * [b_1(T - b_o) + b_2(T - b_o)^2]$$

in which L is daylength in hours from sunrise until sunset and

T is the average of daily maximum and minimum temperatures in ^{o}C. The a and b coefficients vary with variety and phenological stage. S_1 and S_2 represent two phenological stages. They found that while the GDD method was similar to the IRA method for predicting the planting to emergence and emergence to flowering periods, the IRA method was better for predicting the post flowering periods based on the much smaller standard deviation of its predictions. This method was used by Curry et al. (1975) in SOYMOD I, their model of soybean growth and development.

Sierra (1977) described a development model for medium and late soybean cultivars which was useful in parts of Argentina. In order to develop the model for the emergence to flowering phase, a correlation and regression analysis was carried out considering radiation summations as a dependent variable and average phase photoperiod as the independent variable. This regression revealed that the contribution towards flowering of 1 langley received in photoinductive conditions is equivalent to progress towards flowering of 2.35 langleys received in non-photoinductive conditions. Daily radiation values were therefore multiplied by 2.00 and used to compute Photoenergetic Unit Summations (PEUS). Energetic - Photothermal Unit Summations (EPTUS) were then computed using the equation:

$$EPTUS = PEUS * Q^{-1}$$

in which Q is calculated by a complex equation having average phase temperature, variability of average phase temperature, and average phase temperature range as variables. For the flowering to ripeness phase, Energetic - Thermal Unit Summations were calculated aa:

$$ETUS = SRS * Z^{-1}$$

in which SRS is the solar radiation summation and Z is calculated from the same variables as Q but a different equation is used.

Materials and Methods

Field Methods

Crop coefficient curves based on fraction of growing season were developed for corn and soybean. These models were developed using data from Manhattan and Tribune for the years 1974 through 1982. The Manhattan data were collected at the Evapotranspiration Research Field located 14 km southwest of Manhattan. The Tribune data were collected at the Ross Irrigation Field near Tribune. Specific information about and references for the 1974 through 1982 corn and soybean plots are contained in Tablea 1A and 2A in the appendix. All soybean cultivars used in this study are indeterminate, except for the cultivars Bay and Clark Determinate. Two soils at Manhattan are involved in this study. The Muir silt loam is a fine-silty, mixed, mesic Cumulic Haplustoll (U.S. Dept. of Agriculture - S.C.S., 1975). Formed in deep alluvium, the Muir SiL is deep and nearly level and has moderate permeability and high available water holding capacity. The Eudora silt loam is a coarse - silty, mixed mesic Fluventic Hapludoll (U.S.D.A.-S.C.S, 1975). Formed in coarse silty alluvium, the Eudora SiL is deep and nearly level, with moderate permeability and high available water holding capacity. The plots at Tribune were located on a Ulysses SiL, a fine - silty, mixed mesic Aridic Haplustoll (Gwin et al., 1974). The soil was developed in upland loess. It has a water intake rate of about 1.3 cm per hour and 0 - 1% slopes. Its water holding capacity is high, and its subsoil is calcereous.

The crop coefficient models were tested using data collected at the Manhattan site in 1983 and 1984. Three corn and three soybean cultivars were chosen for their differing growing season lengths, since one objective of the study was to evaluate the validity of basing crop coefficient curves on fraction of growing season. The corn cultivars used and their expected heat units needed for maturity (according to the Cargill seed catalogue for 1983) were 805 hybrid, 2040 heat units; 872 hybrid, 2410 heat units; and 980 hybrid, 2820 heat units. In 1984, Cargill hybrid 874 with 2410 heat units replaced 872 in the field plots (1983-84 Growers Guide, Cargill). The soybean cultivars used and their respective maturity groups were Amsoy 71, MG II; Union, MG IV; and Bay, MG V.

In both 1983 and 1984, the study was organized in a randomized complete block design. The corn cultivars were grown on the Muir SiL in 1983, and the plot arrangement and dimensions are shown in Fig 1. On 20 April 1983, 224 kg N/ha as liquid nitrogen was applied to the corn plots and the corn was planted on 6 May. Lasso-Bladex herbicide was applied the evening after planting. On 22 June 1983, berms were built around the corn and soybean plots to prevent runoff. The 1983 corn plots were furrow irrigated on 7 July and again on 18 July. In 1983, the soybean cultivars were grown on the Endora

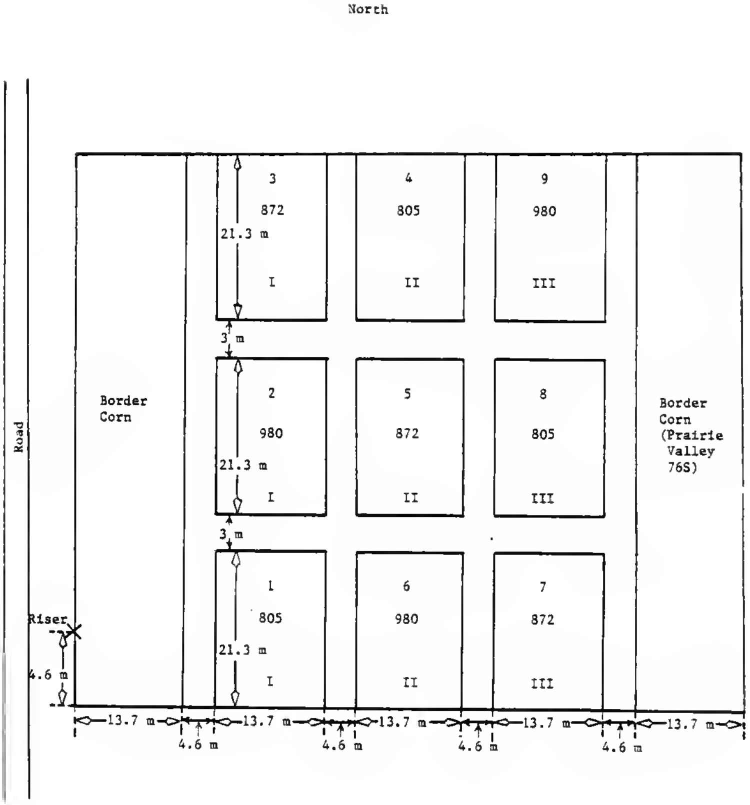

Fig. 1. Plot arrangement for corn in 1983, showing plot number (top), cultivar, and block number (bottom).

SiL and the plot arrangement and dimensions are seen in Fig. 2. Treflan was applied to this field on 4 May and the soybean cultivars were planted on 16 May 1983. The soybean plots were furrow irrigated on 21 July and again on 29 July 1983.

Three 3.66 meter aluminum neutron access tubes were installed in each corn plot in the two center rows. Four such tubes were installed in each soybean plot, also in the two center rows. Approximately 15 cm of each tube remained above the soil surface, and the tubes were kept plugged with rubber stoppers to keep out rain and other material. Care was taken not to disturb the plants during installation, and any gaps in the rows near tubes were replanted by hand to maintain a good stand in the vicinity of soil moisture measurement.

Soil water content was read from these tubes through the use of a Troxler neutron probe and a Troxler scaler, model 2601. A simplified discussion of the working of this device is as follows: The probe contains a mixture of Americium - 241 and Beryllium as a source of fast neutrons. These neutrons are emitted radially into the soil and lose kinetic energy as they collide with various atomic nuclei. The average loss of energy is greatest when these fast neutrons collide with the hydrogen nuclei of water, since the two are of nearly equal mass. The slowed neutrons scatter randomly in the soil, and those returning to the probe are counted by a detector cell filled with BF_3 gas. When a slowed neutron hits a ^{10}B nucleus and is absorbed, an alpha particle (a helium nucleus) is emitted, creating an electrical pulse on a charged wire. The number of

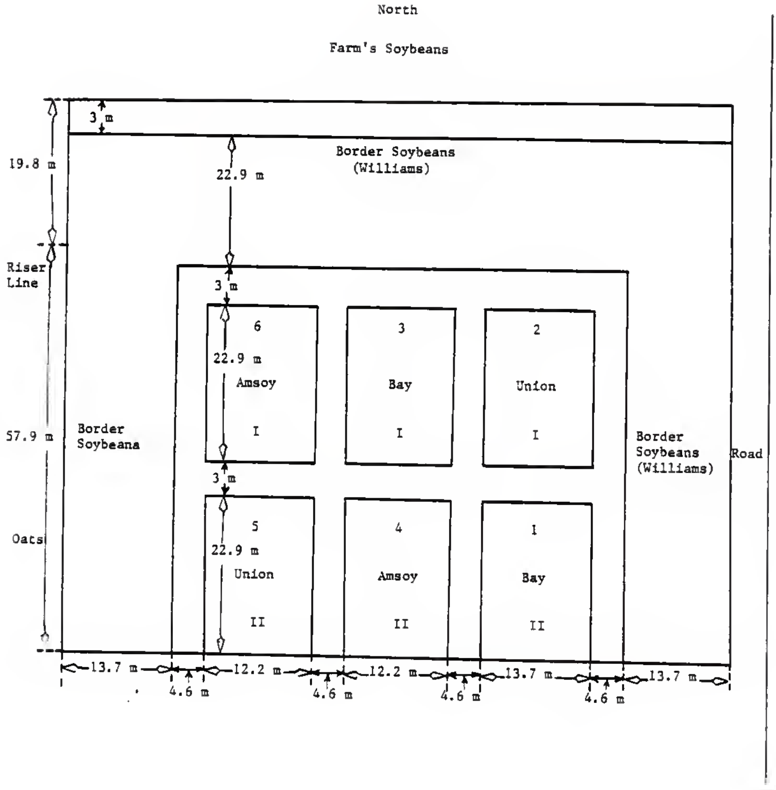

Fig. 2. Plot arrangement for soybean in 1983, showing plot number (top), cultivar, and block number (bottom).

pulses over a time interval is counted by the scaler (Hillel, 1971). Using this device, we measured soil water content down to 3.12 meters at approximately 7 to 10 day intervals. We measured counts per 15 seconds at 20 consecutive 15.24 cm depths in the soil profile at each tube. A 15 second standard count was taken within the probe case of lead and polyethelene at each tube. These rough data were converted to mm of water using the calibration equations discussed in the calculations section of this chapter. Three gravimetric samples were taken from each plot to determine the water content of the top 7.62 cm of soil. These samples were weighed, dried in an oven at 105 °C for 48 hours, then reweighed. Water content by dry weight was calculated using the formula: (wet wt. - dry wt.)/ dry wt. This gravimetric water content was then multiplied by the soil bulk density, 1.4 g/cm^3, to obtain water content by volume.

Plant samples were taken at approximately weekly intervals throughout the 1983 season from at least 3 rows into the plot but never from the center six rows. One meter of row was taken from soybean and 4 plants in a row were taken from corn. Leaf area was read using a Hayashi Denko automatic area meter model AAM - 5. This photoelectric apparatus measures the total area of objects by determining how much the objects shade the scanning light beam. Leaf area index (leaf area per ground area) was calculated for soybean by dividing leaf area by 7620 cm^2. This value was obtained by multiplying a row spacing of

76.2 cm by sample length of 100 cm. For corn, leaf area was divided by 5604 cm^2, which is a row spacing of 76.2 cm multiplied by a row length of 73.54 cm/4 plants (calculated from plant population taken at harvest). Dry weights of leaves, stems, and reproductive parts were measured after plant parts had dried in an oven at 70 ^{o}C for approximately 1 week.

Growth stages of the cultivars were monitored at approximately 3 day intervals. The system outlined by Hanway and Thompson (1971) was used to determine growth stages in soybean. The growth stage system decribed by Ritchie and Hanway (1982) was used for corn.

Twenty meters of row were harvested from each of the corn plots. These samples were taken from rows 7, 8, 11, and 12, thereby avoiding the rows containing neutron tubes. Thirty meters of row were harvested from each of the soybean plots from the two pairs of rows flanking the neutron tube rows. Plants were counted when the samples were taken to determine population. The harvest samples were threshed and the kernels and beans were weighed. Then two gravimetric samples were taken from each harvest sample and these were treated in the same way as the soil discussed above. These water contents were used to adjust the weight of soybean to 13% moisture (on a wet weight basis) and corn to 15.5%.

On 4 May 1984 , ammonium phosphate having a grade of 18-46-0 was applied to all study areas at a rate of 308 kg/ha. Approximately 224 kg N/ha were knifed into the corn area as liquid nitrogen solution (28%) in late April 1984. The 1984 corn cultivars were grown on the Eudora SiL and the plot arrangement and dimensions are shown in Fig. 3. The corn was planted on 11 May and Lasso-Bladex was applied to this field on 12 May. Three neutron access tubes were installed as described for the 1983 corn plots. Treflan was applied to the soybean field on 11 May 1984, and the soybean cultivars were planted on 18 May. The 1984 soybean plot arrangement and dimensions on the Muir SiL are seen in Fig. 4. Three neutron access tubes per plot were installed. On 28 June 1984 the berms were built around the plots. The corn and soybean plots were not irrigated in 1984.

Field methods in 1984 were the same as those in 1983, except plant sampling was not done. Soil moisture in the 1984 soybean plots was read with a Troxler neutron probe and scaler model 3221. In this case, a 5 minute standard count was read every hour. Twenty meters of row were harvested from soybean, since we had 3 replications of each cultivar instead of 2 as in 1983.

Weather Data

Rainfall amounts were measured at the study sites with a rain gauge. Other climatological data for the 10 years involved in this study were obtained from records at the Weather Data Library of Kansas State University. Maximum and minimum temperatures for Manhattan were read with a "max - min" glass thermometer. These values for Tribune were taken from "Climatological Data: Kansas" published by the NOAA of the U.S.

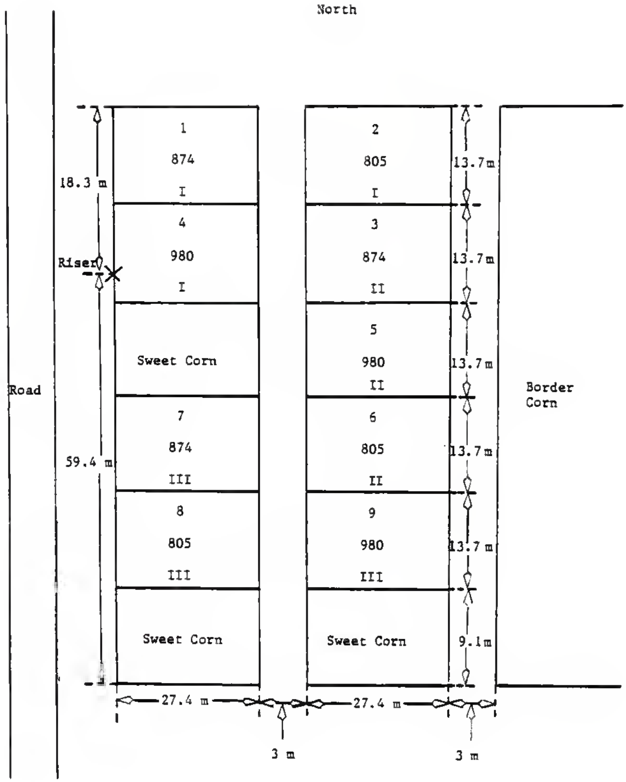

Fig. 3. Plot arrangement for corn in 1984, showing plot number (top), cultivar, and block number (bottom).

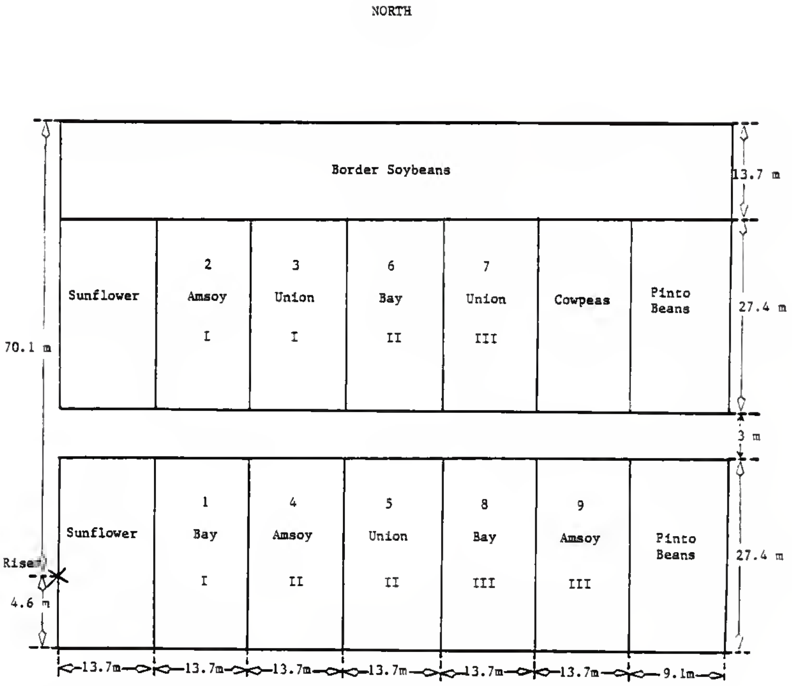

Fig. 4. Plot arrangement for soybean in 1984, showing plot number (top), cultivar, and block number (bottom).

Dept. of Commerce.

Solar radiation was measured with an Epply PSP pyranometer in Manhattan and was recorded at Tribune by a Licor pyranometer in a CR 21 automated weather station (Campbell Scientific Inc. micrologger). Manhattan windrun was measured with an anemometer located at the evaporation station at the Tuttle Creek Resevoir. This station was maintained by the Army Corps of Engineers. Anemometer data collected at the Tribune experiment station was also used in this study.

Previous to 1981, 0800 h CST relative humidity (RH) and temperature for Manhattan were obtained from hygrothermograph records. This information for 1981 to the present was obtained from records of the automated weather station (CR 21) located on the research farm near the K.S.U. campus. Tribune 0800 h MST relative humidity and temperature were recorded by the CR 21 located there.

Calculations

The neutron probe readings were converted to mm of water by the following procedure. First, each reading was divided by the standard to obtain a count ratio (CR). The equation used to convert these count ratios obtained with probe and scaler model 2601 to mm of water is $w = (0.45715*CR - 0.03482) * 152.4\text{mm}$. The value 152.4 mm is the thickness of each layer whose water content was measured. Probe and scaler model 3221 was calibrated by reading various tubes on the same day with both 3221 and the 2601 probe and scaler. The equation resulting from a regression analysis performed with these data is $w = (-0.01073 + 0.8033*CR - 0.25016*CR^2) * 152.4$ mm. The 3221 probe and scaler was recalibrated for the 1984 soybean data in the way described above. The resulting equation is $w = (-0.039055 + 0.90605*CR - 0.35394*CR^2) * 152.4$. The volumetric water content was multiplied by 76.2 mm to obtain the mm of water in the top layer of soil. The water contents of these layers were summed to obtain mm of water down to the 38, 68, 99, 129, and 160 cm depths. For the years 1981 through 1984, the water contents of the 190 and 312 cm depths were also determined, as readings were taken at deeper depths during these years. The water content sums were averaged for each variety or treatment.

Percent available soil water was calculated for the 38, 68, 99, 129, and 160 cm layers by subtracting from measured soil water content the soil water content of a given layer at a pressure potential of -15 bars, and then dividing by available water content at field capacity. The -15 bar water contents for the Muir SiL were obtained from work done by Brady (1972), and for the Eudora SiL these values were obtained from work done by Anderson et al. (1982). Available water content at field capacity for the soils was considered to be the upper limit of soil water measured in the field over the 10-year time period, minus the -15 bar soil water content. The values thus obtained for the Muir SiL were 80 mm in the 38 cm layer, 136 mm in the 68 cm layer, 220 mm in the 99 cm layer, 308 mm in the 129 cm layer, and 405 mm in the 160 cm layer. The field capacity values determined from the 10 years of data for the Endora SiL were 81 mm in the 38 cm layer, 129 mm in the 68 cm layer, 187 mm in the 99 cm layer, 251 mm in the 129 cm layer, and 330 mm in the 160 cm layer. The -15 bar and field capacity available water contents for the Ulysses SiL were derived from work done by Stone (1982). These available soil water percentages (%ASW) were also averaged for each variety or treatment.

The Et rate for a particular time period in mm/day was calculated in the following manner. The water content of the soil profile which was read at the end of the time period was subtracted from water content at the start of the time period, and any rainfall amounts during the interval were added. The resulting value was then divided by the number of days in the time period to obtain mm of water per day. These calculated Et rates (Etc) were averaged for each variety or treatment. Prior to 1981, the water contents in the 160 cm layer were used to calculate Et. For the years 1981 through 1984, water contents in the 312 cm layer were used to determine Etc.

Reference Et was calculated using the Penman, Jensen - Haise, modified Jensen - Haise, and Priestley - Taylor equations. The form of the Penman equation used is found in an article by Wright and Jensen (1978). It estimates "maximum daily or potential Et, Etp, for a well - watered reference crop of alfalfa with 20 cm or more of top growth." The equation takes the form:

$$E^* = [\Delta/(\Delta+\gamma)](Rn-G) + [\gamma/(\Delta+\gamma)]\ 15.36(0.75 + 0.0115U)(e^o_z - e_z).$$

In the above equation, E^* is the estimated daily evaporative flux, Rn is net radiation, and G is soil heat flux in cal/cm^2/day. The parameter U is wind run in km/day at a height of 2 meters; e^o_z is the mean saturation vapor pressure in mb at maximum and minimum air temperature, and e_z is the saturation vapor pressure based on the 0800 h dewpoint temperature; Δ is the slope of the saturation vapor pressure - temperature curve, and γ is the psychrometric constant in mb/°C.

The inputs of the Penman equation were calculated from our weather data in the following manner. Net radiation was calculated using the locally calibrated equations proposed for corn by Rosenthal et al. (1977) and for soybean by Kanemasu et al. (1976). These equations are listed in the literature review. According to Jensen et al. (1971) "where day-to-day temperatures do not change greatly and day-to-day radiation is similar, soil heat flux is relatively small during the summer months and can be neglected." Since this statement closely describes summer conditions in Kansas, we chose to disregard this input.

Our windrun was measured at a height of 0.61m. Estimated daily windrun at 2m, U_2, was calculated by the following equation recommended by Burman et al. (1980):

$$U_2 = U_z\ (2/z)^{0.2}$$

in which z is the elevation of the wind measurement and U_z is measured windrun at a height of z meters. The following expression was used to approximate Δ, the slope of the vapor pressure - temperature curve in mb/°C:

$$\Delta = 2.00(0.00738T + 0.8072)^7 - 0.00116 \quad \text{(Burman et al., 1980)}$$

in which T is mean daily temperature in °C. The following set of equations was used to calculate γ, the psychrometer constant in mb/°C:

$$\gamma = 0.386P/L$$

$$P = 1013 - 0.1055E$$

$$L = 595 - 0.51T \quad \text{(Burman et al., 1980).}$$

In the above equations, P is station barometric pressure in mb corrected for elevation, L is the latent heat of vaporization in cal/g, E is sea level elevation in meters (314 m at Manhattan and 1067 m at Tribune), and T is temperature in °C (we used the average daily temperature). The input e^o_z was calculated by taking the average of the saturation vapor pressure at the maximum daily temperature and at the minimum daily temperature. These saturation vapor pressures were determined by the following equation listed by Burman et al. (1980):

$$e_s \simeq 33.8639[(0.00738T + 0.8072)^8 - 0.000019|1.8T + 48| + 0.001316]$$

in which e_s is in mb and T is in °C. Saturation vapor pressure at the 0800 h dew point temperature, e_z, was determined from 0800 h relative humidity (RH) and temperature data. The 0800 h temperature was used in the above equation to calculate saturation vapor pressure, and this value was then multiplied by RH (expressed as a fraction) to obtain e_z. The daily average temperature was used to calculate the daily value of L, latent heat of vaporization in cal/g. This value was divided by 10 to obtain L in cal/(cm^2*mm), and the daily evaporative fluxes calculated with all of the reference Et equations were divided by this value to obtain Etr in mm/day.

Two versions of the Jensen - Haise equation were used to calculate Etr. The standard Jensen - Haise equation,

$$Etp = (0.014T - .37)Rs \quad \text{(Jensen and Haise 1963)}$$

relates reference Et to solar radiation in equivalent depth of evaporation (in our case, cal/cm^2/day). T is daily mean temperature in ^{o}F. The modified Jensen - Haise equation (Jensen et al., 1970) was also used to calculate Etr:

$$Etr = C_T(T - T_x)Rs \quad \text{(Burman et al., 1980)}$$

In the above equation, T is daily average temperature in ^{o}C and Rs is solar radiation in cal/cm^2/day. The constants C_T and T_x were calculated by the following series of equations listed by Burman et al. (1980):

$$C_T = 1/(C_1 + 7.3C_H)$$

$$C_H = 50 \text{ mb}/(e_2 + e_1)$$

$$C_1 = 38 - 2E/305$$

$$T_x = -2.5 - 0.14(e_2 - e_1) - E/550$$

In the above equations, e_2 is the saturation vapor pressure in mb at the mean monthly maximum air temperature of the warmest month of the year (33.2 ^{o}C for Manhattan and 33.7 ^{o}C for Tribune in July), and e_1 is the saturation vapor pressure in mb at the mean monthly minimum air temperature of the warmest month of the year (20.0 °C for Manhattan and 16.5 °C for Tribune). E is the site elevation in meters (314 m at Manhattan and 1067 m at Tribune). The modified Jensen-Haise equation constants for Manhattan were 0.020315 for C_T and -6.9177 for T_x. For Tribune, these constants were 0.0238712 for C_T and -9.13333 for T_x.

The Priestley - Taylor equation used is found in a publication by Kanemasu et al. (1976):

$$ETmax = \alpha\ [s/(s+\gamma)]\ Rn$$

In the above equation, ETmax is the "energy-limited Et occurring from a well-watered surface during nonadvective conditions" (Kanemasu et al., 1976). Rn is net radiation in $cal/cm^2/day$ and was calculated as described for the Penman equation. The constants s and γ are the slope of the saturation vapor pressure-temperature curve and the psychrometric constant in mb/°C at mean daily temperature. We used an α of 1.32 for both corn and soybean.

The time scale used in the crop coefficient, leaf area index, and depletion curves presented in this paper is fraction of growing season. Fraction of growing season is defined as the heat units accumulated from emergence to the time in question, divided by the total number of heat units accumulated from emergence to physiological maturity.

In order to choose a heat unit method to calculate fraction of growing season for corn, 5 heat unit methods, as well as days after emergence, were used to calculate fraction of growing season to silking for each year - cultivar data set (see Table 3A in the appendix). This analysis is discussed in the results and discussion section of this paper. The methods used were the growing degree day method (GDD), the modified growing degree day method (MGDD), the Gilmore and Rogers (1958) heat stress method, the Cross and Zuber (1972) heat stress method, and the CORNF method. In the following equations, Tmax is the daily maximum temperature in $^{\circ}$C and Tmin is the daily minimum temperature in $^{\circ}$C. Tmax^{*} is 30°C if $\text{Tmax} > 30^{\circ}\text{C}$, and Tmin^{*} is 10°C if $\text{Tmin} < 10^{\circ}\text{C}$. $\text{Tavg} = (\text{Tmax} + \text{Tmin})/2$.

$$\text{GDD} = [(\text{Tmax} + \text{Tmin})/2] - 10.$$

$$\text{MGDD} = [(\text{Tmax}^{*} + \text{Tmin}^{*})/2] - 10.$$

$\text{Heat Stress (GR)} = \{[(\text{Tmax} + \text{Tmin}^{*})/2\ ] - (\text{Tmax} - 30)\} - 10$ if $\text{Tmax} > 30$, and $[(\text{Tmax} + \text{Tmin}^{*})/2] - 10$ if $\text{Tmax} < 30$.

$\text{Heat Stress (CZ)} = \{[30 - (\text{Tmax} - 30)] + \text{Tmin}^{*}\}/2$ if $\text{Tmax} > 30$, and $(\text{Tmax} + \text{Tmin}^{*})/2$ if $\text{Tmax} < 30$.

$\text{CORNF} = 1/\pi\ \{\text{AMP} * \text{COSINE(ZETA)} + (\text{Tavg} - 10)(\pi/2 - \text{ZETA})\}$ if $\text{Tmin} < 10$, and $\{(\text{Tmax}^{*} + \text{Tmin})/2\} - 10$ if $\text{Tmin} => 10$.

$$\text{AMP} = \text{Tmax} - \text{Tavg}.$$

$$\text{ZETA} = \text{ARCSINE}[(10 - \text{Tavg})/\text{AMP}].$$

The CORNF heat units were multiplied by a daylength factor (HUDAYL) calculated by:

$$\text{HUDAYL} = 1 - (14.2 - \text{DAYLN}) * 0.10$$

in which DAYLN is daylength in hours and 14.2 is the average of the average corn growing season daylengths at Manhattan and Tribune. The CORNF model is described in more detail by Stapper and Arkin (1980). We chose the growing degree day method (GDD) as the basis for fraction of growing season for corn. In accumulating GDD to calculate fraction of growing season, any negative daily value was considered to be 0.

The selected method of calculating photothermal units (PTU) for soybean was described by Major et al. (1975b). The basic equation is:

$$M = \sum_{S_1}^{S_2} [a_1(L-a_o) + a_2(L-a_o)^2] * [b_1(T-b_o) + b_2(T-b_o)^2]$$

in which M is accumulated PTU, T is the average of the daily maximum and minimum temperatures in ^oC and L is daylength in hours from sunrise to sunset. Major et al. (1975b) presented the daylength and temperature coefficients for 10 cultivars, two in each of the maturity groups I through V. One set of coefficients was used from emergence to flowering and another set was used from flowering to physiological maturity. Since the present study involved cultivars from maturity groups II through V, we used the average of the coefficients of the two cultivars in each maturity group. We found that the recommended coefficients for flowering to physiological maturity resulted in an unusually high fraction of growing season for emergence to beginning bloom for an MG IV cultivar in a hot season (see Table 4A in appendix). We decided to use only MG II coefficients for flowering to physiological maturity for all cultivars. A comparison of the performance of the specific F-PM coefficients and the MG II F-PM coefficients is

Table 1. Daylength and temperature coefficients used in photothermal unit equation for soybean.

Phase and MG	Daylength			Temperature		
	a_o	a_1	a_2	b_o	b_1	b_2
E-F						
II	9.02	0.02503	-0.003095	3.00	0.03952	0.0
III	9.24	0.02695	-0.003644	3.61	0.04196	0.0
IV	8.89	0.02598	-0.003472	2.72	0.04052	0.0
V	17.84	-0.01351	0.0	6.92	0.02431	0.0
F-PM						
All	18.07	-0.01932	0.0	11.46	0.03556	-0.001391

shown in the results and discussion section of this paper. The coefficients which we used in the above equation are listed in Table 1. Daylength in hours was calculated from the equation:

$$L = 12 + A * \text{COSINE}[\ 0.0161 * (D - 172)]$$

in which A is the number of hours that daylength on the summer solstice exceeds daylength at the equinox, and D is the day number from 1 January. In this equation, 12 represents the daylength at the equinox, 172 adjusts the day number to the summer solstice, and 0.0161 converts the day number to radians (Major et al., 1975b). In accumulating PTU to calculate fraction of growing season, any negative daily value was set to 0.

<u>Model Development</u>

Curves of maximum depth of depletion vs. fraction of growing season were derived for corn and soybean. This was done by first subtracting total mm of water in each 15.24 cm layer (below the top 7.62 cm) on the last day from mm of water in the same layer on the first day of a time period. Depletion in mm was calculated in this way for each layer down to the deepest reading depth (160 cm before 1981, 312 cm from 1981 onwards). Maximum depth of depletion was considered to be the depth after which depletion dropped to a substantially lower amount. Maximum depth of depletion was determined only for time periods in which rainfall averaged less than 1 mm/day. All such data from 1974 through 1984 were used in these models. Fraction of growing season using the growing degree day method for corn and the photothermal unit method for soybean was calculated for the first and last days of a time period. These two numbers were averaged, and maximum depth of depletion was regressed against this mean fraction of growing season. The STEPWISE procedure of the SAS statistical analysis computer system was used to choose the best regression equations (SAS Istitute Inc., 1982). The maximum R^2 improvement technique (MAXR) was used, and the independent variables were fraction of growing season raised to the first through the fifth powers. I considered the best model to be that with the highest R^2 as well as parameters which were significant at the 10% level. This procedure was also used for choosing the LAI and crop coefficient models. Occasionally, a more complicated model with significant parameters was disregarded if its improvement in R^2 was very small.

Since, as discussed earlier, I calculated available soil water for the 38, 68, 99, 129, and the 160 cm layers, I solved these depletion equations for the fractions of growing season at which the equations equaled these depths of maximum depletion. These values served as estimates of effective rooting zone throughout the growing season. The ASW values which had been calculated for these layers on each reading day were used in the crop coefficient curves described later.

Since the net radiation equations in this model require an estimate of when LAI reaches 3 and then drops below 3, we developed LAI models using the 1981 and 1982 data. Each measured LAI value was divided by the maximum LAI reached by that particular cultivar in the growing season of the measurement. These values of "relative leaf area index" were regressed against fraction of growing season and a regression equation was chosen using STEPWISE (SAS Institute Inc., 1982) as described for maximum depth of depletion.

These curves of relative LAI vs. fraction of growing season were then used to predict relative LAI for the 1983 data. The predicted relative LAI values were regressed against the measured values using a linear model in the REG procedure in SAS (SAS Institute Inc., 1982). An F test was used to test if the slopes of the predicted vs. measured lines equaled 1 and if the intercepts equaled 0. This was done using the TEST procedure in REG. The corn and soybean LAI models were solved for the fractions of growing season at which relative LAI is equal to 0.6, producing an LAI of 3 if maximum LAI is assumed to be 5. For corn, if fraction of growing season was between 0 and 0.287, the first Rn equation for corn listed in the literature review was used in the Penman and Priestley - Taylor equations. If fraction of growing season was betwen 0.287 and 0.831, the second equation was used and the third was used for fractions of growing season greater than 0.831. For soybean, the first equation was used when fraction of growing season was less than 0.521, the second when fraction of growing season was between 0.521 and 0.876, and the first equation was used again when fraction of growing season was greater than 0.876.

The crop coefficients for corn and soybean were developed by calculating the ratios of actual Et (Etc) to reference Et

(Etr), adjusting these ratios for percent available soil water, and regressing these Kcb's against fraction of growing season. The data used in these basal crop coefficient curves were all neutron probe reading time periods in which rainfall was less than 3 mm for the years 1974 through 1982. Actual Et (mm/day) was calulated for a given time period in the way described in the calculations section. Reference Et for each day was calculated using the Penman, Priestley - Taylor, Jensen-Haise, and modified Jensen-Haise equations. Reference Et in mm/day (Etr) for a time period was determined by summing the daily values from the first day of a time period through the last day, and then dividing this value by the number of days in the time period. Actual Et (Etc) in mm/day was divided by Etr in mm/day to obtain the crop coefficient (Kc) for a given time period.

These Kc values were adjusted for percent available soil water since, as described in the literature review, available water within the effective rooting zone limits transpiration. These basal crop coefficients (Kcb) were calculated by rearranging the equation:

$$Kc = Kcb*Ka + Ks \quad \text{(Burman et al., 1980)}$$

to read:

$$Kcb = Kc/Ka.$$

The rainfall correction term was disregarded since only times of no or very little rainfall were included in the model. The ASW correction Ka was calculated by:

$$Ka = [\ln(\%ASW + 1)]/[\ln(101)]$$

in which %ASW is the percent of available soil water in the effective rooting zone and ln is the natural log function. The %ASW used was the average of the %ASW values for the first and last days of a time period.

Fraction of growing season using the methods previously described was calculated for the first and last days of a time period and these two values were averaged. The STEPWISE procedure was performed on the crop coefficient curve data as described for the depletion curves. The MAXR option was again used with Kcb serving as the dependent variable and the first through fifth powers of average fraction of growing season serving as the independent variables (SAS Institute Inc., 1982). The models chosen were those which had the highest R^2 values as well as parameters significant at the 10% level. In the case of soybean, several such models were plotted for each Etr equation used, and the most reasonable ones were chosen.

The equations of these derived Kcb curves were used to predict Et for neutron probe reading time periods in 1983 and 1984. These predicted values were then compared with the measured values. The average fraction of growing season for a time period was the first input used in the basal crop coefficient curve equation to yield the Kcb. Average %ASW for the time period was used to calculate a Ka value as explained above. The Kcb was then multiplied by Ka to obtain Kc. This Kc was then multiplied by Etr in mm/day. This Etr was calculated by the equation used to derive the Kcb curve being used in the prediction.

Since Et for all time periods in 1983 and 1984 were predicted regardless of rainfall, the Ks factor proposed by Jensen et al. (1971) was added to the predicted Et if rain did occur. Ks was approximated by (0.9 - Kcb)0.8, (0.9 - Kcb)0.5, and (0.9 - Kcb)0.3, for the first, second, and third days after a rainfall, respectively (Burman et al., 1980). We considered Kcb for the rainfall corrections to be the average Kcb of the time period obtained, as described above, by using average fraction of growing season in the crop coefficient curve equation. The three Ks values were totaled each time a rainfall event occurred, the total amount of correction never exceeding the actual amount of rain. Any leftover correction value from one time period was added onto the next time period. Before the total of the Ks values for a time period was added onto the Et predicted by Kc*Etr (mm/day), it was divided by the number of days in the time period. As described for the prediction of LAI, the predicted Et values were compared with the measured values using the REG procedure in SAS. Linear regression was performed and the TEST option was used to test equality to 1 of the slopes of the predicted vs. measured Et lines. TEST was also used to test equality of the intercepts to 0 (SAS Institute Inc., 1982).

Results and Discussion

The leaf area index, depletion depth, and crop coefficient curves presented in this section are based on fraction of growing season (FGS) as their time scale. For corn, this fraction was computed using the growing degree day method (GDD) described in the last chapter. This method was chosen by analyzing fraction of growing season to silking, calculated by using six methods, for 18 year-cultivar data sets (see Table 3A). I used the coefficient of variation (CV) in evaluating various heat unit methods. I intended to combine data sets of different years, locations, and cultivars into FGS-based models, and then use fraction of growing season as an input into the models in order to make predictions about independent test data. Consistency of results was therefore a criterion in choosing heat unit methods. CV, estimated by sample standard deviation divided by the sample mean, is a relatively stable measure of variation because it is independent of the sample mean. It is therefore a suitable measure of consistency of results (Snedecor and Cochran, 1980).

Tables 2 and 3 show this analysis for corn, performed with and without the 1983 and 1984 data used to test the crop coefficient curves. The CV of the GDD method is only slightly higher than those of the other heat unit methods. Considering also the simplicity of the GDD method, I found it to be the most attractive of the methods tested.

Table 2. Fraction of growing season to silking in corn, calculated by using five heat unit methods and days after emergence (DAE). The analysis did not include the 1983 and 1984 data. N=12.

Method	Fraction	Std. dev.	CV (%)
GDD	0.502	0.039	7.85
MGDD	0.508	0.034	6.66
Heat stress (GR)	0.516	0.032	6.26
Heat stress (CZ)	0.522	0.032	6.08
CORNF	0.531	0.038	7.10
DAE	0.528	0.037	6.19

Table 3. Fraction of growing season to silking in corn, calculated by five heat unit methods and days after emergence (DAE). The analysis included the 1983 and 1984 data. N=18.

Method	Fraction	Std. dev.	CV (%)
GDD	0.500	0.042	8.30
MGDD	0.515	0.037	7.21
Heat stress (GR)	0.532	0.040	7.60
Heat stress (GR)	0.539	0.041	7.53
CORNF	0.535	0.040	7.47
DAE	0.548	0.042	7.72

A similar analysis was made of fraction of growing season to beginning bloom calculated for 22 soybean cultivar-year data sets (see Table 4A). In the first method used to calculate FGS, coefficients specific to each maturity group were used in the photothermal unit equation described in the Materials and Methods section. The second method involved using specific coefficients for the emergence to flowering period and MGII coefficients only for the flowering to physiological maturity period (F-PM). The third method used was days after emergence. Tables 4 and 5 show this analysis performed with and without the 1983 and 1984 test data. Without the 1983 and 1984 data, the CV values are very close. However, the addition of the six extra data sets considerably raises the CV for both the "specific coefficient" method and the days after emergence method. Since the CV of the method using only MGII F-PM coefficients is essentially unchanged by adding the test data to the analysis, we considered this to be a more consistent method and used it to calculate FGS for our soybean curvea.

The curves of relative leaf area index vs. fraction of growing season for corn and soybean are shown in Figs. 5 and 6. Relative leaf area index is defined as measured LAI divided by the maximum LAI achieved by the particular cultivar in the growing season of the measurement. These curves were developed by using the 1981 and 1982 data from Manhattan and Tribune described by Hattendorf (1982) and Redelfs (1983) (see Table 1A). These curves were then used to predict corn and soybean relative LAI for the 1983 data. Linear regressions of

Table 4. Fraction of growing season to beginning bloom in soybean, calculated by using the maturity group-specific coefficients and MG II coefficients for flowering to physiological maturity in the PTU equation, as well as using days after emergence (DAE). The analysis did not include the 1983 and 1984 data. N=16.

Method	Fraction	Std. dev.	CV (%)
Specific coefficients F-PM	0.532	0.050	9.38
MGII coefficients F-PM	0.459	0.042	9.05
DAE	0.332	0.028	8.48

Table 5. Fraction of growing season to beginning bloom in soybean, calculated by using the maturity group-specific coefficients and MG II coefficients for flowering to physiological maturity in the PTU equation, as well as using days after emergence (DAE). The analysis included the 1983 and 1984 data. N=22.

Method	Fraction	Std. dev.	CV (%)
Specific coefficients F-PM	0.533	0.056	10.56
MGII coefficients F-PM	0.467	0.040	8.61
DAE	0.349	0.048	13.74

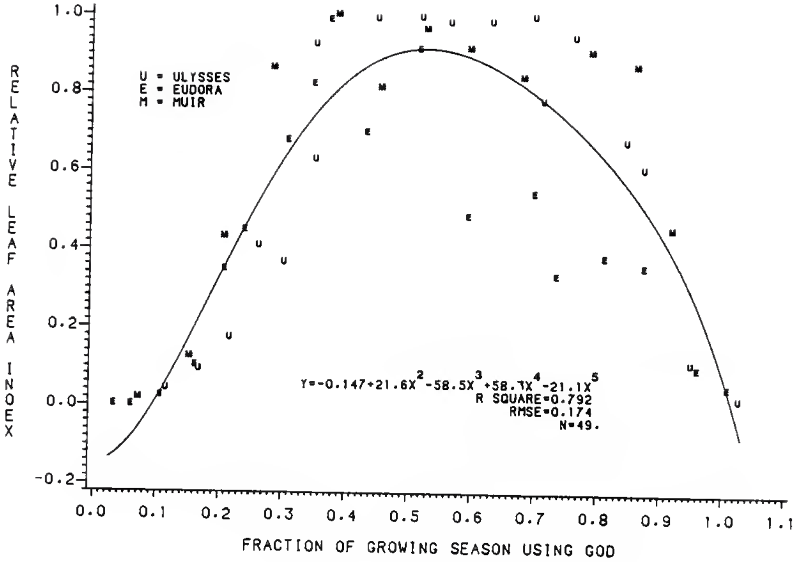

Fig. 5. Regression curve of corn relative leaf area index vs. fraction of growing season based on growing degree days. The curve was developed by using the 1981 and 1982 data.

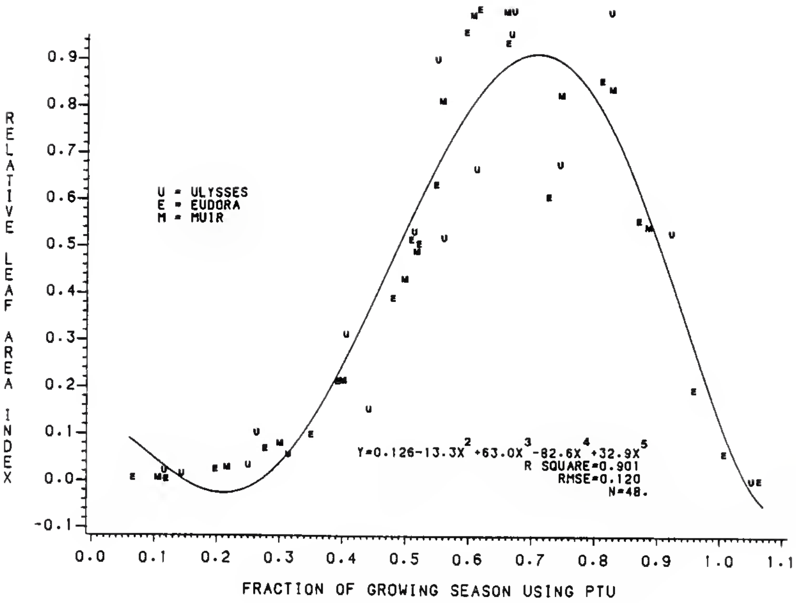

Fig. 6. Regression curve of soybean relative leaf area index vs. fraction of growing season based on photothermal units. The curve was developed by using the 1981 and 1982 data.

predicted relative LAI for corn and soybean, calculated by using the chosen prediction equations, on measured relative LAI are shown in Figs. 7 and 8. My criteria for successful prediction equations were slopes equal or nearly equal to 1 and intercepts equal or nearly equal to 0 for linear regression lines of predicted vs. actual values.

The TEST procedure within the REG procedure in the SAS statistical analysis system (SAS Institute Inc., 1982) was used to test these slopes and intercepts. For the corn GDD method, the null hypotheais that the slope of the predicted vs. measured relative LAI line is equal to 1 yielded an F value of 1.034, significant at the 0.32 level. The null hypothesis that the intercept of this line is equal to 0 resulted in an F value of 1.40, significant at the 0.24 level. Since these F values are smaller than F significant at the 0.05 level, the hypotheses that the slope is equal to 1 and that the intercept is equal to 0 can not be rejected. I therefore concluded that this LAI curve for corn is suitable for estimating the fractions of growing season at which corn LAI is equal to 3.0. This information was used in net radiation equations as described in the Materials and Methods section.

The soybean relative LAI vs. FGS curve also proved to be successful in predicting the 1983 relative LAI. The TEST procedure calculated an F value of 1.56, sigificant at the 0.22 level for the null hypothesis that the slope of the predicted vs. actual line is equal to 1. For the null hypothesis that

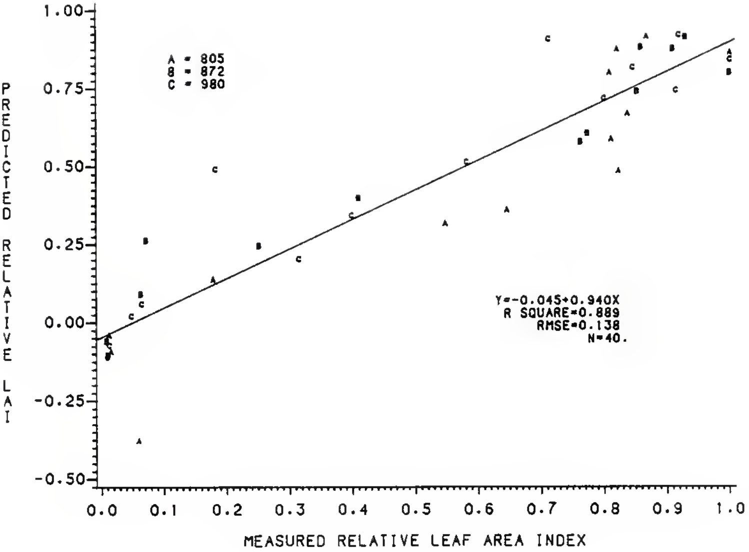

Fig. 7. Regression line of predicted relative leaf area index for corn vs. measured relative leaf area index for the 1983 data.

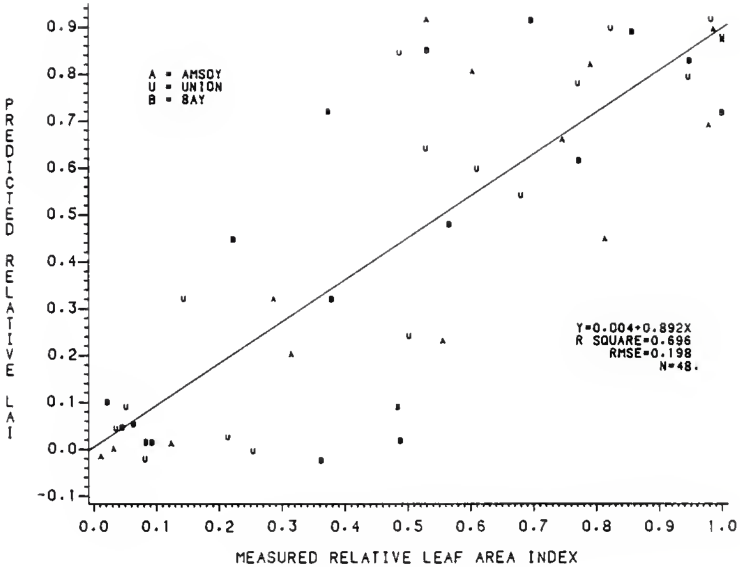

Fig. 8. Regression line of predicted relative leaf area index for soybean vs. measured relative leaf area index for the 1983 data.

the intercept equals 0, the procedure produced an F value of 0.01, significant at the 0.94 level.

I also regressed the 1981 and 1982 relative LAI data against days after emergence (DAE) and fraction of growing season based on DAE and modified growing degree days for corn. The equations of these curves for corn are shown in Table 6, and in Table 7 for soybean. These equations were then used to predict the 1983 relative LAI, and the TEST procedure was used to evaluate the predicted vs. actual relative LAI regression lines. Table 8 shows the predicted vs. actual corn relative LAI regression equations with their F statistics. Table 9 shows this information for soybean. The slope of the predicted vs. actual corn relative LAI line using the modified growing degree day method is significantly different from 1. The F values of the lines resulting from prediction equations for corn based on days after emergence and fraction of growing season using DAE have F statistics which are highly significant. This shows that for these LAI models for corn, fraction of growing season based on GDD is better than that based on MGDD, and is a far better time scale than DAE or fraction of growing season calculated using DAE.

The curves of maximum depth of depletion vs. fraction of growing season, based on the 1974 through 1984 data sets, are seen in Figs. 9 and 10. These curves were used to estimate the effective rooting zone for use in available soil water corrections of crop coefficients (see Materials and Methods section).

Table 6. Regression equations of relative leaf area index for the 1981 and 1982 corn data vs. fraction of growing season, calculated by using three methods, and days after emergence (DAE). R square and root mean square error are also shown.

Time base	Equation	R^2	RMSE
Fraction GDD	$Y=-0.147+21.6X^2-58.5X^3+58.3X^4-21.1X^5$	0.792	0.174
Fraction MGDD	$Y=-0.072+13.2X^2-23.6X^3+10.6X^4$	0.779	0.177
Fraction DAE	$Y=-0.163+13.8X^2-24.5X^3+11.0X^4$	0.779	0.177
DAE	$Y=-0.282+0.024X-3.60*10^{-8}X^4+1.99*10^{-10}X^5$	0.635	0.227

Table 7. Regression equations of relative leaf area index for the 1981 and 1982 soybean data vs. fraction of growing season, calculated by using two methods, and days after emergence (DAE). R square and root mean square error are also shown.

Time base	Equation	R^2	RMSE
Fraction PTU	$Y=0.126-13.3X^2+63.0X^3-82.6X^4+32.9^5$	0.901	0.120
Fraction DAE	$Y=-0.048+21.3X^3-38.7^4+17.6^5$	0.924	0.104
DAE	$Y=0.172-0.026X+0.001X^2-1.40*10^{-7}X^4 +7.28*10^{-10}X^5$	0.912	0.113

Table 8. Regression equations of predicted vs. measured relative leaf area index for the 1983 corn data, predicted by using curves based on fraction of growing season, calculated by using three methods, and days after emergence (DAE). R squares, root mean square errors, and siginificance levels of the F statistics for the slope and intercept are also shown.

Time base	Equation	R^2	RMSE	Prob>F Slope	Prob>F Int.
Fraction GDD	Y=-0.045+0.940X	0.869	0.138	0.316	0.244
Fraction MGDD	Y=0.025+0.864X	0.874	0.124	0.015	0.463
Fraction DAE	Y=0.134+0.749X	0.775	0.153	0.001	0.003
DAE	Y=0.234+0.624X	0.636	0.179	0.0001	0.0001

Table 9. Regression equations of predicted vs. measured relative leaf area index for the 1983 soybean data, predicted by using curves based on fraction of growing season, calculated by using two methods , and days after emergence (DAE). R square, root mean square error, and significance levels of the F statistics for the slope and intercept are also shown.

Time base	Equation	R^2	RMSE	Prob>F Slope	Prob>F Int.
Fraction PTU	Y=0.004+0.892X	0.696	0.198	0.219	0.937
Fraction DAE	Y=0.028+0.905X	0.784	0.160	0.183	0.509
DAE	Y=0.046+0.864X	0.695	0.193	0.114	0.364

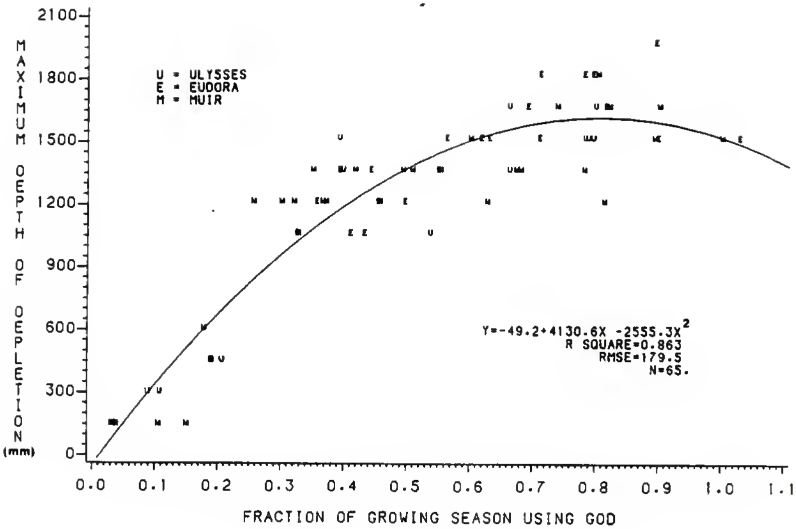

Fig. 9. Regression curve of maximum depth of depletion for corn vs. fraction of growing season based on growing degree days. The curve was developed by using the 1974 through 1984 data.

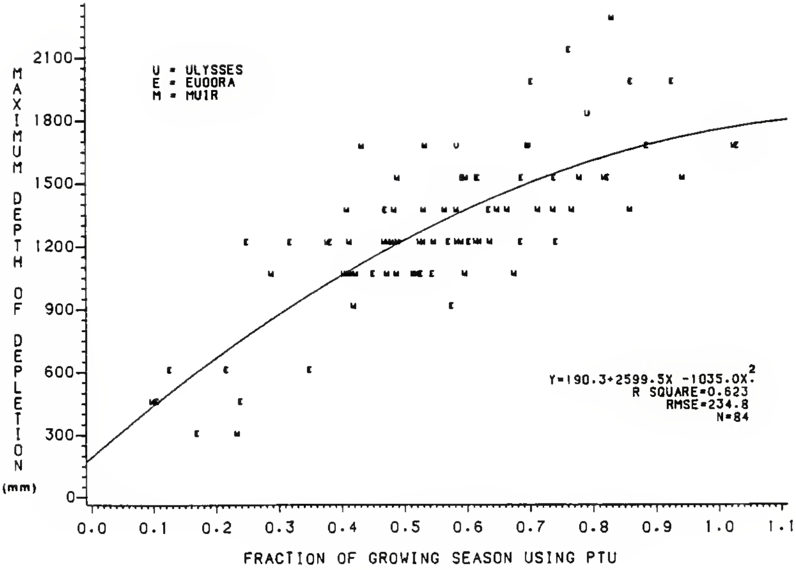

Fig. 10. Regression curve of maximum depth of depletion for soybean vs. fraction of growing season based on photothermal units. The curve was developed by using the 1974 through 1984 data.

The basal crop coefficient curves for corn are shown in Figs. 11 through 14. Using fraction of growing season, % available soil water, and Etr calculated by the method used to derive the particular curve, we used each of these models to predict the 1983 and 1984 Et values. The predicted vs. actual Et regression lines are shown in Figs. 15 through 18. The TEST procedure was used on these regression lines. The intercepts of the lines resulting from using the Jensen-Haise, the modified Jensen-Haise, and the Priestley-Taylor-based curves were not significantly different from 0 (see Table 10). The TEST procedure would not test hypotheses about the predicted vs. actual Et regression line resulting from the Kcb curve based on the Penman equation. Since its intercept is closer to 0 than those of the other predicted vs. actual corn Et lines, it is reasonable to assume that it also is not siginificantly different from 0. However, as the F statistics listed in Table 10 indicate, the slopes of these predicted vs. actual Et lines are significantly lower than 1. The prediction equations tended to underestimate Et, particularly during the middle period of the season when actual Et rates were high. In developing these crop coefficient curves, measured Et rates of various treatments within a given year-cultivar data set were used. These treatments may not have affected water use of the crop, and perhaps should have been averaged together to avoid the effects of unusually low measured Et values resulting from variation in the neutron probe readings. A reevaluation of the

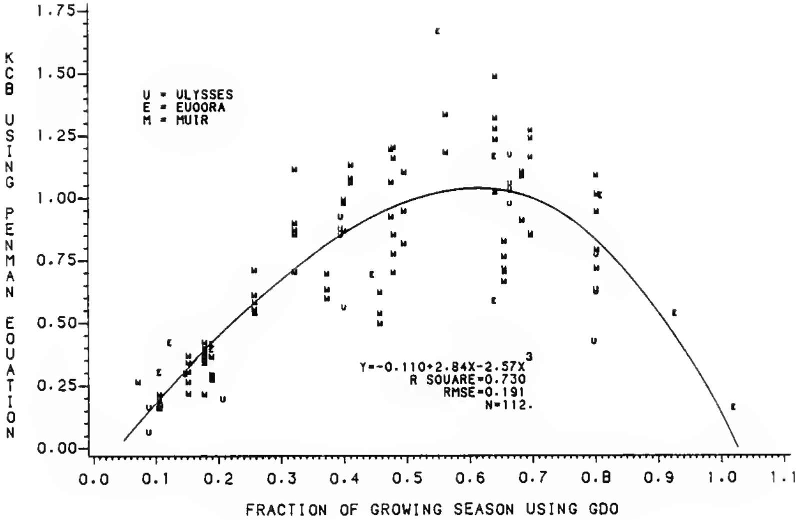

Fig. 11. Regression curve of basal crop coefficients for corn, calculated by using the Penman reference Et equation, vs. fraction of growing season based on growing degree days. The curve was developed by using the 1974 through 1982 data.

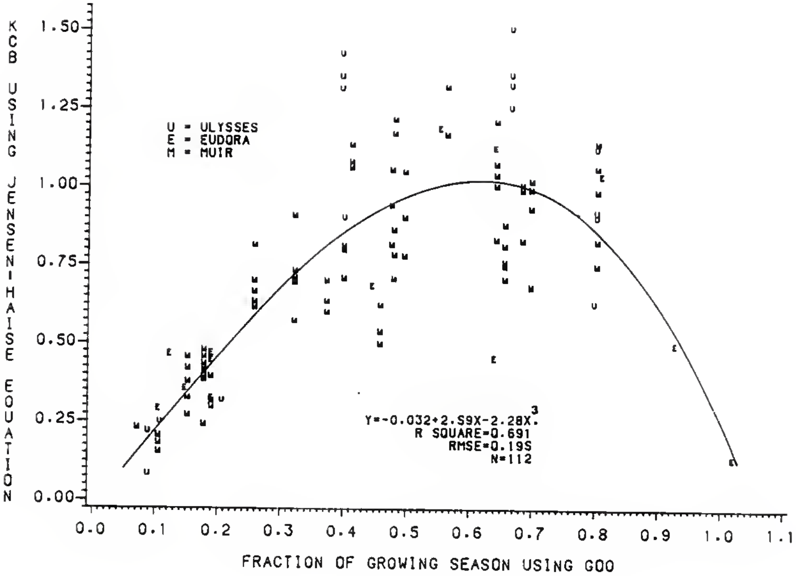

Fig. 12. Regression curve of basal crop coefficients for corn, calculated by using the Jensen-Haise reference Et equation, vs. fraction of growing season based on growing degree days. The curve was developed by using the 1974 through 1982 data.

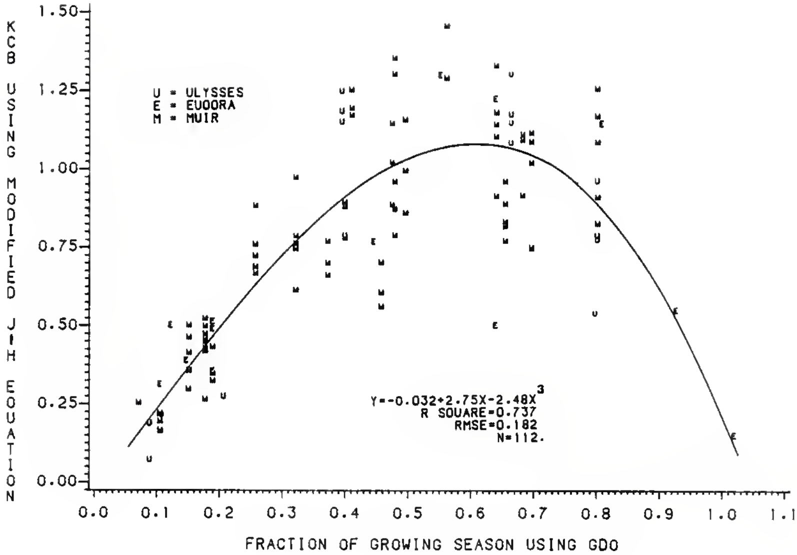

Fig. 13. Regression curve of basal crop coefficients for corn, calculated by using the modified Jensen-Haise reference Et equation, vs. fraction of growing season based on growing degree days. The curve was developed by using the 1974 through 1982 data.

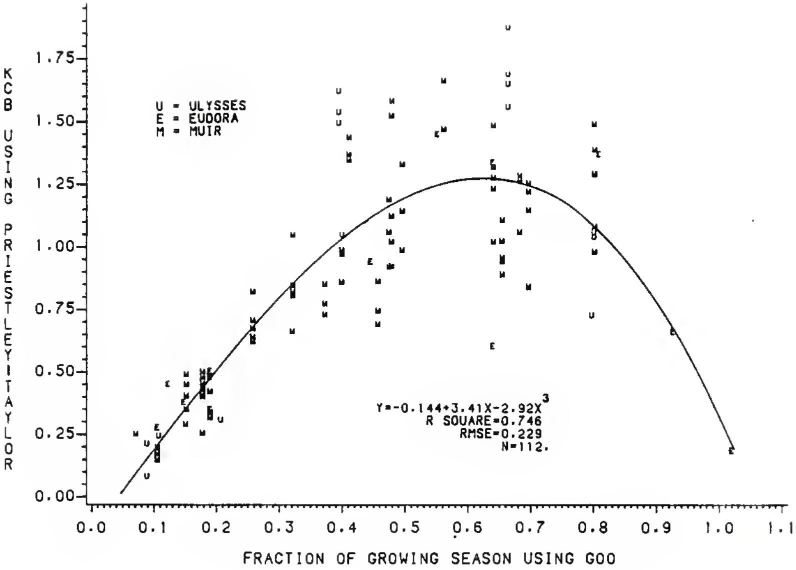

Fig. 14. Regression curve of basal crop coefficients for corn, calculated by using the Priestley-Taylor reference Et equation, vs. fraction of growing season based on growing degree days. The curve was developed by using the 1974 through 1982 data.

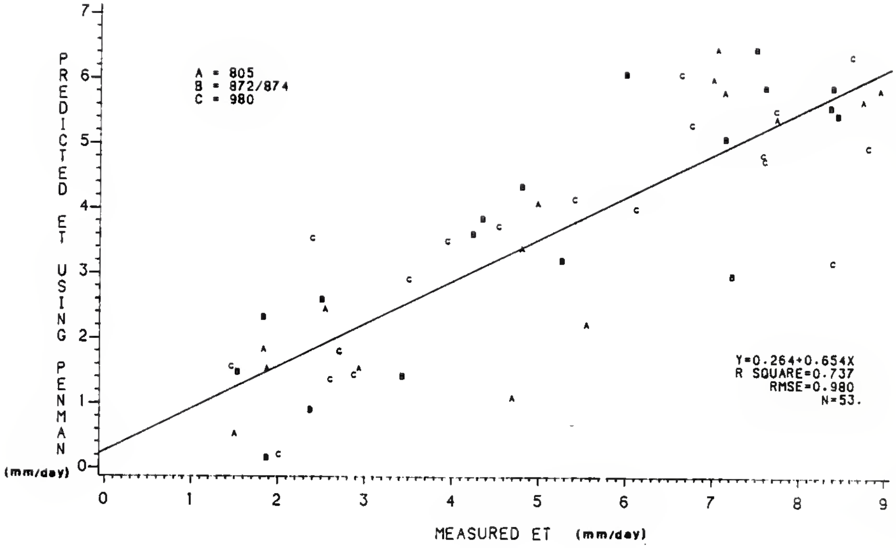

Fig. 15. Regression line of predicted corn evapotranspiration, predicted by using the basal crop coefficient curve developed with the Penman reference Et equation, vs. measured Et for the 1983 and 1984 data.

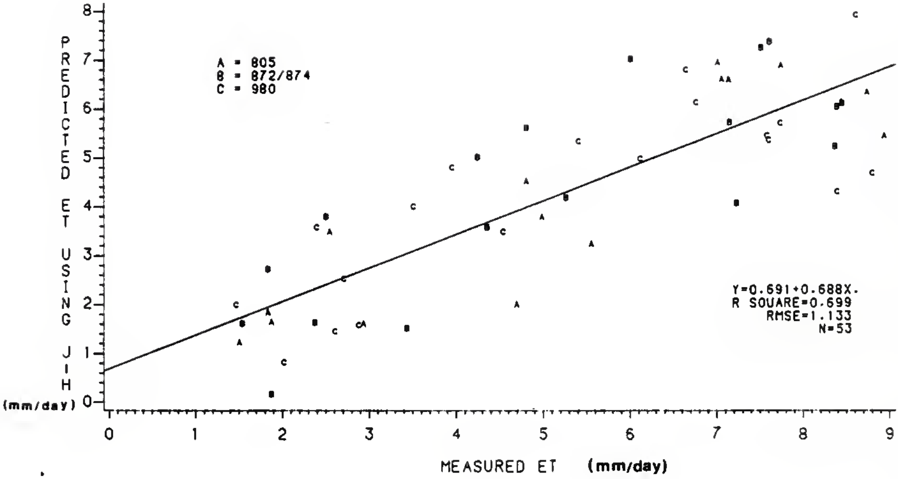

Fig. 16. Regression line of predicted corn evapotranspiration, predicted by using the basal crop coefficient curve developed with the Jensen-Haise reference Et equation, vs. measured Et for the 1983 and 1984 data.

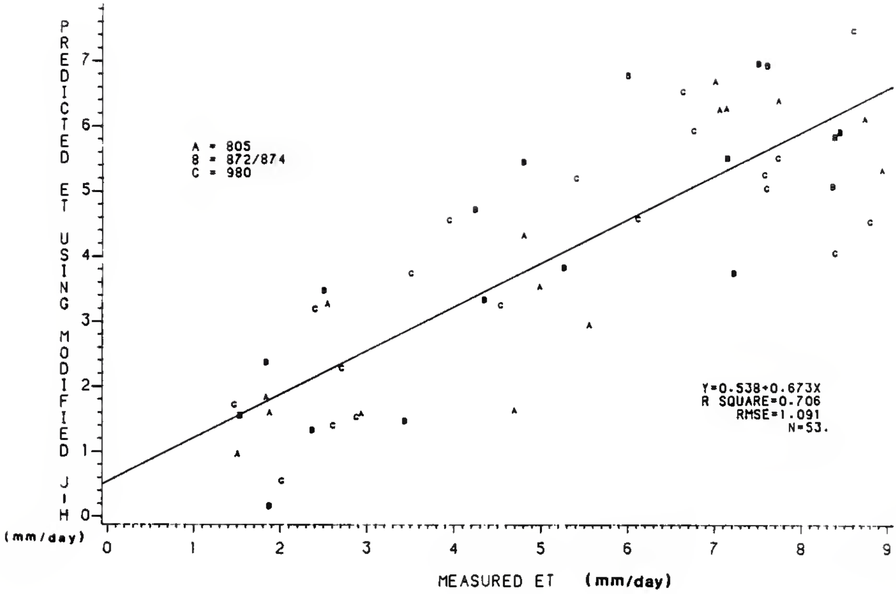

Fig. 17. Regression line of predicted corn evapotranspiration, predicted by using the basal crop coefficient curve developed with the modified Jensen-Haise reference Et equation, vs. measured Et for the 1983 and 1984 data.

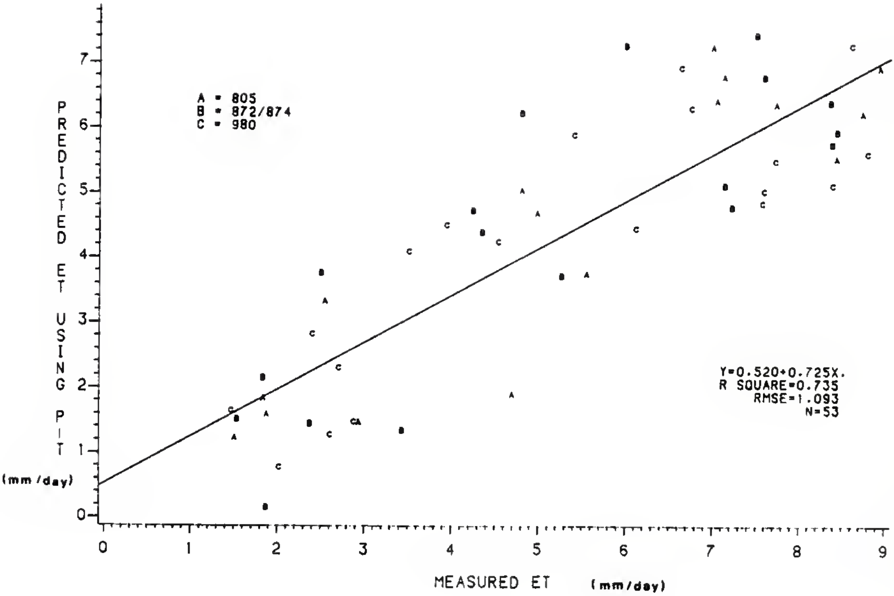

Fig. 18. Regression line of predicted corn evapotranspiration, predicted by using the basal crop coefficient curve developed with the Priestley-Taylor reference Et equation, vs. measured Et for the 1983 and 1984 data.

Table 10. Regression equations of predicted evapotranspiration, predicted by using basal crop coefficient curves developed with four reference Et equations, vs. measured evapotranspiration for the 1983 and 1984 corn data. R squares, root mean square errors, and the significance levels for the F statistics for the slopes and intercepts are also shown.

Reference Et equation	Equation	R^2	RMSE	Prob>F Slope	Prob>F Int.
Penman	$Y=0.264+0.654X$	0.737	0.980	___*	___
Jensen-Haise	$Y=0.691+0.688X$	0.699	1.133	0.0001	0.065
Modified Jensen-Haise	$Y=0.538+0.673X$	0.706	1.091	0.0001	0.133
Priestley-Taylor	$Y=0.520+0.725X$	0.735	1.093	0.0001	0.147

* The TEST procedure in SAS did not test hypotheses about this regression equation.

model data and possible redevelopment of the curves is planned in the thought that a better prediction model can be developed from these data.

The basal crop coefficient curves for soybean are presented in Figs. 19 through 22, and the regression lines of the predicted Et rates using each Kcb curve vs. the actual Et rates for the 1983 and 1984 data are shown in Figs. 23 through 26. Table 11 shows the F values for these lines resulting from the TEST procedure. All F values are significant at levels less than 0.05. Like the corn curves, these soybean Kcb curves underestimated Et rates, particularly for the higher Et rates occurring in the middle portion of the season. It is thought that a reworking of these data, in the manner described for corn, will improve the predictive ability of these curves.

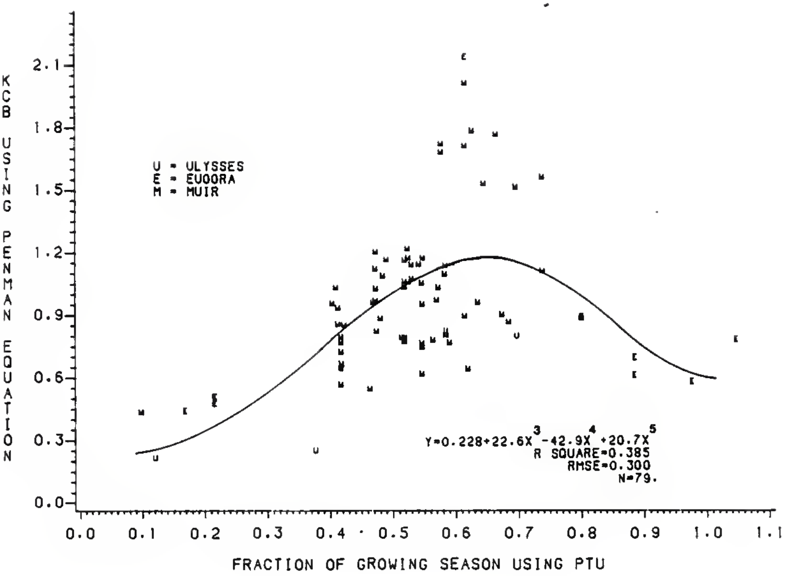

Fig. 19. Regression curve of basal crop coefficients for soybean, calculated by using the Penman reference Et equation, vs. fraction of growing season based on photothermal units. The curve was developed by using the 1974 through 1982 data.

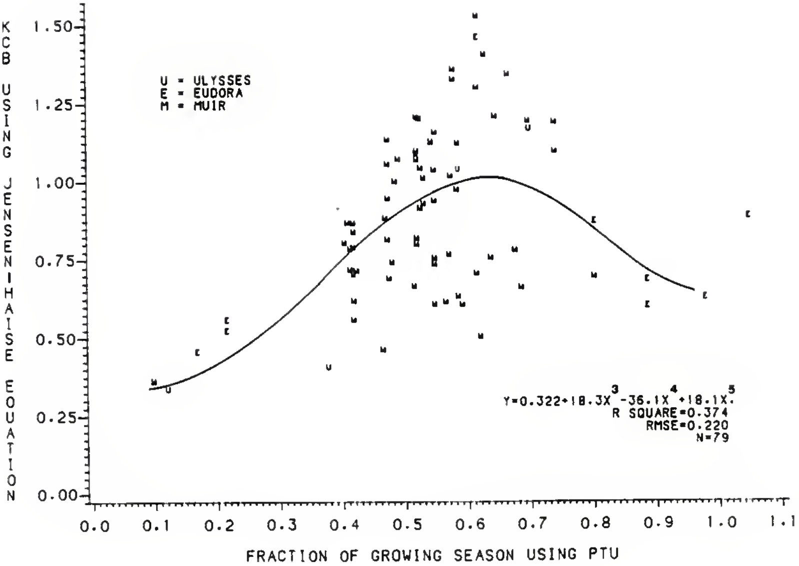

Fig. 20. Regression curve of basal crop coefficients for soybean, calculated by using the Jensen-Haise reference Et equation, vs. fraction of growing season based on photothermal units. The curve was developed by using the 1974 through 1982 data.

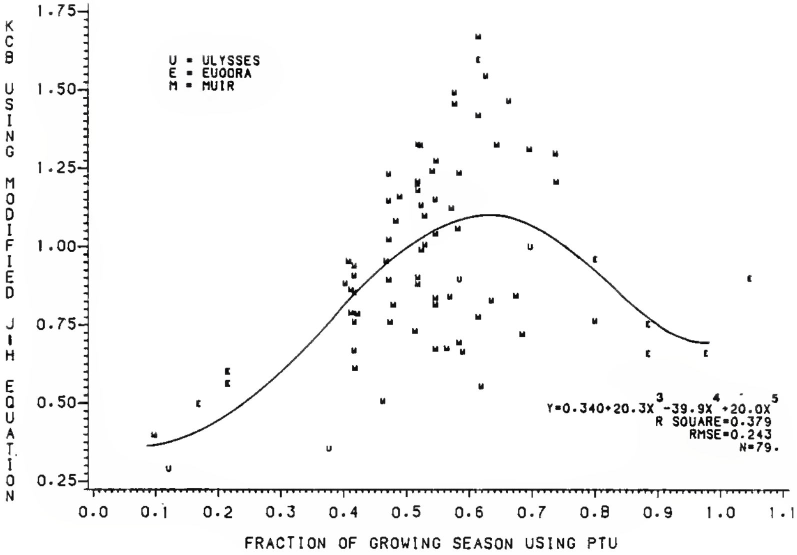

Fig. 21. Regression curve of basal crop coefficients for soybean, calculated by using the modified Jensen-Haise reference Et equation, vs. fraction of growing season based on photothermal units. The curve was developed by using the 1974 through 1982 data.

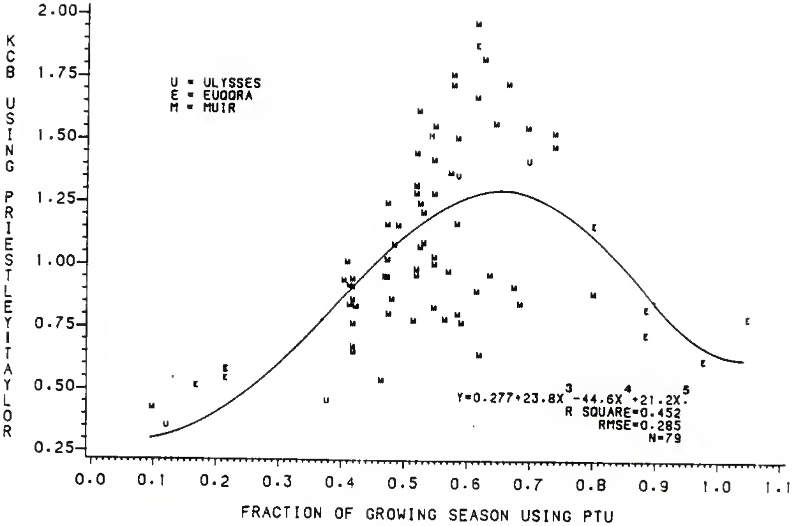

Fig. 22. Regression curve of basal crop coefficients for soybean, calculated by using the Priestley-Taylor reference Et equation, vs. fraction of growing season based on photothermal units. The curve was developed by using the 1974 through 1982 data.

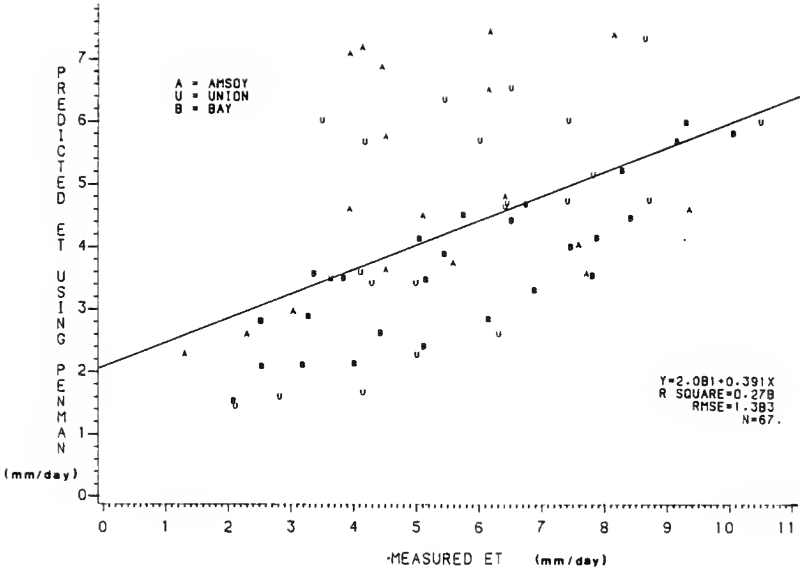

Fig. 23. Regression line of predicted soybean evapotranspiration, predicted by using the basal crop coefficient curve developed with the Penman reference Et equation, vs. measured Et for the 1983 and 1984 data.

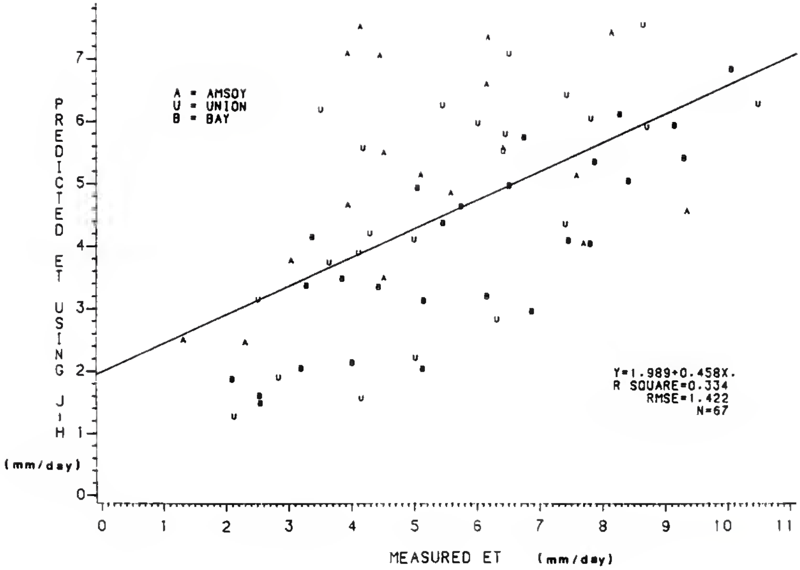

Fig. 24. Regression line of predicted soybean evapotranspiration, predicted by using the basal crop coefficient curve developed with the Jensen-Haise reference Et equation, vs. measured Et for the 1983 and 1984 data.

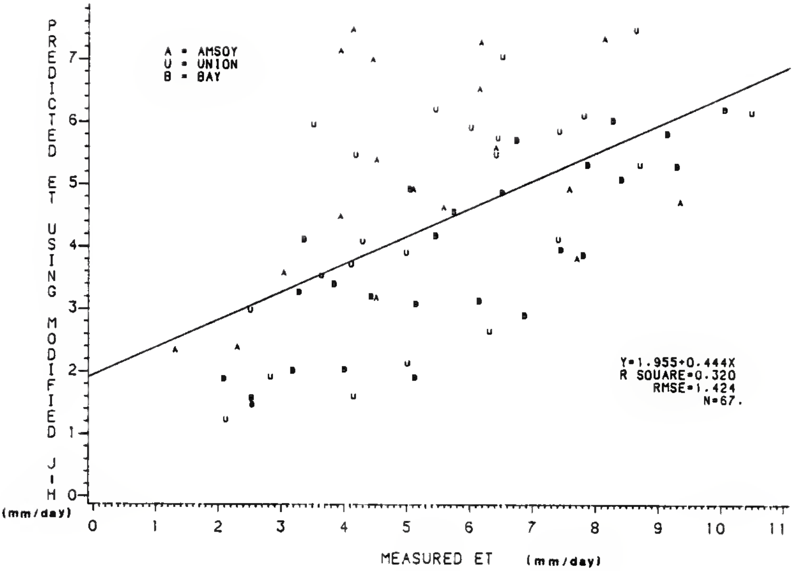

Fig. 25. Regression line of predicted soybean evapotranspiration, predicted by using the basal crop coefficient curve developed with the modified Jensen-Haise reference Et equation, vs. measured Et for the 1983 and 1984 data.

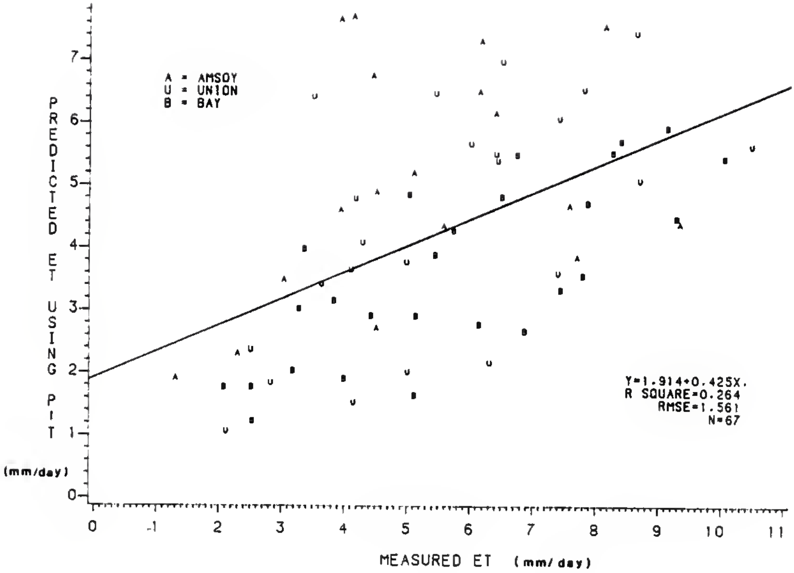

Fig. 26. Regression line of predicted soybean evapotranspiration, predicted by using the basal crop coefficient curve developed with the Priestley-Taylor reference Et equation, vs. measured Et for the 1983 and 1984 data.

Table 11. Regression equations of predicted evapotranspiration, predicted by using basal crop coefficient curves developed with four reference Et equations, vs. measured evapotranspiration for the 1983 and 1984 soybean data. R squares, root mean square errors, and the significance levels for the F statistics for the slopes and intercepts are also shown.

Reference Et equation	Equation	R^2	RMSE	Prob>F Slope	Prob>F Int.
Penman	Y=2.081+0.391X	0.278	1.383	0.0001	0.0001
Jensen-Haise	Y=1.989+0.458X	0.334	1.422	0.0001	0.0001
Modified Jensen-Haise	Y=1.955+0.444X	0.320	1.424	0.0001	0.0001
Priestley-Taylor	Y=1.914+0.425X	0.264	1.561	0.0001	0.0005

Summary and Conclusions

This study was conducted to develop and test basal crop coefficient curves for corn and soybean based on fraction of growing season, calculated by using growing degree days for corn and photothermal units for soybean. Four curves were developed for each crop, each one developed by using a different reference Et equation. The reference Et equations used in these curves were the Penman (Wright and Jensen, 1978), Jensen-Haise (1963), modified Jensen-Haise (Burman et al., 1980), and Priestley-Taylor (Kanemasu et al., 1976) equations. These curves were derived from water use and meteorological data collected at sites near Manhattan and Tribune, Kansas during the years 1974 through 1982. The predictive ability of the curves was tested by using Manhattan data for the years 1983 and 1984. Other objectives were the evaluation of various heat unit methods, the development of curves of maximum depth of depletion vs. fraction of growing season to estimate effective rooting depth, and the development and testing of relative leaf area index curves based on fraction of growing season.

A comparison of the coefficients of variation for fraction of growing season to silking in corn, calculated by using five heat unit methods and days after emergence, led to the choice of the growing degree day method (Neild and Seeley, 1977). A similar analysis of fraction of growing season to beginning bloom in soybean led to the choice of maturity group II coefficients for flowering to physiological maturity for use in a photothermal unit equation for soybean (Major et al., 1975b).

Curves of corn relative leaf area index vs. four time scales were used to predict relative leaf area index for the 1983 data. F tests performed on regression lines of predicted vs. measured relative LAI showed fraction of growing season based on growing degree days to be a better time scale for this purpose than that based on modified growing degree days, and far better than days after emergence and fraction of growing season based on DAE. For soybean, curves of relative LAI vs. fraction of growing season based on photothermal units and days after emergence, as well as one vs. days after emergence, performed equally well in predicting the 1983 relative LAI.

The basal crop coefficient curves for corn were used to predict the Et rates for the 1983 and 1984 data. Linear regressions were performed on the predicted vs. measured Et values. F tests performed on these regression lines revealed that, although the intercepts were not significantly different from 0, the slopes of these lines were significantly lower than 1. This shows that these basal crop coefficient curves for corn underestimated Et. Likewise, F tests performed on regression lines of Et predicted by using the soybean basal crop coefficient curves vs. measured Et for the 1983 and 1984 soybean data revealed that these curves underestimated Et.

The basal crop coefficient curves underestimated Et rates, particularly during the middle of the growing season when Et rates were high. A reevaluation and possible redevelopment of the curves is planned. Averaging of Et rates of treatments which did not affect water use may eliminate some unusually low outlier points in the model data, thus allowing the curves to reach higher maximum values at midseason. Such a redevelopment of the curves would be particularly worthwhile for corn, since these curves were often quite successful in predicting Et.

REFERENCES

Allmaras, R.R., W.W. Nelson, and W.B. Voorhees. 1975. Soybean and corn rooting in southwestern Minnesota: II Root distributions and related water inflow. Soil Sci. Soc. Amer. Proc. 39:771-777.

Anderson, C.K., L.R. Stone, and L.S. Murphy. 1982. Corn yield as influenced by in-season application of nitrogen with limited irrigation. Agron. J. 74:396-401.

Brady, R.A. 1972. Stomatal resistance, leaf water potential, and yield in irrigated and nonirrigated soybeans. M.S. Thesis. Kansas State Univ., Manhattan.

Brown, D.M. 1960. Soybean ecology. I. Development-temperature relationships from controlled environment studies. Agron. J. 52:493-496.

Burman, R.D., P.R. Nixon, J.L. Wright, and W.O. Pruitt. 1980. Water requirements. P. 189-232. In M.E. Jensen (ed.) Design and operation of farm irrigation systems. ASAE, St. Joseph, MI.

Cargill, 1983. Cargill's hot ones for 1983. Cargill Seeds Co., Minneapolis, MN.

Cargill, 1983. 1983-84 Grower's guide. Cargill Seeds Co., Minneapolis, MN.

Coelho, D.T. and R.F. Dale. 1980. An energy-crop growth variable and temperature function for predicting corn growth and development: planting to silking. Agron. J. 72:503-510.

Cross, H.Z. and M.S. Zuber. 1972. Prediction of flowering dates in maize based on different methods of estimating thermal units. Agron. J. 64:351-355.

Curley, S.H. 1981. Soybean root systems as influenced by cultivar, nitrogen fertility, and water level. M.S. Thesis. Kansas State Univ., Manhattan.

Curry, R.B., C.H. Baker, and J.G. Streeter. 1975. SOYMOD I: A dynamic simulator of soybean growth and development. Trans. ASAE. 18:963-968.

Daughtry, C.S.T., J.C. Cochran, and S.E. Hollinger. 1984. Estimating silking and maturity dates of corn for large areas. Agron. J. 76:415-420.

Davies, J.A. and C.D. Allen. 1973. Equilibrium, potential and actual evaporation from cropped surfaces in southern Ontario. J. Appl. Met. 12:649-656.

De Brnin, H.A.R. 1983. A model for the Priestley-Taylor parameter α. J. Climate Appl. Meteor. 22:572-578.

de Jong, R., C.F. Shaykewich, and A. Reimer. 1980. The calculation of the net radiation flux. Arch. Met. Geoph. Biokl. B 28:353-363.

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

Doss, B.D., O.L. Bennett, and D.A. Ashley. 1962. Evapotranspiration by irrigated corn. Agron. J. 54:497-498.

Dylla, A.S., D.R. Timmons, and H. Shnll. 1980. Estimating water used by irrigated corn in West Central Minnesota. Soil. Sci. Soc. Am. J. 44:823-827.

Eik, K., and J.J. Hanway. 1965. Some factors affecting development and longevity of leaves of corn. Agron. J. 57:7-12.

Foth, H.D. 1962. Root and top growth of corn. Agron. J. 54:49-52.

Gilmore, E.C. and J.S. Rogers. 1958. Heat units as a method of measuring maturity in corn. Agron. J. 50:611-615.

Goldsworthy, P.R. 1975. Some growth and yield characteristics of tropical maize. p. 166-177. In L.F. Banman, E.T. Mertz, A. Carballo, and E.W. Spragne (ed.) High-quality protein maize. Dowden, Hutchinson and Ross, inc., Stroudsburg, PA.

Gwin, R.E., O.W. Bidwell, R.C. Angell, and G. Mnilenbnrg. 1974. Making the most of soil, water, climate in west-central Kansas through research at Tribune brach experiment station. Kansas Agric. Exp. Stn Bull. 577.

Hanway, J.J. and H.E. Thompson. 1971. How a soybean plant develops. Iowa State Univ. Cooperative Extension Service, Special Report No. 53.

Hattendorf, M.J. 1982. Evapotranspiration relationships and crop coefficient curves of irrigated field crops. M.S. Thesis. Kansas State Univ., Manhattan.

Hill, R.W., E.L. Johns, and D.K. Frevert. 1983. Comparison of equations used for estimating agricultural crop evapotranspiration with field research. Technical report. Bureau of Reclamation, Engineering and Research Center, Denver, CO.

Hillel, D. 1971. Soil and water physical principles and processes. Academic Press Inc., New York.

Idso, S.B. and R.D. Jackson, 1969. Thermal radiation from the atmosphere. J. Geophys Res. 74:5397-5403.

Jantz, D.R., R.F. Harner, H.T. Rowland, and D.A. Gier. 1975. Soil survey of Riley county and part of Geary county, Kansas. U.S.D.A. and S.C.S. in coop. with KS. Agric. Exp. Stn.

Jensen, M.E. and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. Proc. Am. Soc. Civ. Engr., J. Irrig. and Drain. Div. 89:15-41.

Jensen, M.E., D.C.N. Robb, and C.E. Franzoy. 1970. Scheduling irrigations using climate-crop-soil data. Proc. Am. Soc. Civ. Engr., J. Irrig. and Drain. Div. 96:25-38.

Jensen, M.E., J.L. Wright, and B.J. Pratt. 1971. Estimating soil moisture depletion from climate crop and soil data. Trans. ASAE. 14:954-959.

Kanemasn, E.T., L.R. Stone, and W.L. Powers. 1976. Evapotranspiration model tested for soybean and sorghum. Agron. J. 68:569-572.

Kaspar, T.C., C.D. Stanley, and H.M. Taylor. 1978. Soybean root growth during the reproductive stages of development. Agron. J. 70:1105-1107.

Koller, H.R. 1972. Leaf area-leaf weight relationships in the soybean canopy. Crop. Sci. 12:180-183.

Knfimfntn, B.B. 1981. Corn (*Zea mays* L.) yield and water use as influenced by irrigation level, nitrogen fertilization, and plant population. M.S. Thesis. Kansas State Univ., Manhattan.

Lehenbaner, P.A. 1914. Growth of maize seedlings in relation to temperature. Physiological Researches. 1:247-288.

Linacre, E.T. 1968. Estimating the net radiation flux. Agric. Meteor. 5:49-63.

Major, D.J., D.R. Johnson, and V.D. Lnedders. 1975a. Evaluation of eleven thermal unit methods for predicting soybean development. Crop. Sci. 15:172-174.

Major, D.J., D.R. Johnson, J.W. Tanner, and I.C. Anderson. 1975b. Effects of daylength and temperature on soybean development. Crop Sci. 15:174-179.

Mayaki, W.C., L.R. Stone, and I.D. Teare. 1976. Irrigated and nonirrigated soybean, corn, and grain sorghum root systems. Agron. J. 68:532-534.

Mederski, H.J., M.E. Miller, and C.R. Weaver. 1973. Accumulated heat units for classifying corn hybrid maturity. Agron. J. 65:743-747.

Merva, G. and A. Fernandez. 1982. Simplified application of Penman's equation. Paper presented at Summer Meeting ASAE., Madison, WI. 27-30 June 1982. ASAE. St. Joseph, MI.

Mitchell, R.L. and W.J. Russell. 1971. Root development and rooting patterns of soybean (Glycine max. (L) Merrill) evaluated under field conditions. Agron. J. 63:313-316.

Mukammal, E.I., and H.H. Neumann. 1977. Application of the Priestley-Taylor evaporation model to asses the influence of soil moisture on the evaporation from a large weighing lysimeter and class A pan. Boundary-Layer Meteorol. 12:243-256.

Narda, N.K., and R,B. Curry. 1981. SOYROOT - A dynamic model of soybean root growth and water uptake. Trans. ASAE. 24:651-662.

Neild, R.E. and M.W. Seeley. 1977. Growing degree days predictions for corn and sorghum development and some applications to crop production in Nebraska. Nebraska Agric. Exp. Stn. Res. Bull. 280.

Newman, J.E. 1971. Measuring corn maturity with heat units; the simplest method is also one of the most accurate. Crops Soils. 23(8):11-14.

Ogbuehi, S.N. and J.R. Brandle. 1981. Limitations in the use of leaf dry weight and leaf number for predicting leaf area of soybeans. Crop. Sci. 21:344-346.

Penman, H.L. 1948. Natural evaporation from open water, bare soil, and grass. Proc. Roy. Soc. London. A 193:120-145.

Penman, H.L. 1956. Evaporation: an introductory survey. Neth. J. Agric. Sci. 4:9-29.

Priestley, C.H.B. and R.J. Taylor. 1972. On the assesment of surface heat flux and evaporation using large-scale parameters. M. Weath. Rev. 100:81-92.

Redelfs, M.S. 1983. The determination of greenness indices and the relationships between greenness and leaf area index and total dry weight of seven crops. M.S. Thesis. Kansas State Univ., Manhattan.

Ritchie, J.T. 1973. Influence of soil water status and meteorological conditions on evaporation from a corn canopy. Agron. J. 65:893-897.

Ritchie, S.W. and J.J. Hanway. 1982. How a corn plant develops. Iowa State Univ. Cooperative Extension Service, Special Report No. 48.

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

Sammis, T.W., C.L. Mapel, D.G. Lugg, R.R. Lansford, and J.T. Mcguckin. 1985. Evapotranspiration crop coefficients predicted using growing-degree-days. Trans. ASAE. 28:773-780.

SAS Institute Inc. 1982. SAS user's guide: statistics, 1982 edition. SAS Institute Inc., Cary, NC.

Shaw, R.H. 1963. Estimation of soil moisture under corn. Iowa Agric. and Home Econ. Exp. Stn. Res. Bull. 520.

Sierra, E.M. 1977. Energetic-photo-thermal development model for medium late and late soybean cultivars. Agric. Meteor. 18:277-291.

Sinclair, T.R. 1984. Leaf area development in field-grown soybeans. Agron. J. 76:141-146.

Sivakumar, M.V.K. 1978. Prediction of leaf area index in soya bean (Glycine max. (L.) Merrill). Ann. Bot. 42:251-253.

Snedecor, G.W. and W. G. Cochran. 1980. Statistical Methods. The Iowa State University Press, Ames, Iowa.

Stapper, M. and G.F. Arkin. 1980. CORNF: a dynamic growth and development model for maize (Zea mays L.) Texas Agric. Exp. Stn. Res. Center Program and Model Documentation No. 80-2.

Stegman, E.C., A. Bauer, J.C. Zubriski, and J. Bauder. 1977. Crop curves for water balance irrigation scheduling in S.E. North Dakota. Agric. Exp. Stn. North Dakota Res. Rep. No. 66.

Stegman, E.C. and H.M. Olson. 1976. Water management relationships for irrigated pinto beans. Agric. Exp. Stn. North Dakota Res. Rep. No. 61.

Stegman, E.C. and J.D. Valer. 1972. Irrigation scheduling by computational methods: crop data and evaluations in North Dakota. Agric. Exp. Stn. North Dakota Res. Rep. No. 41.

Stone, J.A., T.C. Kaspar, and H.M. Taylor. 1983. Predicting soybean rooting depth as a function of soil temperature. Agron.

J. 75:1050-1054.

Stone, J.A., and H.M. Taylor. 1983. Temperature and the development of the taproot and lateral roots of four indeterminate soybean cultivars. Agron. J. 75:613-618.

Stone, L.R. 1982. Movement of water and nitrate-nitrogen in a typical silt loam soil of western Kansas. Kansas Water Resources Res. Inst. Project Completion Rep. No. 238. (Also U.S. Dept. Int., Project No. A-101-Kan).

Stone, L.R., R.E. Gwin, and M.A. Dillon. 1978. Corn and grain sorghum yield response to limited irrigation. J. Soil Water Conserv. 33:235-238.

Stone, L.R., D.A. Whitney, and C.K. Anderson. 1985. Soybean yield response to residual NO_3-N and applied N. Plant and Soil. 84:259-265.

Wiersma, J.V., and T.B. Bailey. 1975. Estimation of leaflet, trifoliate, and total leaf areas of soybeans. Agron. J. 67:26-30.

Winter, S.R. and J.W. Pendleton. 1968. Soybean roots - how deep do they go? Soybean Dig. 28:14.

Wright, J.L. 1981. Crop coefficients for estimates of daily crop evapotranspiration. p. 18-26. In Irrigation scheduling for water and energy conservation in the 80's. Proc. ASAE Irrig. Sched. Conf., Chicago, IL, 14-15 Dec. 1981. ASAE. St. Joseph, MI.

Wright, J.L. 1982. New evapotranspiration crop coefficients. Proc. Am. Soc. Civ. Engr., J. Irrig. and Drain. Div. 108:57-74.

Wright, J.L. and M.E. Jensen. 1972. Peak water requirements of crops in southern Idaho. Proc. Am. Soc. Civ. Engr., J. Irrig. and Drain. Div. 98:193-201.

Wright, J.L. and M.E. Jensen. 1978. Development and evaluation of evapotranspiration models for irrigation scheduling. Trans. ASAE. 21:88-96.

Znr, B., J.W. Jones, and K.J. Boote. 1983. Field evaluation of a water relations model for soybean. I. Validity of some basic assumptions. Agron. J. 75:272-280.

APPENDIX

Table 1A. Years, locations, soils, cultivars (all Prairie Valley cultivars), maximum depths of neutron probe readings, and references for data sets used to derive corn crop coefficient curves.

Year	Loc.	Soil (SiL)	Cultivar	Max. (cm)	Reference
1974	Man.	Muir	PV82S	160	Stone et al., 1978
1975	Man.	Muir	PV82S	160	Stone et al., 1978
1976	Man.	Muir	PV82S	160	Stone et al., 1978
1976	Man.	Eudora	PV82S	160	Anderson et al., 1982
1977	Man.	Eudora	PV82S	160	Anderson et al., 1982
1978	Man.	Eudora	PV76S	160	Anderson et al., 1982
1979	Man.	Muir	PV76S	160	Kufimfutu, 1981
1980	Man.	Muir	PV76S	160	Kufimfutu, 1981
1980	Man.	Eudora	PV76S	160	Kufimfutu, 1981
1981	Man.	Muir	PV76S	312	Hattendorf, 1982
1981	Trib.	Ulysses	PV76S	312	Hattendorf, 1982
1981	Trib.	Ulysses	PV76S	312	Stone, 1982
1982	Man.	Eudora	PV76S	312	Redelfs, 1983
1982	Trib.	Ulysses	PV76S	312	Redelfs, 1983
1982	Trib.	Ulysses	PV76S	312	Stone, 1982

Table 2A. Years, locations, soils, cultivars, maturity groups, maximum depths of neutron probe readings, and references for data sets used to derive soybean crop coefficient curves.

Year	Loc.	Soil (SiL)	Cultivar	MG	Max. (cm)	Reference
1974	Man.	Muir	Williams	III	160	Mayaki et al., 1976
1975	Man.	Muir	Amsoy	II	160	Curley, 1981
1975	Man.	Muir	Bonus	IV	160	Curley, 1981
1975	Man.	Muir	Calland	III	160	Curley, 1981
1975	Man.	Muir	Clark Det.	IV	160	Curley, 1981
1975	Man.	Muir	Clark 63	IV	160	Curley, 1981
1975	Man.	Muir	Columbus	IV	160	Curley, 1981
1975	Man.	Muir	Pomona	IV	160	Curley, 1981
1975	Man.	Muir	Williams	III	160	Curley, 1981
1975	Man.	Muir	Woodworth	III	160	Curley, 1981
1978	Man.	Eudora	Pomona	IV	160	Stone, 1978*
1979	Man.	Eudora	Pomona	IV	160	Stone et al., 1985
1981	Man.	Muir	Cumberland	III	312	Hattendorf, 1982
1981	Trib.	Ulysses	Cumberland	III	312	Hattendorf, 1982
1982	Man.	Eudora	Cumberland	III	312	Redelfs, 1983
1982	Trib.	Ulysses	Cumberland	III	312	Redelfs, 1983

---

*Unpublished work by L.R. Stone, Kansas State University, Manhattan.

Table 3A. Fraction of growing season to silking in corn calculated by using the growing degree day, modified growing degree day, Gilmore and Rogers heat stress, Cross and Zuber heat stress, CORNF, and days after emergence methods.

Year	Cultivar	GDD	MGDD	Stress GR	Stress CZ	CORNF	Days
1974	PV82S	0.521	0.518	0.517	0.517	0.540	0.518
1975	PV82S	0.456	0.476	0.498	0.512	0.490	0.530
1976	PV82S	0.457	0.476	0.500	0.510	0.502	0.521
1977	PV82S	0.472	0.486	0.502	0.511	0.497	0.522
1978	PV76S	0.522	0.529	0.537	0.542	0.549	0.548
1979	PV76S	0.502	0.511	0.517	0.534	0.530	0.555
1980	PV76S	0.518	0.527	0.542	0.543	0.547	0.545
1981M	PV76S*	0.477	0.469	0.459	0.454	0.494	0.449
1982M	PV76S	0.460	0.464	0.467	0.480	0.490	0.495
1981T	PV76S	0.572	0.556	0.538	0.534	0.589	0.529
1982T	PV76S	0.563	0.564	0.563	0.570	0.599	0.576
1983	805	0.433	0.473	0.516	0.538	0.481	0.565
1984	805	0.464	0.491	0.520	0.527	0.498	0.536
1983	872	0.485	0.526	0.573	0.590	0.539	0.609
1984	874	0.558	0.580	0.604	0.607	0.595	0.611
1983	980	0.486	0.525	0.570	0.585	0.541	0.602
1984	980	0.551	0.574	0.599	0.601	0.593	0.602
1984	G4507+	0.502	0.525	0.551	0.551	0.548	0.551

* M signifies Manhattan, T signifies Tribune.

\+ Cultivar Funks G-4507. (These data were not used in development of depletion curves and testing of crop coefficient curves.)

Table 4A. Fraction of growing season to beginning bloom in soybean calculated by using the flowering to physiological maturity (F-PM) coefficients specific to each maturity group, MG II coefficients for F-PM, and days after emergence.

Year	Cultivar	MG	Specific coeffs. F-PM	MG II coeffs. F-PM	Days
1974	Williams	III	0.510	0.446	0.308
1975	Amsoy	II	0.554	0.554	0.373
1975	Bonus	IV	0.504	0.410	0.310
1975	Calland	III	0.533	0.428	0.298
1975	Clark Det.	IV	0.502	0.406	0.303
1975	Clark 63	IV	0.504	0.410	0.310
1975	Columbus	IV	0.590	0.495	0.368
1975	Pomona	IV	0.596	0.501	0.377
1975	Williams	III	0.557	0.463	0.324
1975	Woodworth	III	0.625	0.514	0.364
1978	Pomona	IV	0.590	0.457	0.327
1979	Pomona	IV	0.512	0.454	0.357
1981M*	Cumberland	III	0.503	0.466	0.321
1981T	Cumberland	III	0.461	0.452	0.310
1982M	Cumberland	III	0.531	0.471	0.355
1982T	Cumberland	III	0.445	0.417	0.310
1983	Amsoy	II	0.509	0.509	0.337
1983	Union	IV	0.674	0.479	0.367
1983	Bay	V	0.460	0.492	0.492
1984	Amsoy	II	0.534	0.534	0.356
1984	Union	IV	0.548	0.463	0.356
1984	Bay	V	0.478	0.461	0.453

* M signifies Manhattan, T signifies Tribune.

Table 5A. Fraction of growing season to tasseling and blister stage in corn, calculated by using growing degree days and days after emergence. This analysis was performed without the 1983 and 1984 data. N=12.

	Tasseling			Blister		
Method	Fraction	Std. dev.	CV (%)	Fraction	Std dev.	CV (%)
GDD	0.450	0.040	8.78	0.640	0.088	13.66
DAE	0.485	0.032	6.57	0.650	0.078	12.06

Table 6A. Fraction of growing season to tasseling and blister stage in corn, calculated by using growing degree days and days after emergence. The 1983 and 1984 data are included in this analysis. N=18.

	Tasseling			Blister		
Method	Fraction	Std. dev.	CV (%)	Fraction	Std. dev.	CV (%)
GDD	0.448	0.041	9.08	0.632	0.073	11.62
DAE	0.503	0.042	8.36	0.663	0.066	9.96

Table 7A. Fraction of growing season to beginning pod set and beginning bean fill in soybean, calculated by using photothermal units and days after emergence. This analysis was performed without the 1983 and 1984 data. N=16 for beginning pod set. N=14 for beginning bean fill.

	Beginning pod set			Beginning bean fill		
Method	Fraction	Std. dev.	CV (%)	Fraction	Std. dev.	CV (%)
PTU	0.559	0.042	7.51	0.660	0.049	7.49
DAE	0.481	0.036	7.44	0.619	0.047	7.65

Table 8A. Fraction of growing season to beginning pod set and beginning bean fill in soybean, calculated by using photothermal units and days after emergence. This analysis includes the 1983 and 1984 data. N=22 for beginning pod set. N=20 for beginning bean fill.

	Beginning pod set			Beginning bean fill		
Method	Fraction	Std. dev.	CV (%)	Fraction	Std. dev.	CV (%)
PTU	0.568	0.044	7.67	0.671	0.049	7.33
DAE	0.497	0.048	9.68	0.636	0.049	7.65

Table 9A. Corn growth stages (according to Ritchie and Hanway, 1982) and dates of observance in 1983.

Stage number	Description	Cultivar 805	872	980
	Planting	6 May	6 May	6 May
VE	Emergence	22 May	22 May	22 May
V2	2 Leaf	27 May	28 May	28 May
V4	4 Leaf	5 June	5 June	6 June
V6	6 Leaf	15 June	16 June	16 June
V8	8 Leaf	25 June	24 June	24 June
VT	Tasseling	7 July	15 July	18 July
R1	Silking	9 July	17 July	20 July
R2	Blister	18 July	26 July	29 July
R3	Milk	21 July	28 July	3 Aug.
R4	Dough	25 July	31 July	6 Aug.
R5	Dent	29 July	7 Aug.	15 Aug.
R6	Physiological maturity	15 Aug.	22 Aug.	28 Aug.
*	Tasseling (Tassel visible)	4 July	14 July	17 July

* Growth stage in addition to those of Ritchie and Hanway (1982).

Table 10A. Soybean growth stages (according to Hanway and Thompson, 1971) and dates of observance in 1983.

Stage number	Description	Cultivar		
		Amsoy	Union	Bay
	Planting	16 May	16 May	16 May
VE	Emergence	26 May	26 May	26 May
V0	Unifoliolate leaves emerged	31 May	31 May	31 May
V1	First trifoliolate leaves	13 June	15 June	14 June
V2	Trifoliolate leaves at 4 nodes	21 June	22 June	22 June
V3	Trifoliolate leaves at 6 nodes	*______	28 June	30 June
R4	Beginning bloom	26 June	5 July	28 July
R5	Full bloom	8 July	16 July	4 Aug.
R5.5	Beginning pod development	13 July	20 July	15 Aug.
R6	Upper pod development	18 July	27 July	18 Aug.
R7	Beginning bean fill	24 July	9 Aug.	23 Aug.
R8	Upper bean fill	31 July	16 Aug.	27 Aug.
R9	Beans full size	18 Aug.	30 Aug.	10 Sept.
R10	Physiological maturity	26 Aug.	12 Sept.	1 Oct.

* Amsoy reached R4 before this stage.

Table 11A. Corn growth stages (according to Ritchie and Hanway, 1982) and dates of observance in 1984.

Stage number	Description	Cultivar 805	 874	 980
	Planting	11 May	11 May	11 May
VE	Emergence	20 May	20 May	20 May
V2	2 Leaf	25 May	25 May	25 May
	Tasseling (Tassel visible)	29 June	11 July	16 July
R1	Silking	4 July	17 July	21 July
R2	Blister	17 July	23 July	30 July
R3	Milk	21 July	29 July	4 Aug.
R4	Dough	25 July	3 Aug.	10 Aug.
R5	Dent	29 July	9 Aug.	18 Aug.
R6	Physiological maturity	12 Aug.	23 Aug.	31 Aug.

Table 12A. Soybean growth stages (according to Hanway and Thompson, 1971) and dates of observance in 1984.

Stage number	Description	Cultivar Amsoy	Union	Bay
	Planting	18 May	18 May	18 May
VE	Emergence	28 May	28 May	28 May
V0	Unifoliolate leaves emerged	2 June	2 June	2 June
V1	First trifoliolate leaves	12 June	12 June	12 June
V2	Trifoliolate leaves at 4 nodes	19 June	18 June	18 June
R4	Beginning bloom	28 June	3 July	25 July
R5	Full boom	----	----	2 Aug.
R5.5	Beginning pod development	10 July	20 July	9 Aug.
R6	Upper pod development	20 July	28 July	16 Aug.
R7	Beginning bean fill	27 July	4 Aug.	22 Aug.
R8	Upper bean fill	2 Aug.	14 Aug.	27 Aug.
R10	Physiological maturity	23 Aug.	6 Sept.	3 Oct.

Table 13A. Corn yield data for 1983.

Cultivar	Plot	Corn grain yield*	Plant population
		Kg/ha	Plants/ha
805	1	6 548	69 554
	4	6 268	69 554
	8	6 560	75 459
872	3	6 452	73 491
	5	6 384	70 210
	7	6 059	73 491
980	2	6 021	73 491
	6	4 937	66 273
	9	6 116	70 866

* Reported at 15.5% moisture.

Table 14A. Soybean yield data for 1983.

Cultivar	Plot	Bean yield*	Plant population
		Kg/ha	Plants/ha
Amsoy	4	1 697	355 206
	6	2 105	353 018
Union	2	1 691	199 913
	5	1 361	255 468
Bay	1	1 172	420 385
	3	1 807	378 828

* Reported at 13.0% moisture.

Table 15A. Corn yield data for 1984.

Cultivar	Plot	Corn grain yield*	Plant population
		Kg/ha	Plants/ha
805	2	2 964	62 336
	6	3 696	57 087
	8	4 567	59 711
874	1	1 822	64 691
	3	4 377	77 428
	7	2 088	74 147
980	4	814	60 367
	5	2 596	64 304
	9	3 293	63 648

* Reported at 15.5% moisture.

Table 16A. Soybean yield data for 1984.

Cultivar	Plot	Bean yield*	Plant population
		Kg/ha	Plants/ha
Amsoy	2	1 434	189 633
	4	1 667	198 163
	9	1 396	199 475
Union	3	1 266	146 325
	5	1 188	167 323
	7	1 261	180 446
Bay	1	1 217	121 391
	6	918	187 008
	8	1 450	162 730

* Reported at 13.0% moisture.

Table 17A. Leaf area index, wet weights, and dry weights of 805 corn cultivar in 1983. The sampling unit was 4 plants.

Date	LAI	Wet wt. whole plant	Dry wt. leaves	Dry wt stems	Dry wt. reproductive parts
		grams			
2 June	0.05	8.10	0.77	0.08	0
6 June	0.04	17.40	0.87	0.44	0
14 June	0.60	176.49	11.21	6.39	0
20 June	1.85	533.48	36.84	22.07	0
24 June	2.78	1227	89.99	62.33	0.43
30 June	2.83	1645	70.58	91.64	11.90
8 July	3.38	1959	91.59	181.85	26.87
13 July	2.93	2173	88.89	203.71	48.64
22 July	2.77	2641	109.45	206.06	235.56
27 July	2.73	2875	108.41	244.79	272.92
4 Aug.	2.74	2583	109.85	217.18	289.99
10 Aug.	2.18	2472	108.95	228.57	575.64
19 Aug.	0.20	1716	118.62	274.09	507.62
29 Aug.	0	1039	54.26	185.96	348.31

Table 18A. Leaf area index, wet weights, and dry weights of 872 corn cultivar in 1983. The sampling unit was 4 plants.

Date	LAI	Wet wt. whole plant	Dry wt. leaves	Dry wt. stems	Dry wt. reproductive parts
		grams			
2 June	0.05	7.50	0.60	0.11	0
6 June	0.04	13.50	1.03	0.31	0
14 June	0.31	72.07	5.63	1.99	0
20 June	1.24	312.98	25.39	12.90	0
24 June	2.02	673	49.68	30.77	0
30 June	3.77	1644	87.12	67.31	0
8 July	4.94	2162	128.31	141.68	8.49
13 July	4.24	2217	122.41	141.81	12.38
22 July	4.59	3061	160.35	257.49	133.31
27 July	4.49	3013	164.00	313.92	120.14
4 Aug.	4.21	3086	150.86	292.18	345.97
10 Aug.	3.82	2370	144.85	229.30	380.67
19 Aug.	0.35	2349	178.82	256.46	673.92
29 Aug.	0	1384	152.62	270.61	607.37

Table 19A. Leaf area index, wet weights, and dry weights of 980 corn cultivar in 1983. The sampling unit was 4 plants.

Date	LAI	Wet wt. whole plant	Dry wt. leaves	Dry wt. stems	Dry wt. reproductive parts
		grams			
2 June	0.05	8.86	0.69	0.20	0
6 June	0.07	28.97	1.99	0.69	0
14 June	0.36	88.45	6.62	2.08	0
20 June	1.76	517.28	34.71	18.17	0
24 June	2.23	853	58.22	34.54	0
30 June	3.26	1611	76.48	57.88	0
8 July	5.13	2634	140.03	144.63	2.51
13 July	5.61	3752	159.97	195.80	9.06
22 July	5.15	3974	191.28	388.87	69.50
27 July	3.99	2807	152.77	315.05	53.77
4 Aug.	4.74	4070	174.19	423.95	215.14
10 Aug.	4.48	4205	209.04	484.86	387.49
19 Aug.	1.02	3300	177.91	400.36	561.65
29 Aug.	0.27	2203	183.54	344.51	635.06

Table 20A. Leaf area index, wet weights, and dry weights of Amsoy soybean cultivar in 1983. The sampling unit was 1 meter of row.

Date	LAI	Wet wt. whole plant	Dry wt. leaves	Dry wt. stems	Dry wt. reproductive parts
		grams			
6 June	0.11	48.14	5.04	1.54	0
14 June	0.44	126.18	16.79	6.75	0
20 June	1.12	250.98	25.26	13.60	0
22 June	1.02	249.28	25.79	14.33	0
30 June	2.66	784	62.15	54.31	0
8 July	2.15	605	57.52	65.45	0
13 July	3.57	1083	105.62	114.30	0.34
22 July	1.89	646	70.24	70.88	5.15
27 July	3.52	1447	124.60	156.50	53.59
3 Aug.	2.82	1428	111.11	141.06	68.83
9 Aug.	3.49	1940	121.22	169.97	126.93
16 Aug.	2.90	1753	121.04	180.82	181.36
23 Aug.	1.98	1652	101.30	139.26	196.57
31 Aug.	0.04	392	50.25	95.91	131.26

Table 21A. Leaf area index, wet weights, and dry weights of Union soybean cultivar in 1983. The sampling unit was 1 meter of row.

Date	LAI	Wet wt. whole plant	Dry wt. leaves	Dry wt. stems	Dry wt. reproductive part
		grams			
6 June	0.16	69.60	7.11	1.86	0
14 June	0.37	104.19	13.47	6.59	0
20 June	1.15	240.48	24.51	12.58	0
22 June	0.97	235.48	24.06	10.72	0
30 June	2.28	604	55.08	40.54	0
8 July	3.09	821	77.15	77.34	0
13 July	2.40	672	69.38	63.32	0
22 July	3.50	1013	108.84	108.95	0.56
27 July	2.21	775	80.60	115.43	0.46
3 Aug.	3.74	1320	124.26	129.00	6.34
9 Aug.	4.47	1577	138.99	181.33	34.83
16 Aug.	4.55	2051	158.42	238.03	73.53
23 Aug.	4.30	2746	146.55	278.95	157.95
31 Aug.	2.77	1651	106.99	199.13	128.08
7 Sept.	0.65	1354	92.79	255.18	230.76
13 Sept.	0.23	865	57.29	190.04	162.49

Table 22A. Leaf area index, wet weights, and dry weights of Bay soybean cultivar in 1983. The sampling unit was 1 meter of row.

Date	LAI	Wet wt. whole plant	Dry wt. leaves	Dry wt. stems	Dry wt. reproductive parts
		grams			
6 June	0.16	60.12	5.93	1.99	0
14 June	0.48	126.06	14.04	5.37	0
20 June	0.63	123.88	12.97	7.03	0
22 June	0.70	160.88	16.59	8.44	0
30 June	2.74	706	56.58	48.17	0
8 July	3.68	878	84.60	98.72	0
13 July	3.65	929	114.30	92.97	0
22 July	2.86	779	92.41	94.53	0
27 July	4.27	1402	129.61	167.56	0
3 Aug.	5.83	1910	161.90	237.28	0
9 Aug.	7.56	2121	174.41	265.44	0
16 Aug.	7.16	2710	231.75	389.55	0.51
23 Aug.	6.41	2399	177.15	357.02	6.50
31 Aug.	5.26	2572	229.24	384.87	48.41
7 Sept.	4.01	2199	169.38	368.60	76.50
13 Sept.	2.82	1648	144.11	288.48	53.36
23 Sept.	1.68	1637	132.02	283.99	92.92
3 Oct.	0.34	1588	90.80	352.33	259.55

Table 23A. Rainfall record for the Manhattan site in 1983.

Day	May[*]	June	July	Aug.	Sept.	Oct.[+]
	mm					
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0.5	10.9	0	0	0	0
4	0	0	1.3	0	0	0
5	0	0	0	0	0	0
6	0	2.3	0	0	0	1.8
7	0	0	0	1.3	0	--
8	0	0	0	0	0	--
9	0	0	0	0	0	--
10	0	0	0	0	0	--
11	17.0	7.6	0	0	0	--
12	6.4	0	0	0	36.3	--
13	31.8	0	0	0	0	--
14	0	39.4	0	1.8	0	--
15	0	0	0	0	3.8	--
16	0	0	0	0	0	--
17	0	0	0	0	0	--
18	20.8	4.6	0	0	0	--
19	1.8	0	0	0	0	--
20	7.4	0	0	0	27.7	--
21	31.8	0	0	10.4	0	--
22	1.3	0	0	0	0	--
23	0	0	0	6.1	0	--
24	0	0	0	0	0	--
25	6.4	0	0	0	0	--
26	0	0	0	0	0	--
27	0	4.1	0	0	0	--
28	0	6.1	0	0	0	--
29	0	7.6	0	0	0	--
30	0	0	0	0	0	--
31	0	--	19.8	1.1	--	--
Total	125.2	82.6	21.1	67.8	67.8	

[*] May rainfall amounts are from the agronomy farm records.

[+] The rain guage was dissasembled after the last neutron reading.

Table 24A. Rainfall record for the Manhattan site in 1984.

Day	May[*]	June	July	Aug.	Sept.	Oct.[+]
	mm					
1	0.3	0	0	0	0	0
2	3.0	0.3	0	0	20.3	2.8
3	3.8	0	0	0	0	0
4	0	0	0	1.0	0	0
5	0	0	0	0	0	4.1
6	0	0	5.6	0	0	8.1
7	4.3	52.1	0	0	0	0
8	0	1.0	0.5	6.4	0	--
9	0	97.8	0	0	0	--
10	0	0	0	0	0	--
11	0	0	0	0	0	--
12	0	0	0	0	0	--
13	0	14.2	0	0	0	--
14	0	0	0	0	109.5	--
15	6.1	41.9	0	0	1.5	--
16	0	0	0	0	0	--
17	0	2.0	30.0	0	0	--
18	0	0	0	0	2.0	--
19	50.8	0	0	0	0	--
20	0	3.0	0	0	0	--
21	0	24.9	0	25.4	0	--
22	11.7	20.8	0	0	0	--
23	0	16.8	0	0	0	--
24	0	0	0	0	0	--
25	2.3	0	0	0	0	--
26	15.5	3.3	0	0	0.8	--
27	25.4	2.5	0	0	10.4	--
28	0.5	0	0	0	0	--
29	0	0	0	0	0	--
30	0	0	0	0	0	--
31	0	0	--	0	--	--
Total	123.7	280.6	36.1	32.8	144.5	

[*] May rainfall amounts are from the agronomy farm records.

[+] The rain guage was disassembled after the last neutron probe reading.

Table 25A. SAS program for calculating corn heat units (by using five methods) and soybean photothermal units.

```
1          OATA ONE:
2          INPUT DATE SOLRAD TMAXF TMINF RH8 TF8 WRMI NULL:
3          TMAXC=(TMAXF-32)*.556;
4          TMINC=(TMINF-32)*.556;
5          IF TMAXC>30 THEN MAXCUT=30: ELSE MAXCUT=TMAXC:
6          IF TMINC<10 THEN MINCUT=10: ELSE MINCUT=TMINC:
7          IF TMAXC>30 THEN STRESS=30-(TMAXC-30): ELSE STRESS=TMAXC:
8          JULCAY=121+_N_;
9          *JULIAN CAY STARTING WITH MAY 1 FCR A LEAP YEAR::
10         CARDS:

NOTE: OATA SET WORK.ONE HAS 31 OBSERVATIONS AND 14 VARIABLES. 164 OBS/TRK.
NCTE: THE DATA STATEMENT USED 0.16 SECONUS ANO 214K.

42         PPOC PRINT; VAR OATE SOLRAD TMAXF TMINF RH8 TF8 WRMI THAXC TNINC HAXCUT MINCUT
ERROR:              341
43         STRESS JULDAY:

341: YOUR SERVICE AGREEMENT HAS EXPIRED. PLEASE
     CONTACT YOUR COMPUTING INSTALLATION'S USER SERVICE
     PERSONNEL OR INSTALLATIUN SAS REPRESENTATIVE.

NCTE: THE PROCEDURE PRINT USED 0.31 SECONDS AND 208K AND PRINTED PAGE 1.

44         OATA TWO:
45         SET ONE:
46         CAVG=(TMAXC+TMINC)/2:
47         GDO=CAVG-10:
48         IF GDO<0 THEN GDO=0:
49         ACGDD+GOD:
50         *PREFIX AC SIGNIFIES ACCUMULATED:
51         *MOOIFIED GRCWING DEGREE CAY METHOD::
52         MODGDD=((MAXCUT+MINCUT)/2)-10:
53         IF MODGDO<0 THEN MODGOO=0:
54         ACMDD+MODGOO:
55         *GILMORE AND ROGERS HEAT STRESS METHOO::
56         IF TMAXC>30 THEN STRESSGR =(((TMAXC+MINCUT)/2)-(TMAXC-30))-10:
57         ELSE STRESSGR=((TMAXC+MINCUT)/2)-10:
58         IF STRESSGR<0 THEN STRESSGR=0:
59         ACSTREGR+STRESSGR:
60         *CRCSS AND ZUBER HEAT STRESS METHOD::
61         STRESSCZ=(STRESS+MINCUT)/2:
62         ACSTRECZ+STRESSCZ:
63         A=2.937:
64         *THIS IS A FOR MANHATTAN. A FOR TRIBUNE = 2.863:
65         OAYLN=12+A*(COS(0.0161*(JULDAY-172))):
66         *CORNF METHOD::
67         PI=3.14159:
68         AMP=TMAXC-CAVG:
```

Table 25A. Cont.

```
2       S A S   L O G   OS SAS 82.3           OS/MVT JO8 XPRS6019 STEP SAS      PRCC
          IF TMINC<10 THEN ZETA=ARSIN((10-CAVG)/AMP):
          HUDAYL=1-(14.2-OAYLN)*0.10:
          *14.2 * AVERAGE OF AVERAGE MANHATTAN ANO AVERAGE TRIBUNE OAYLENGTHS OVER GROWING
            SEASDN;
          IF TMINC<10 THEN HUNITS=1/PI*(AMP*COS(ZETA)+(CAVG-10)*(PI/2-ZETA));
          ELSE HUNITS=((TMINC+MAXCUT)/2)-10:
          HUNITSDL=HUNITS*HUDAYL;
          ACHUNDL+HUNITSDL:
          *SCY8EAN "PHOTOTHERMAL UNITS" CALCULATICNS PER MAJOR ET. AL.:;
          * M# SIGNIFIES MATURITY GROUP. EF SIGNIFIES EMERGENCE TC FLCWERING. FP SIGNIFIES
            FLCWERING TC PHYSIOLOGICAL MATURITY:
          M2EF=(.02503*(OAYLN-9.02)-.003095*((OAYLN-9.02)**2))*.03952*(CAVG-3.0);
          IF M2EF<0 THEN M2EF=0;
          ACM2EF+M2EF;
          M3EF=(.02695*(OAYLN-9.24)-.003644*((OAYLN-9.24)**2))*.04196*(CAVG-3.61);
          IF M3EF<0 THEN M3EF=0;
          ACM3EF+M3GF;
          M4EF=(.02598*(OAYLN-8.89)-.003472*((OAYLN-8.89)**2))*.04052*(CAVG-2.72):
          IF M4EF<0 THEN M4EF=0;
          ACM4EF+M4EF;
          M5EF=(-.0135I*(DAYLN-17.84))*.02431*(CAVG-6.92):
          IF M5EF<0 THEN M5EF=0;
          ACM5EF+M5EF;
          M2FP=(-.01932*(DAYLN-18.07))*(.03556*(CAVG-11.46)-.001391*((CAVG-11.46)**2));
          IF M2FP<0 THEN M2FP=0;
          ACM2FP+M2FP;
          M3FP=(-.02390*(DAYLN-17.68))*(.04438*(CAVG-12.84)-.002451*((CAVG-12.84)**2));
          IF M3FP<0 THEN M3FP=0:
          ACM3FP+M3FP;
          M4FP=(-.02408*(OAYLN-17.70))*(.04473*(CAVG-12.91)-.002526*((CAVG-12.91)**2));
          IF M4FP<0 THEN M4FP=0;
          ACM4FP+M4FP;
          M5FP=(-.01764*(OAYLN-15.36))*(.03176*(CAVG-9.08)):
          IF M5FP<0 THEN M5FP=0;
          ACM5FP+M5FP;

NCTE: DATA SET WORK.TWC HAS 31 OBSERVATICNS AND 48 VARIABLES. 49 OBS/TRK.
NCTE: THE OATA STATEMENT USED 0.56 SECONOS AND 214K.

          PROC PRINT;
                VAR OATE JULDAY CAVG GDO ACGDD MOOGDD ACMOO STRESSGR ACSTREGR STRESSCZ
          ACSTRECZ DAYLN AMP ZETA HUOAYL TMINC HUNITS HUNITSDL ACHUNDL M2EF ACM2EF
          M3EF ACM3EF M4EF ACM4EF M5EF ACM5EF M2FP ACM2FP M3FP ACM3FP M4FP ACM4FP
          M5FP ACM5FP;

NOTE: THE PROCEDURE PRINT USEO 0.80 SECONOS ANO 218K ANO PRINTEO PAGES 2 TO 3.
NCTE: SAS USED 218K MEMORY.
```

Table 25A. Cont.

```
                                                            SAS                              14:11 SATURDAY, MARCH 23, 1985

OBS   DATE     SOLRAD   TMAXF   TMINF   RH8   TF8   WRMI.   TMAXC     TMINC    MAXCUT   MINCUT    STRESS   JULDAY

  1   50184    450.0     69      41     81     9     17    20.572     5.004   20.572   10.000    20.572    122
  2   50284    275.2     65      49     78    12     28    18.348     9.452   18.348   10.000    18.348    123
  3   50384    310.0     63      50     80    10     12    17.236    10.008   17.236   10.088    17.236    124
  4   50484    630.9     66      44     70    14     38    18.904     6.672   18.904   10.000    18.904    125
  5   50584    185.6     64      48     79    11     45    17.792     8.896   17.792   10.000    17.792    126
  6   50684    132.0     63      51     78    10     35    17.236    10.564   17.236   10.564    17.236    127
  7   50784    338.4     59      42     72    13      8    15.012     5.560   15.012   10.000    15.012    128
  8   50884    610.3     66      35     65    10     46    18.904     1.668   18.904   10.000    18.904    129
  9   50984    670.0     69      34     61    18     49    20.572     1.112   20.572   10.000    20.572    130
 10   51084    623.1     81      50     49    17     11    27.244    10.008   27.244   10.008    27.244    131
 11   51184    496.7     76      57     63    16     19    24.464    13.900   24.464   13.900    24.464    132
 12   51284    559.9     87      55     73    17     15    30.580    12.708   30.000   12.788    29.420    133
 13   51384    627.4     83      66     72    22     40    28.356    18.904   28.356   18.904    28.356    134
 14   51484    553.1     75      52     67    14      7    23.908    11.120   23.908   11.120    23.908    135
 15   51584    209.5     73      53     71    16     18    22.796    11.676   22.796   11.676    22.796    136
 16   51684    512.0     81      53     70    17     16    27.244    11.676   27.244   11.676    27.244    137
 17   51784    641.0     84      60     59    20     55    28.912    15.568   28.912   15.568    28.912    138
 18   51884    607.7     85      61     61    21     64    29.468    16.124   29.468   16.124    29.468    139
 19   51984     92.4     79      61     77    18     57    26.132    16.124   26.132   16.124    26.132    140
 20   52084    656.3     78      54     79    13      6    25.576    12.232   25.576   12.232    25.576    141
 21   52184    660.5     83      53     71    20     11    28.356    11.676   28.356   11.676    28.356    142
 22   52284    359.2     76      58     77    15     20    24.464    14.456   24.464   14.456    24.464    143
 23   52384    695.3     78      47     68    17      9    25.576     8.340   25.576   10.000    25.576    144
 24   52484    419.3     86      63     50    22     31    30.024    17.236   30.088   17.236    29.976    145
 25   52584    440.2     81      52     77    14    139    27.244    11.120   27.244   11.120    27.244    146
 26   52684    491.1     69      49     72    14     26    20.572     9.452   20.572   10.000    20.572    147
 27   52784    114.9     65      54     80    13      2    18.348    12.232   18.348   12.232    18.348    148
 28   52884    443.8     64      49     76    11     24    17.792     9.452   17.792   10.000    17.792    149
 29   52984    664.8     70      41     70    15     37    21.128     5.004   21.128   10.000    21.128    150
 30   53084    634.3     73      43     47    16     25    22.796     6.116   22.796   10.000    22.796    151
 31   53184    700.8     84      56     52    15     25    28.912    13.344   28.912   13.344    28.912    152
```

Table 26A. SAS program for calculating reference Et by using four equations.

```
1          DATA ETR;
2          INPUT DATE SOLRAD TMAXF TMINF RH8 TF8 WRMI NULL;
3          TMAXC=(TMAXF-32)*.556;
4          TMINC=(TMINF-32)*.556;
5          TC8=(TF8-32)*.556;
6          WRKM=WRMI*1.61;
7          WR2=WRKM*(3.28**.2);
8          * ADJUSTS MANHATTAN ANEMOMETER WIND RUN TO A 2 METER HEIGHT;
9          CARDS;

NOTE: DATA SET WORK.ETR HAS 30 OBSERVATIONS AND 13 VARIABLES. 176 OBS/TRK.
NOTE: THE DATA STATEMENT USED 0.17 SECONDS AND 208K.

40         PROC PRINT;

NOTE: THE PROCEDURE PRINT USED 0.29 SECONDS AND 202K AND PRINTED PAGE 1.

41         DATA TWG;
42         SET ETR;
43         CAVG=(TMAXC+TMINC)/2;
44         L=595-0.51*CAVG;
45         ELEVM=313.944;
46         * ELEVATION IN METERS FOR TRIBUNE SITE IS 1066.8;
47         P=1013-(0.1055*ELEVM);
48         Y=(0.386*P)/L;
49         DELTA=(2.00*((0.00738*CAVG)+0.8072)**7)-0.00116;
50         ESMIN=33.8639*((0.00738*TMINC+0.8072)**8-0.000019*(1.8*TMINC+48)+0.001316);
51         ESMAX=33.8639*((0.00738*TMAXC+0.8072)**8-0.000019*(1.8*TMAXC+48)+0.001316);
52         ESAVE=(ESMIN+ESMAX)/2;
53         ES8=33.8639*((0.00738*TC8+0.8072)**8-.000019*(1.8*TC8+48)+0.001316);
54         RHFRACT8=RH8/100;
55         EDP8=ES8*RHFRACT8;
56         * NET RADIATION EQUATIONS;
57         RNCORN1=0.861*SOLRAD-103.92;
58         RNCORN2=0.848*SOLRAD-144.49;
59         RNCORN3=0.766*SOLRAD-99.89;
60         RNSOYRG=0.725*SOLRAD-50.74;
61         RNSOY82=0.805*SOLRAD-137.59;
62         RNSORG2=0.837*SOLRAD-132.34;
63         * ETR CALCULATED USING THE PENMAN EQUATION;
64         EPENC1=(DELTA/(DELTA+Y))*RNCORN1+(Y/(DELTA+Y))*15.36*(0.75+0.0115*WR2)*(ESAVE-ED
65         P8);
66         EPENC2=(DELTA/(DELTA+Y))*RNCORN2+(Y/(DELTA+Y))*15.36*(0.75+0.0115*WR2)*(ESAVE-ED
67         P8);
68         EPENC3=(DELTA/(DELTA+Y))*RNCORN3+(Y/(DELTA+Y))*15.36*(0.75+0.0115*WR2)*(ESAVE-ED
69         P8);
70         EPSOYR=(DELTA/(DELTA+Y))*RNSOYRG+(Y/(DELTA+Y))*15.36*(0.75+0.0115*WR2)*(ESAVE-ED
71         P8);
72         EPSOY2=(DELTA/(DELTA+Y))*RNSOY82+(Y/(DELTA+Y))*15.36*(0.75+0.0115*WR2)*(ESAVE-ED
73         P8);
```

Table 26A. Cont.

```
2        SAS  LOG    OS SAS 82.3          OS/MVT JOB XPRS9317 STEP SAS       PROC
74          EPSRG2=(DELTA/(OELTA+Y))*RNSORG2+(Y/(OELTA+Y))*15.36*(0.75+0.0115*WR2)*(ESAVE-EO
75          P8);
76          LMM=L/10;
77          * ETR CALCULATEO USING THE PRIESTLEY-TAYLOR EQUATION:
78          EPRTYC1=1.32*(DELTA/(DELTA+Y))*RNCORN1;
79          EPRTYC2=1.32*(OELTA/(OELTA+Y))*RNCORN2;
80          EPRTYC3=1.32*(OELTA/(OELTA+Y))*RNCORN3;
81          EPTSOYR=1.32*(DELTA/(CELTA+Y))*RNSDYRG;
82          EPTSDY2=1.32*(DELTA/(OELTA+Y))*RNSDY82;
83          EPTSRG2=1.32*(DELTA/(OELTA+Y))*RNSORG2;
84          FAVG=(TMAXF+TMINF)/2;
85          * ETR CALCULATED USING THE JENSEN-HAISE EOUATION;
86          JHLY=(0.014*FAVG-0.37)*SDLRAD;
87          TCWMAX=33.2;
88          TCWMIN=20.0;
89          * LONG-TERM MEAN MAXIMUM AND MINIMUM TEMPERATURES FCR JULY AT MANHATTAN.  THESE
90          NORMAL TEMPERATURES FCR TRIBUNE ARE 33.7 AND 16.5;
91          EWMAX=33.8639*((0.00738*TCWMAX+.8072)**8-0.000019*(1.8*TCWMAX+48)+0.001316);
92          EWMIN=33.8639*((0.00738*TCWMIN+.8072)**8-0.000C19*(1.8*TCWM(N+48)+0.001316);
93          * ETR CALCULATEO USING THE MODIFIEO JENSEN-HAISE EOUATION;
94          C1=38-((2*ELEVM)/305);
95          CH=50/(EWMAX-EWMIN);
96          CT=1/(C1+7.3*CH);
97          TX=-2.5-0.14*(EWMAX-EWMIN)-(ELEVM/550);
98          MODJHLY=CT*(CAVG-TX)*SOLRAO;
99          * CONVERTING ETR VALUES FROM LANGLEYS TO MM PER OAY.  PREFIX AC SIGNIFIES
100         ACCUMULATEO;
101         PENCOR1=EPENC1/LMM;
102         IF PENCOR1<0 THEN PENCOR1=0;
103         ACPENC1+PENCOR1;
104         PENCOR2=EPENC2/LMM;
105         IF PENCOR2<0 THEN PENCDR2=0;
106         ACPENC2+PENCDR2;
107         PENCOR3=EPENC3/LMM;
108         IF PENCCR3<0 THEN PENCOR3=0;
109         ACPENC3+PENCOR3;
110         PENSOYR=EPSCYR/LMM;
111         IF PENSOYR<0 THEN PENSDYR=0;
112         ACPENSRY+PENSDYR;
113         PENSCY2=EPSCY2/LMM;
114         IF PENSOY2<D THEN PENSOY2=0;
115         ACPENSY2+PENSCY2;
116         PENSRG2=EPSRG2/LMM;
117         IF PENSRG2<D THEN PENSRG2=0;
118         ACPENSG2+PENSRG2;
119         PTCDRN1=EPRTYC1/LMM:
120         IF PTCORN1<0 THEN PTCCRN1=0;
121         ACPTCOR1+PTCDRN1:
122         PTCCRM2=EPRTYC2/LMM;
123         IF PTCORN2<0 THEN PTCCRN2=0;
124         ACPTCDR2+PTCURN2;
125         PTCCRN3=EPRTYC3/LMM;
126         IF PTCDRN3<0 THEN PTCORN3=0;
127         ACPTCOR3+PTCORN3;
128         PTSCYRG=EPTSOYR/LMM;
129         IF PTSOYRG<0 THEN PTSCYRG=0;
130         ACPTSYRG+PTSOYRG;
131         PTSOY82=EPTSDY2/LMM;
```

Table 26A. Cont.

```
3       S A S   L O G    OS SAS 82.3          OS/MVT JOB XPRS9317 STEP SAS       PROC

132         IF PTSOY82<0 THEN PTSOY82=0;
133         ACPTSY82+PTSOY82;
134         PTSRGM2=EPTSRG2/LMM;
135         IF PTSRGM2<0 THEN PTSRGM2=0;
136         ACPTSRG2+PTSRGM2;
137         JHMM=JHLY/LMM;
138         ACJHMM+JHMM;
139         MOOJHMM=MOOJHLY/LMM;
140         ACMOOJH+MOOJHMM;

NOTE: DATA SET WORK.TWO HAS 30 OBSERVATIONS AND 83 VARIABLES. 28 OBS/TRK.
NOTE: THE DATA STATEMENT USED 0.81 SECONDS AND 208K.

141         PROC PRINT;
142         VAR DATE          TMAXF TMINF RH8 TC8 WRMI TMAXC TMINC WRKM WR2 SOLRAD
143         DATE          CAVG L ELEVM P Y DELTA ESMIN ESMAX ESAVE ES8 RHFRACT8 EOP8
144         DATE RNCORN1 RNCORN2 RNCORN3 RNSOYRG RNSOY82 RNSORG2 EPENC1 EPENC2 EPENC3
145         DATE EPSOYR EPSOY2 EPSRG2 LMM EPRTYC1 EPRTYC2 EPRTYC3 EPTSOYR EPTSOY2 EPTSRG2
146         DATE FAVG JHLY TCWMAX TCWMIN EWMAX EWMIN C1 CH CT TX MOOJHLY PENCOR1 ACPENC1 DAT
147         E          PENCOR2 ACPENC2 PENCOR3 ACPENC3 PENSOYR ACPENSRY PENSOY2 ACPENSY2 DATE
148         PENSRG2 ACPENSG2 PTCORN1 ACPTCOR1 PTCORN2 ACPTCOR2 PTCORN3 ACPTCOR3 PTSOYRG
149         DATE ACPTSYRG PTSOY82 ACPTSY82 PTSRGM2 ACPTSRG2 JHMM ACJHMM MOOJHMM ACMOOJH DATE
150         ;

NOTE: THE PROCEDURE PRINT USED 1.50 SECONDS AND 220K AND PRINTED PAGES 2 TO 5.
NOTE: SAS USED 220K MEMORY.

NOTE: SAS INSTITUTE INC.
      SAS CIRCLE
      PO BOX 8000
      CARY, N.C.  27511-8000
```

Table 26A. Cont.

SAS 20:28 FRIDAY, JUNE 7, 1985

OBS	DATE	SOLRAD	TMAXF	TMINF	RH8	TF8	WRM1	NULL	TMAXC	TMINC	TC8	WRKM	WR2
1	60174	673.1	77	49	80	56	32	0.00	25.020	9.452	13.344	51.52	65.336
2	60274	673.7	82	54	61	62	21	0.00	27.800	12.232	16.683	33.81	42.877
3	60374	522.7	81	67	69	69	80	0.00	27.244	19.460	20.572	128.80	163.339
4	60474	405.3	79	67	80	69	100	0.00	26.132	19.460	20.572	161.00	204.174
5	60574	425.9	82	62	93	64	33	0.00	27.800	16.680	17.792	53.13	67.377
6	60674	345.6	79	61	93	63	64	1.27	26.132	16.124	17.235	103.04	130.671
7	60774	465.7	74	57	94	59	22	1.82	23.352	13.900	15.012	35.42	44.918
8	60874	75.9	71	59	88	60	8	0.02	21.684	15.012	15.563	12.88	16.334
9	60974	234.7	67	56	75	57	73	1.84	19.460	13.344	13.900	117.53	149.047
10	61074	681.4	79	52	63	58	105	0.00	26.132	11.120	14.456	169.05	214.383
11	61174	623.3	77	58	87	60	37	0.48	25.020	14.456	15.569	59.57	75.544
12	61274	704.6	77	49	78	54	28	0.00	25.020	9.452	12.232	45.08	57.169
13	61374	587.8	83	59	80	63	42	0.41	28.356	15.012	17.236	67.62	85.753
14	61474	689.2	93	61	84	69	16	0.00	33.916	16.124	20.572	25.76	32.668
15	61574	643.1	82	66	66	66	4	0.00	27.800	18.904	18.904	6.44	8.167
16	61674	734.7	75	50	54	55	42	0.00	23.908	10.008	12.789	67.62	85.753
17	61774	570.4	80	55	60	56	26	0.00	26.688	12.788	13.344	41.86	53.085
18	61874	680.7	91	65	71	70	22	0.00	32.804	18.348	21.124	35.42	44.918
19	61974	580.7	92	72	70	78	74	0.00	33.360	22.240	25.576	119.14	151.089
20	62074	666.8	100	75	60	79	119	0.00	37.808	23.908	26.132	191.59	242.967
21	62174	541.5	100	78	49	81	156	0.00	37.808	25.576	27.244	251.16	318.512
22	62274	667.3	95	71	71	72	79	0.00	35.028	21.684	22.243	127.19	161.298
23	62374	623.8	81	54	82	60	40	0.00	27.244	12.232	15.563	64.40	81.670
24	62474	720.6	78	54	66	64	25	0.00	25.576	12.232	17.792	40.25	51.044
25	62574	647.1	81	51	59	64	6	0.00	27.244	10.564	17.792	9.66	12.250
26	62674	713.1	81	57	54	66	36	0.00	27.244	13.900	18.904	57.96	73.503
27	62774	716.7	83	55	54	64	6	0.00	28.356	12.788	17.792	9.66	12.250
28	62874	662.8	87	65	47	69	78	0.00	30.580	18.348	20.572	125.58	159.256
29	62974	632.4	98	69	51	73	136	0.00	36.696	20.572	22.795	218.96	277.677
30	63074	343.6	91	71	45	75	62	0.00	32.804	21.684	23.903	99.82	126.588

Table 27A. SAS program for estimating soybean evapotranspiration from the equations of the soybean basal crop coefficient curves.

```
          DATA EST;
          INPUT SOIL $ MOAE MFGS ASW ET PENM JHA MODJHA PTY;
          FGS=MFGS/1000;
          KA=(LOG(ASW+1))/4.615;
          PEN=PENM/100;
          JH=JHA/100;
          MODJH=MODJHA/100;
          PT=PTY/100;
          ETMM=ET/100;
          CARDS;

NOTE: DATA SET WORK.EST HAS 12 OBSERVATIONS AND 16 VARIABLES. 144 OBS/TRK.
NOTE: THE DATA STATEMENT USED 0.16 SECONDS AND 208K.

          PROC PRINT;

NOTE: THE PROCEDURE PRINT USED 0.23 SECONDS AND 202K AND PRINTED PAGE 1.

          DATA TWO;
          SET EST;
          PENKCB=0.22760237+22.60717113*(FGS*FGS*FGS)-42.89622761*(FGS*FGS*FGS*FGS)+20.659
          41959*(FGS*FGS*FGS*FGS*FGS);
          PENKCW=PENKCB*KA;
          ETPENW=PENKCW*PEN;
          PENKS1=(0.9-PENKCB)*0.8;
          PENKS2=(0.9-PENKCB)*0.5;
          PENKS3=(0.9-PENKCB)*0.3;
          PENKMM1=PENKS1*PEN;
          PENKMM2=PENKS2*PEN;
          PENKMM3=PENKS3*PEN;
          PENKTOT=PENKMM1+PENKMM2+PENKMM3;
          JHKCB=0.32175851+18.2978470*(FGS*FGS*FGS)-36.06279311*(FGS*FGS*FGS*FGS)+18.1253
          2568*(FGS*FGS*FGS*FGS*FGS);
          JHKCW=JHKCB*KA;
          ETJHW=JHKCW*JH;
          JHKS1=(0.9-JHKCB)*0.8;
          JHKS2=(0.9-JHKCB)*0.5;
          JHKS3=(0.9-JHKCB)*0.3;
          JHKMM1=JHKS1*JH;
          JHKMM2=JHKS2*JH;
          JHKMM3=JHKS3*JH;
          JHKTOT=JHKMM1+JHKMM2+JHKMM3;
          MODKCB=0.33954012+20.25528511*(FGS*FGS*FGS)-39.87782750*(FGS*FGS*FGS*FGS)+19.994
          07719*(FGS*FGS*FGS*FGS*FGS);
          MODKCW=MODKCB*KA;
          ETMODW=MODKCW*MODJH;
          MODKS1=(0.9-MODKCB)*0.8;
          MODKS2=(0.9-MODKCB)*0.5;
          MODKS3=(0.9-MODKCB)*0.3;
          MODKMM1=MODKS1*MODJH;
```

Table 27A. Cont.

```
2       S A S   L O G    OS SAS 82.3         OS/MVT JOB XPRS0454 STEP SAS      PROC

56          MODKMM2=MODKS2*MODJH;
57          MODKMM3=MODKS3*MODJH;
58          MODKTOT=MODKMM1+MODKMM2+MODKMM3;
59          PTKCB=0.27724393+23.77211660*(FGS*FGS*FGS)-44.60000634*(FGS*FGS*FGS*FGS)+21.1949
60          8880*(FGS*FGS*FGS*FGS*FGS);
61          PTKCW=PTKCB*KA;
62          ETPTW=PTKCW*PT;
63          PTKS1=(0.9-PTKCB)*0.8;
64          PTKS2=(0.9-PTKCB)*0.5;
65          PTKS3=(0.9-PTKCB)*0.3;
66          PTKMM1=PTKS1*PT;
67          PTKMM2=PTKS2*PT;
68          PTKMM3=PTKS3*PT;
69          PTTOT=PTKMM1+PTKMM2+PTKMM3;

NOTE: DATA SET WORK.TWO HAS 12 OBSERVATIONS AND 56 VARIABLES. 42 OBS/TRK.
NOTE: THE DATA STATEMENT USED 0.42 SECONDS AND 208K.

70          PROC PRINT;

NOTE: THE PROCEDURE PRINT USED 0.57 SECONDS AND 222K AND PRINTED PAGES 2 TO 3.
NOTE: SAS USED 222K MEMORY.

NOTE: SAS INSTITUTE INC.
      SAS CIRCLE
      PO BOX 8000
      CARY, N.C.  27511-8000
```

Table 27A. Cont.

```
                                                      SAS                      16:30 MONDAY, AUGUST 19, 1985
OBS  SOIL  MOAE  MFGS  ASW   ET   PENM  JHA  MODJHA  PTY   FGS       KA      PEN    JH   MOUJH   PT   ETMM

  1   E    110   103   61   292   462   435   419    470  0.103  0.894281  4.62  4.35  4.19  4.70  2.82
  2   E    110    50   66   208   462   435   419    470  0.050  0.911093  4.62  4.35  4.19  4.70  2.08
  3   E    165   233   72   229   477   424   398    397  0.233  0.929677  4.77  4.24  3.98  3.97  2.29
  4   E    165   161   65   500   477   424   398    397  0.161  0.907834  4.77  4.24  3.99  3.97  5.00
  5   E    165    83   72   400   477   424   398    397  0.083  0.929677  4.77  4.24  3.98  3.97  4.00
  6   E    230   348   74   393   647   653   605    611  0.348  0.935534  6.47  6.53  6.05  6.11  3.93
  7   E    230   237   65   410   647   653   605    611  0.237  0.907834  6.47  6.53  6.05  6.11  4.10
  8   E    230   122   73   327   647   653   605    611  0.122  0.932625  6.47  6.53  6.05  6.11  3.27
  9   E    305   473   65   509   515   613   563    538  0.473  0.907834  5.15  6.13  5.63  5.38  5.09
 10   E    305   335   58   498   515   613   563    538  0.335  0.883540  5.15  6.13  5.63  5.38  4.98
 11   E    305   177   63   442   515   613   563    538  0.177  0.901166  5.15  6.13  5.63  5.38  4.42
 12   E    390   573   53   616   760   850   773    675  0.573  0.864352  7.60  8.50  7.73  6.75  6.16
```

Crop Coefficient Curves for Corn (*Zea mays* L.) and Soybean (*Glycine max* (L.) Merr,) Based on Fraction of Growing Season

by

Brigid Amos

B.A., Wellesley College, 1981

AN ABSTRACT OF

A MASTER'S THESIS

Submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

Kansas State University
Manhattan, Kansas

1985

ABSTRACT

Basal crop coefficient (Kcb) curves for corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.), based on the time scale fraction of growing season calculated by using growing degree days for corn and photothermal units for soybean, were developed from neutron probe water use data collected at a site near Manhattan, Kansas during the years 1974 through 1982 and at a site near Tribune, Kansas during the years 1981 and 1982. The crop coefficients were basal because they were developed from data collected during times of minimal evaporation and were corrected for the lowering effects of inadequate soil water. The time scale was chosen with the thought that such curves would not be subject to shifts due to cultivar and climate related differences in crop development. An examination of the coefficients of variation (CV) of fraction of growing season to silking in corn and beginning bloom in soybean, calculated by various heat unit methods as well as days after emergence (DAE), led to the choice of the methods mentioned above. Four reference Et (Etr) equations were used in these curves. These were the Penman, Jensen-Haise, modified Jensen-Haise, and Priestley-Taylor equations.

With the inputs of fraction of growing season, Etr values calculated from meteorological data, and correction coefficients calculated from available soil water percentages and rainfall amounts, the basal crop coefficient curves were

used to predict Et rates for data collected at the Manhattan site in 1983 and 1984. The predicted Et rates were regressed on the measured Et rates and F tests were performed on the linear equations. For corn, the intercepts of these lines were not different from 0, but the slopes were significantly lower than 1. In the case of soybean, the intercepts of these lines were significantly greater than 0 and the slopes were significantly lower than 1. This showed that the basal crop coefficient curves underestimated the corn and soybean Et rates for the 1983 and 1984 growing seasons.

Curves of maximum depth of depletion vs. fraction of growing season for corn and soybean were developed from 1974 through 1984 water use data collected at the Manhattan site and from 1981 and 1982 data collected at the Tribune site. Curves of corn and soybean relative leaf area index (LAI) vs. fraction of growing season, calculated by various heat unit methods and DAE, were developed from 1981 and 1982 data collected at the Manhattan and Tribune sites. The equation based on fraction of growing season, calculated by using the GDD method, successfully predicted relative LAI of the 1983 data collected at the Manhattan site while the other methods failed. The soybean relative LAI models predicted the Manhattan 1983 relative LAI equally well.